NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

SUMMARY OF PROGRESS THROUGH 1972

HIGHWAY RESEARCH BOARD
NATIONAL RESEARCH COUNCIL
NATIONAL ACADEMY OF SCIENCES—NATIONAL ACADEMY OF ENGINEERING 1972

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

In recognition of these needs, the highway administrators of the American Association of State Highway Officials initiated in 1962 an objective national highway research program employing modern scientific techniques. This program is supported on a continuing basis by funds from participating member states of the Association and it receives the full cooperation and support of the Federal Highway Administration, United States Department of Transportation.

The Highway Research Board of the National Academy of Sciences-National Research Council was requested by the Association to administer the research program because of the Board's recognized objectivity and understanding of modern research practices. The Board is uniquely suited for this purpose as: it maintains an extensive committee structure from which authorities on any highway transportation subject may be drawn; it possesses avenues of communications and cooperation with federal, state, and local governmental agencies, universities, and industry; its relationship to its parent organization, the National Academy of Sciences, a private, nonprofit institution, is an insurance of objectvity; it maintains a full-time research correlation staff of specialists in highway transportation matters to bring the findings of research directly to those who are in a position to use them.

The program is developed on the basis of research needs identified by chief administrators of the highway departments and by committees of AASHO. Each year, specific areas of research needs to be included in the program are proposed to the Academy and the Board by the American Association of State Highway Officials. Research projects to fulfill these needs are defined by the Board, and qualified research agencies are selected from those that have submitted proposals. Administration and surveillance of research contracts are responsibilities of the Academy and its Highway Research Board.

The needs for highway research are many, and the National Cooperative Highway Research Program can make significant contributions to the solution of highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

SUMMARY OF PROGRESS THROUGH 1972

INTRODUCTION

The National Cooperative Highway Research Program (NCHRP) was established in 1962 to provide a continuing program of highway research. It is sponsored by participating member departments of the American Association of State Highway Officials (AASHO), in cooperation with the Federal Highway Administration (FHWA), U. S. Department of Transportation, and carried out under a three-way agreement between these agencies and the National Academy of Sciences. AASHO annually proposes specific research problems for inclusion in the NCHRP fiscal year activities. At least two-thirds of the participating member departments must approve the research problems and agree to their financial support before they can be brought into the Program. Following balloting by the member departments, the approved problems are referred to the Academy, where an NCHRP Advisory Committee reviews each yearly program to determine its acceptability for administration by the Academy through the Highway Research Board of its National Research Council. Each State annually contracts with the Academy to commit 4½% of its 1½% Federal-aid highway planning research (HPR) funds. From these contributions, a cooperative pool of about $3½ million is made available for NCHRP's contract research and for its administrative and technical operation.

Once accepted, the problems making up the program are assigned to advisory groups (panels or committees) that are made up of persons knowledgeable in each particular problem area and who advise on the technical aspects of the problem. There are presently some 447 members on these panels coming from 44 States, the District of Columbia, and Canada. They analyze the problems, outline particular projects and their objectives, and then prepare research project statements on which proposals are solicited from qualified private and public research agencies. They review the proposals, recommend contract awards, and provide counsel to the NCHRP staff responsible for surveillance of work under the research contracts. Finally, they review final reports for acceptability and for accomplishment of the approved research plan.

A professional staff is assigned to NCHRP by the Board. Projects engineers with individual specialties and training in the broad areas of physical research and traffic planning are responsible for administrative and technical surveillance of the contracts. In addition to reviewing quarterly progress reports and monthly progress schedules and maintaining telephone contacts, each engineer visits his assigned projects throughout their contract periods. He discusses with each principal investigator the project's status to learn if the research is being pursued in line with the approved research plan. Meetings involving the staff, the advisory groups, and agency personnel are held frequently for the purpose of reviewing project progress and providing guidance for continuing work. Finally, the projects engineer and the advisory panel evaluate the completed research to determine the degree of technical compliance with the contract and the acceptability of the final report to the Board and the Academy.

The research findings are published in a special NCHRP report series. Each highway administrator receives a copy immediately on publication, and some 3,500 copies are formally distributed through the Highway Research Board's selective distribution system.

Still another means for bringing research findings before the practicing engineer was initiated in 1968 as the *NCHRP Research Results Digest*—a series of flyers published at frequent intervals in the interest of providing an early awareness of the research results emanating from the various projects. By making these results known as they are developed and prior to publication of the final reports, it is hoped that their early use in practice will be encouraged.

Over the years, 37 detailed progress reports have been submitted by the NCHRP to the sponsors to provide them with current information on the specifics of technical progress of the projects, as well as the specifics of administrative matters relating to Program operation. Beginning with 1966, these reports have been supplemented by publication of an annual summary of progress that has been made available to both the sponsors and the public at large. Prior to 1969 the annual summary reported on a fiscal-year basis. It now reports on a calendar-year basis to permit inclusion of more up-to-date information that will remain current for a longer period of time. The seventh issue covers the Program from its inception through December 31, 1972, and illustrates in detail how the NCHRP functions.

Although research in the NCHRP is presently sponsored by AASHO, the Program is designed to administer research for other agencies as well. However, the following descrip-

tion of how projects are formulated and the research administered applies specifically to the AASHO-sponsored research.

HOW NCHRP PROGRAMS ARE FORMULATED

Research problems from the American Association of State Highway Officials are initiated on an annual basis, and there are many steps (refer to Figure 1) between initiation and the time that the final reports are published. Each fiscal year's program must start with the *identification of critical problems* by:

- The chief administrative officers of the participating member highway departments.
- The chairmen of subcommittees under AASHO's Standing Committee on Administrative Practices.
- The chairmen of subcommittees under AASHO's Standing Committee on Engineering Policies.
- The Executive Committee of AASHO.
- The Federal Highway Administrator.

The many problems received from these sources each year are forwarded to the Special AASHO Select Committee on Research for consideration during an annual meeting that is held specifically to formulate research programs for the NCHRP. Based on the funding anticipated to be available from the Federal apportionment for the given fiscal year, this committee carries out two major activities. First, a review is made to determine which completed or on-going projects should receive additional funding for further work. During this part of program development, the committee receives NCHRP recommendations for continuations and has status reports available on each project in the Program since FY '63. These reports include, among other things, statements of the anticipated project status after the currently allotted funds have been spent and the anticipated status after funds for project continuation

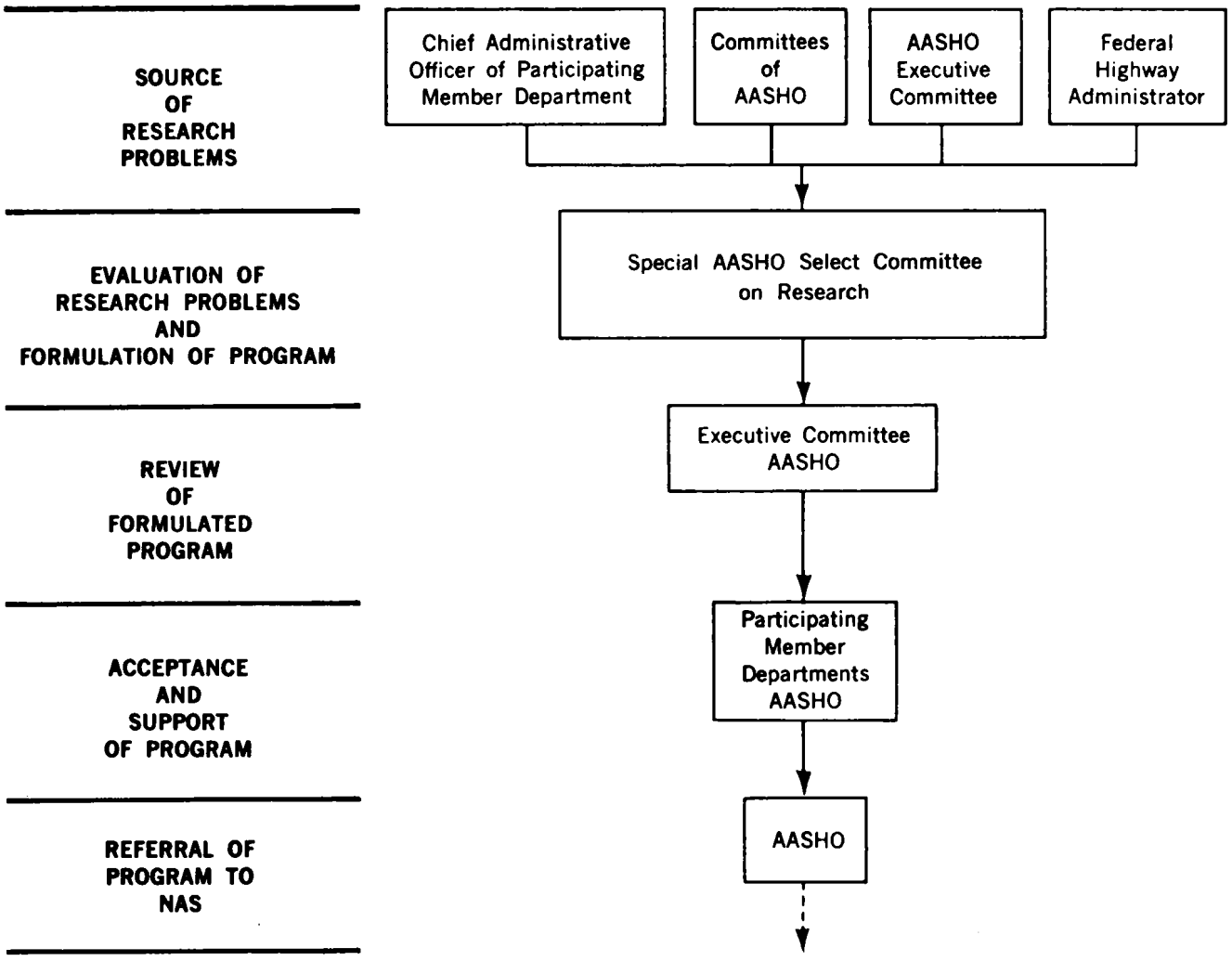

FIGURE 1

Flow Diagram for Each Program from Initiation to Referral by AASHO to the National Academy of Sciences

have been expended. The committee review is also aided materially by reports from the NCHRP, HRB, and Federal Highway Administration research staffs dealing with appropriateness of the proposed research in light of other research that is under way in this and other research programs.

Following allocation of funds to the projects selected for continuation, the committee's second major activity is to determine which new problem submittals should receive the highest priority for programming within the remaining available funds. Each problem is first screened to determine:

- If the proposed problem is of mutual interest to all or many of the States and whether it can be handled more effectively under a cooperative program than by an individual state highway department.
- If the proposed problem represents an immediate research need in the highway field.
- If similar efforts are already under way, or if satisfactory answers are already available.
- The probability of success of completing the problem according to its scope, estimated cost, and time for completion.

The problems that survive this initial screening process are then evaluated in depth as regards their technical merits, and final priorities are placed on them. Based on these priorities, a research program is formulated that does not exceed the funds available for new problems.

Once the program is developed, it is sent to the AASHO Executive Committee for review, approval and/or modification, and acceptance. The Executive Committee acts during its annual winter meeting.

After the program is approved, it is sent by AASHO's Executive Director to the participating state highway departments for balloting. The final program for each fiscal year consists of those problems proposed for study that have received a favorable vote by two-thirds or more of the participating member departments.

After each year's program has been voted on by the States, it is referred by AASHO to the Academy for review and acceptance (refer to Figure 2). At the same time it is also sent to the Federal Highway Administration for its review. Within the Academy structure, the NCHRP staff reviews each item to again ensure that there will be no duplication of either on-going or completed research. In so doing, a search is made of the relevant literature stored in the Board's automated Highway Research Information Service.

PROGRAMS RECEIVED TO DATE

The first research program was received when the three-way agreement was signed and consisted of 34 problems with an average funding of about $55,000. A similar pattern existed for the second program; however, subsequent years have seen a decrease in the numbers of problems programmed (see Table 2) and an increase in the levels of funding for individual projects. Since 1967, for example, each year's program has consisted of some 9 new problems with funding ranging between $100,000 and $300,000 and some 10 continuations—also funded in the same range—of projects begun in earlier years. This is not to be taken as a decrease in the needs of the sponsors. To the contrary, the needs are many and are evidenced by an ever-growing list that has ranged as high as 143 problems to be considered by the AASHO Research Committee for programming in a single year. Regrettably, the Program does not have sufficient funds to permit inclusion of more than a fraction of the problems submitted.

In 1972 NCHRP received its eleventh program of research problems. To date, 203 research projects have resulted, on which contracts have been written with a total funding obligation of about $28 million. The subject matter of the projects ranges across the full spectrum of concern within the transportation industry and evidences the sponsor's immediate interest in acquiring answers at an early date to the many acute problems facing administrators and engineers. The twelfth group of research problems (FY '74 program) will be received in 1973 following Federal apportionment and the States' approval of the recommended problems.

FINANCING THE PROGRAM

Each year each State renews its contract with the National Academy of Sciences, thus agreeing to support the Program. At the same time it casts its ballots to determine which new problems and continuations will be in the program.

The contract with the National Academy of Sciences commits the State to 4½ percent of its 1½ percent Federal-aid planning and research (HPR) funds. A member department's contribution, if so elected and when authorized by the Federal Highway Administrator, may be financed directly from the Federal-aid monies without State matching funds. On the other hand, the member department's contribution may be financed from both Federal and State matching funds or entirely from State funds. From these contributions a cooperative pool of about $3½ million is made available each year for NCHRP's contract research and for its administrative and technical operation. It is a significant indicator of the need for the NCHRP that all States have participated each year except for two of the early years. Even then, all but two States took part in the Program.

HOW THE NCHRP IS ORGANIZED TO ADMINISTER RESEARCH PROGRAMS

In line with its responsibility for administering the NCHRP, the Board has established an advisory committee to consider all matters relating to policies and procedures required for the planning and administration of the Program. This committee is drawn from the officers and ex-officio members of the Highway Research Board Executive Committee.

In addition, the Board has established eight broad research fields under which advisory groups are organized to deal with research in specific problem areas falling within

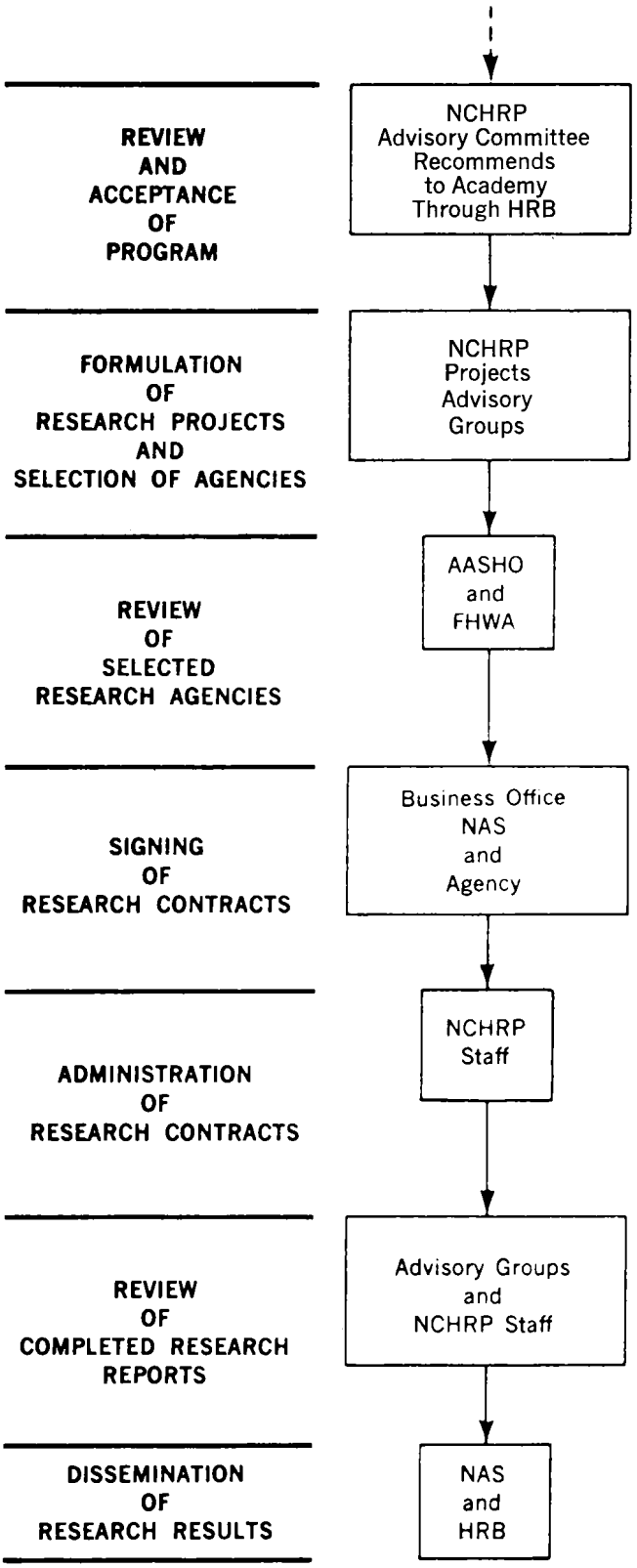

FIGURE 2

Flow Diagram for Each Program After Referral to the National Academy of Sciences

the broad fields (refer to Figure 3). For example, in the broad subject field of Transportation Planning each project falling within the more specific subject areas of Traffic Planning and Urban Transportation—areas 7 and 8, respectively—is assigned an advisory group comprised of outstanding individuals who are very knowledgeable in the specifics of the particular project and who are looked to for guidance and counsel throughout the research and reporting phases. Those projects that do not conveniently fit under one of the first seven general fields are assigned to the eighth one, Special Projects.

The membership of the advisory groups is only advisory to the Board; individuals do not act as consultants or advisors to project investigators. Members may, according to established policy, submit proposals for research. If they do, in order to avoid possible conflict of interest they cannot participate as advisors until the research agencies have been selected. If unsuccessful, they may return to full participation. More than 447 individuals serve without compensation on these panels and committees, and their total yearly contribution to the Program is estimated to be some 3,000 man-days. Members of these committees and panels are outstanding men drawn from the agencies given in Table 1, and they come from 44 States, the District of Columbia, and Canada. State highway department employees constitute a significant portion of advisory group membership, and the duties and responsibilities of the membership include:

- Developing an operation plan geared to reaching the major problem area objective, including estimates of total cost and time to achieve the objectives.
- Drafting definite statements of objectives for projects within the problem area and within the funds allotted.
- Reviewing research proposals and making recommendations regarding selection of research agencies.
- Reviewing research progress.
- Providing counsel and advice regarding technical aspects of the research.
- Reviewing and evaluating project reports as to the accomplishment of objectives and suitability for publication.
- Making recommendations as to whether or not studies of problems included in prior fiscal year programs should be continued.

Following the NCHRP staff review made after program referral to the Academy, the recommended program is referred to the NCHRP advisory committee for comments as to the critical need for the research, the availability of other suitable sponsors, and whether or not the research items are appropriate to be identified with the Academy. Unacceptable problems are returned by the Academy to the AASHO Executive Committee with the reason for rejection and, when appropriate, with a recommendation for disposition.

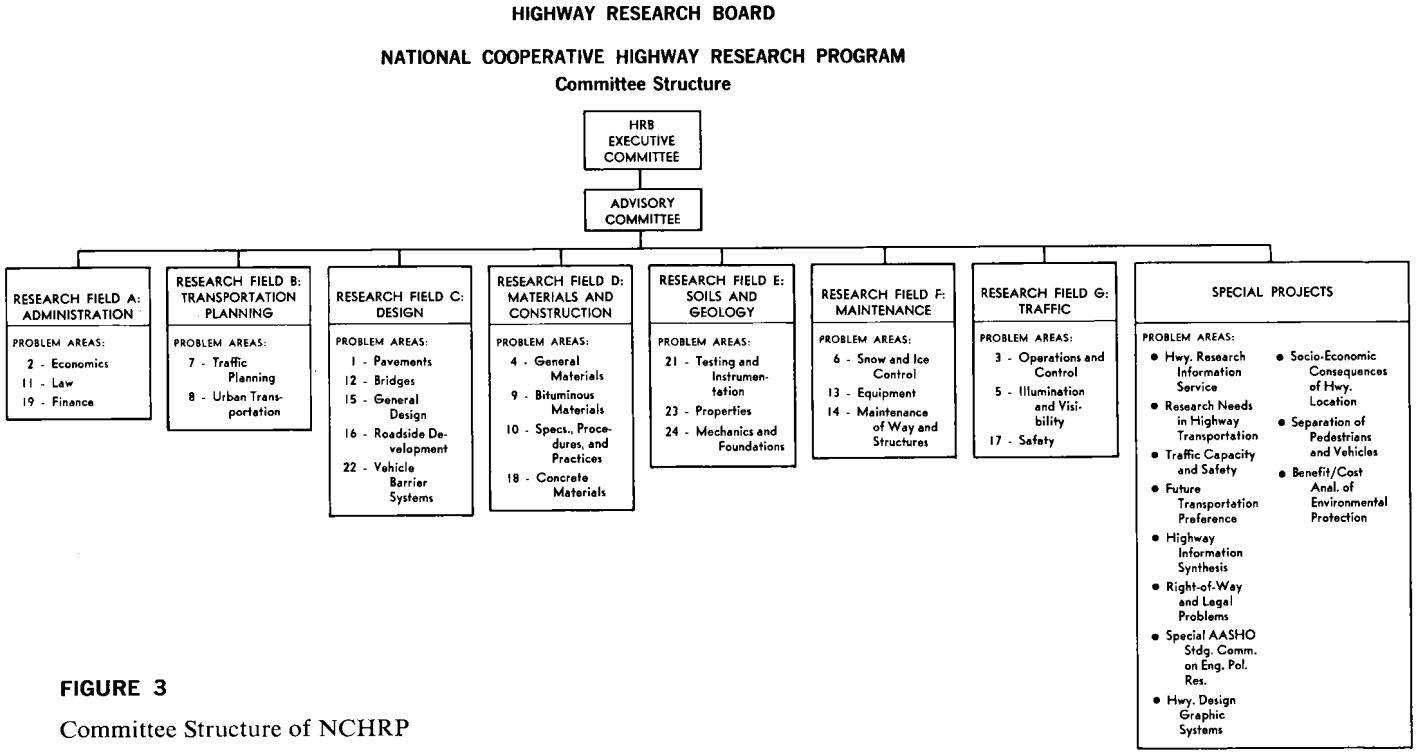

FIGURE 3

Committee Structure of NCHRP

HOW THE PROJECTS ARE PLACED UNDER CONTRACT

It is important to note that the NCHRP is not in the business of awarding grants for basic research. Rather, the Program calls for contract research that specifically spells out what is expected of a contractor in seeking research findings that can be practically applied. As the NCHRP officially gets each year's program under way, the advisory groups meet to write research "project statements" based on the research problems referred by AASHO.

These statements are then sent automatically to a mailing list of some 3,000 interested individuals and research agencies. The subsequent proposal return has increased over the years from an average of 6 per project to a high of 17 per project (refer to Table 2). The highest number of proposals received for any one project has been 35, and an individual agency has submitted as many as 11 proposals during a particular year's program; however, most agencies submit only one (refer to Table 3).

Contracts have been let to agencies headquarted in more than 27 States and the District of Columbia. Educational institutions have received about 40%; research institutes, 28%; industry and consultants; 31%; and state highway departments, 1%. In certain instances, the Board conducts NCHRP research directly in its Special Projects Division.

The opportunity to propose is open to anyone possessing extensive, demonstrated capability and experience in the problem areas in question, and proposals must be submitted according to fixed deadlines; extensions are simply not granted. Because the projects are seeking remedies for pressing operational problems, it is expected that only this high level of capability will be applied in meeting the commitments of the proposal—capability cannot be developed at project expense. Consonant with the goal of

TABLE 1

DISTRIBUTION OF PANEL AND SPECIAL PROJECT ADVISORY COMMITTEE MEMBERSHIP WITH RESPECT TO AFFILIATION

AFFILIATION	NO. OF MEMBERS	POSITIONS INVOLVED
State highway departments	157	240
Federal Highway Administration	66	138
Special transportation and other governmental agencies	53	92
Educational institutions	71	133
Research institutes	10	36
Industry, consultants, and trade associations	67	156
Professional societies and service organizations	9	15
Highway Research Board	14	98
All	447	908

TABLE 2

NUMBER OF PROPOSALS SUBMITTED

ITEM	'62	'63	'64	'65	'66	'67	'68	'69	'70	'71	'72
No. of projects advertised	34	27	14	16	13	16	19	9	14	14	14
Proposals submitted	191	223	171	151	149	209	189	107	236	157	206
Proposals rec'd. per project (avg.)	6	8	12	9	12	13	10	12	17	11	15

TABLE 3

NUMBER OF AGENCIES SUBMITTING ONE OR MORE RESEARCH PROPOSALS

NO. OF PROPOSALS SUBMITTED	NUMBER OF AGENCIES SUBMITTING PROPOSALS										
	'62	'63	'64	'65	'66	'67	'68	'69	'70	'71	'72
1	26	32	56	59	70	90	69	55	103	63	96
2	18	22	29	18	20	18	22	8	22	24	20
3	7	14	11	8	4	11	8	5	8	8	13
4	5	8	2	5	4	0	2	4	8	3	4
5	4	4	1	1	1	5	0	1	2	2	3
6	4	1	0	0	1	3	1	0	1	0	0
7	1	4	0	1	0	1	0	0	0	0	0
8	1	1	0	0	0	0	2	0	1	0	0
9	1	0	0	0	0	0	0	0	1	0	0
10	2	0	0	0	0	0	0	0	0	0	0
11	0	1	1	0	0	0	1	0	0	0	0
All	69	87	100	92	100	128	106	73	146	100	136

TABLE 4

TYPES OF AGENCIES SUBMITTING PROPOSALS

TYPE OF AGENCY	NO. OF AGENCIES SUBMITTING										
	'62	'63	'64	'65	'66	'67	'68	'69	'70	'71	'72
Educational institutions	41	32	39	32	40	51	25	36	53	33	50
Research institutes	11	16	17	22	22	26	19	16	23	14	9
Industry, consultants, and trade associations	14	35	42	35	35	48	59	18	67	51	72
Professional societies and service organizations	2	0	1	2	0	0	0	0	0	0	0
State highway departments	0	3	1	0	0	2	3	1	2	1	3
Special transportation and other governmental agencies	1	1	0	1	3	1	0	2	1	1	2
All	69	87	100	92	100	128	106	73	146	100	136
No. of projects advertised	34	27	14	16	13	16	19	9	14	14	14

providing practical, readily usable solutions to pressing problems, time and experience have led to the development of fairly stringent specifications for proposals and agency attributes that are acceptable to the mission-oriented nature of the NCHRP. The types of agencies responding with proposals for the 11 programs to date are given in Table 4. The staff and panel members evaluate all proposals in a uniform manner, with primary consideration given to:

- The understanding of the problem and the merit of the research plan and approach.
- The experiment design and the promise of fulfilling the objectives of the project statement.
- The qualifications of the principal investigator(s).
- The adequacy of the facilities.

The proposed budget is not one of the primary factors listed and does not enter the evaluation process leading to agency selection, except when costs exceed the funds available as listed on the project statement or when specific items are reviewed to better determine manpower allocations.

The three top proposals are chosen for each project, and an advisory group meeting is held to select an agency. The advisors review all known aspects of agency performance on other research projects under NCHRP or elsewhere. The successful proposals are retained by the group members for use in advisory duties during conduct of the research. Proposals are considered to be privileged and the information in them is not released outside of the Academy unless explicit approval is obtained from the agency. It is also NAS policy that panel notes, deliberations, etc., are privileged and not releasable under any circumstances.

Following the selection meeting, a list of recommended research agencies is transmitted to the AASHO Executive Committee and the Federal Highway Administration for their review and consideration. Contracts between the Academy and the research agencies are executed, and research is begun. Again, it should be emphasized that the NCHRP is a program of *contract* research—it does not operate on a grant basis. Further, proposals can be received only in response to advertised project statements, as the funds available each year to the Program are earmarked in their entirety for research problems specified by the sponsor—AASHO. New research areas can be recognized only through the previously described AASHO procedures.

The projects included in the 11 fiscal year programs conducted to date are listed in Table 5. There are 91 projects in traffic planning research, 100 in physical research, and 12 in the special projects area. The 203 projects are distributed among 27 States and the District of Columbia. To date, 157 of the projects have been completed. The distribution of all projects by agency type is given in Table 6.

The Academy's research contract is either:

- Cost-Reimbursement (CR)
- Cost-Reimbursement Plus Fixed Fee (CRPFF)
- Fixed Price (FP) (used only rarely)

The Academy decides, in agreement with the agency, which type of contract will be used in each case.

The research agency's proposal is made a part of the contract with the Academy. Thus, in addition to the specific research objectives outlined in the contract, the research agency's cost estimates are also recognized as being part of the agreement. The principal investigator, however, does have flexibility in conducting the research, if it is consistent with the general scheme of the proposal.

About two years elapse between the time problems are solicited from the member state highway departments and committees of AASHO and the time that contracts are signed. This appears at first glance to be excessive; however, it is not. It provides for the *advance planning* that is necessary to ensure that the referral to the National Academy of Sciences of an AASHO-developed program for any given year meshes appropriately with the apportionment of Federal-aid funds for that year. This permits smooth progression from year to year throughout the planning and activation phases of each year's program.

For example, initial steps were taken in August 1970 (early in fiscal year 1971) to develop the 1973 fiscal-year program. Federal apportionment was made in late October 1971; States' balloting occurred in March 1972; and contracts were signed in the July-August 1972 period immediately following the availability of the FY '73 funds. In July 1971 the cycle began again for the 1974 fiscal-year program and was repeated once again in July 1972 with respect to the 1975 program.

KEEPING TRACK OF RESEARCH IN PROGRESS

A professional staff is assigned to NCHRP by the Board. Projects engineers with individual specialties and training in the broad areas of physical research, traffic planning, and special projects research are responsible for administrative and technical surveillance of the contracts. In addition to reviewing quarterly progress reports and monthly progress schedules, and maintaining telephone contacts, each projects engineer visits his assigned research agencies throughout their contract periods. He discusses with each principal investigator his project's status to learn if the research is being pursued in line with the approved research plan. Finally, the projects engineer and appropriate advisory panel evaluate the completed research to determine the degree of technical compliance with the contract.

SYSTEMATIC PLANNING FOR IMPLEMENTING RESEARCH RESULTS FROM NCHRP PROJECTS

Promoting Useful Results

Previous reference has been made to the fact that many activities take place between initiation of research programs and execution of research contracts. Many additional ones take place up through formal publication of the final reports. At the milestones of the systematic process designed to accommodate these activities, NCHRP takes

TABLE 5

PROJECTS FOR FY '63 THROUGH FY '73, SUMMARY OF STATUS THROUGH DECEMBER 31, 1972

PROJECT NO.	TITLE	RESEARCH AGENCY	CONTRACT AMOUNT OR CONTRACT COST
	AREA ONE: DESIGN—PAVEMENTS		
1-1(1)	Development of Procedures for Comparing the AASHO Road Test Findings with Performance of (1) Existing Pavements and (2) Newly Constructed Experimental Pavements	HRB	$ 42,800*
1-1(2)	Guidelines for Extending the Findings of the AASHO Road Test—Implementation Phase	HRB	11,356*
1-2	Comparison of Different Methods for Evaluating Pavement Conditions	Purdue U	29,957*
1-3(1)	Factors Influencing Pavement Performance—Regional	Purdue U	45,982*
1-3(2)	Factors Influencing Pavement Performance—Local	Northwestern U	19,850*
1-3(3)	Factors Influencing Pavement Performance	U of California	19,800*
1-4(1)	Extension of Road Test Performance Concepts	Georgia Tech	10,000*
1-4(1)A	Extension of Road Test Performance Concepts	Duke U	19,924*
1-4(2)	Extension of Road Test Performance Concepts	Purdue U	12,243*
1-5	Detecting Variations in Load-Carrying Capacity of Flexible Pavements	Cornell Aero Lab	49,011*
1-5(2)	Detecting Seasonal Changes in Load-Carrying Capabilities of Flexible Pavements	Texas A & M	52,000
1-6	Standard Measurements for Satellite Program—Measurement Team	Texas A & M	61,353*
1-7	Development of Interim Skid-Resistance Requirements for Highway Pavement Surfaces	Penn State U	24,815*
1-8	Factors Involved in the Design of Asphalt Pavement Surfaces	Materials R & D	23,255*
1-9	Evaluation of Studded Tires	Cornell Aero Lab	24,998*
1-10	Translating AASHO Road Test Findings—Basic Properties of Pavement Components	Materials R & D	99,803* 103,291
1-10A	Systems Approach to Pavement Design—Implementation Phase	Texas A & M	100,000
1-11	Evaluation of AASHO Interim Guides for Design of Pavement Structures	Materials R & D	63,720* 20,205
1-12	Determination of Pavement Friction Coefficients Required for Driving Tasks	Franklin Inst	299,990
1-12(2)	Locked-Wheel Pavement Skid Tester Correlation and Calibration Techniques	Penn State U	319,000
1-12(3)	Requirements for Wear-Resistant and Skid-Resistant Highway Pavement Surfaces	Materials R & D	249,651
1-13	Effects of Studded Tires on Highway Safety	Cornell Aero Lab	200,000
1-13(2)	Effects of Studded Tires on Highway Safety	U of Michigan	39,450
1-14	Influence of Combined Highway Grade and Horizontal Alignment on Skidding	U of Michigan	70,000
1-15	Design of Continuously Reinforced Concrete Pavements for Highways	U of Texas	149,985
	AREA TWO: ADMINISTRATION—ECONOMICS		
2-1	Criteria for Highway Benefit Analysis	U of Washington	101,948*
2-2	Guidelines for the Determination of Community Consequences	U of Washington	48,873*
2-3	Analysis of Motor Vehicle Accident Data as Related to Highway Classes and Design Elements	Cornell Aero Lab	155,972*
2-4	The Value of Highway Travel Time, Comfort, Convenience, and Uniform Driving Speed	Texas A & M	77,100
2-5	Running Cost of Motor Vehicles as Affected by Highway Design and Traffic	Catholic U	49,998* 51,265*
2-5A	Running Cost of Motor Vehicles as Affected by Highway Design and Traffic	Paul J. Claffey	35,000* 30,665*
2-6	Warranted Levels of Improvement for Local Rural Roads	Stanford U	40,000*
2-7	Road User Costs in Urban Areas	Catholic U	99,376*
2-8	Estimation and Evaluation of Diverted and Generated (Induced) Traffic	Northwestern U	40,000*
2-9	Effect of Highway Landscape Development on Nearby Property	Franklin Inst	149,103*
2-10	Future Needs for Oversize-Overweight Permit Operation on State Highways	Jorgensen & Assoc	99,655*
2-11	Summary and Evaluation of Economic Consequences of Highway Improvements	HRB	110,000
	AREA THREE: TRAFFIC—OPERATIONS AND CONTROL		
3-1	Development of Criteria for Evaluating Traffic Operations	Cornell Aero Lab	78,965* 79,913*
3-2	Surveillance Methods and Ways and Means of Communicating with Drivers	Cornell Aero Lab	246,756*
3-3	Sensing and Communication Between Vehicles	Ohio State U	163,190*
3-4	Means of Locating Disabled or Stopped Vehicles and Methods of Communication with a Central Location	Airborne Instr	78,517* 49,474*
3-5	Improved Criteria for Designing and Timing Traffic Signal Systems	Planning Res	123,030* 48,155* 93,717
3-6	Effect of Regulatory Devices on Intersectional Capacity and Operation	De Leuw, Cather	153,175*
3-7	Establishment of Standards for Highway Noise Levels	Bolt Beranek	144,920* 69,930* 49,927 299,050
3-8	Factors Influencing Safety at Highway-Rail Grade Crossings	Voorhees & Assoc	17,171* 74,250*
3-9	Analysis and Projection of Research on Traffic Surveillance, Communication, and Control	Jorgensen & Assoc	23,760*
3-10	Application of Vehicle Operating Characteristics to Geometric Design and Traffic Operations	Cornell Aero Lab	41,520*

STARTING DATE	COMPLETION DATE	PROJECT STATUS	PROJECT NO.
3/1/63	2/29/64	Completed—Published as NCHRP Reports 2, 2A	1-1(1)
3/1/64	8/31/65	Contract terminated—No report	1-1(2)
2/15/63	2/28/65	Completed—Initial phase published as NCHRP Report 7; final report not to be published; summarized in Summary of Progress to June 30, 1967	1-2
2/15/63	9/30/67	Completed—Published as NCHRP Report 132	1-3(1)
9/1/63	9/30/64	Completed—Published as NCHRP Report 22	1-3(2)
4/1/64	10/31/65	Completed—Published as NCHRP Report 35	1-3(3)
10/1/63	9/30/64	Completed—Published as NCHRP Report 10	1-4(1)
2/1/65	9/30/66	Completed—Published as NCHRP Report 97	1-4(1)A
2/1/64	1/31/66	Completed—Published as NCHRP Report 30	1-4(2)
1/15/64	7/15/65	Completed—Published as NCHRP Report 21	1-5
9/1/66	6/30/68	Completed—Published as NCHRP Report 76	1-5(2)
3/31/64	1/31/67	Completed—Published as NCHRP Report 59	1-6
6/15/65	12/15/66	Completed—Published as NCHRP Report 37	1-7
1/1/65	2/28/66	Completed—Published as NCHRP Report 39	1-8
10/1/66	6/30/67	Completed—Published as NCHRP Report 61	1-9
9/12/66	3/11/68	Completed—Report to be included in final publication	1-10
12/1/68	12/31/70	Report in editorial and publication process	1-10
3/1/72	12/31/73	Research in progress	1-10A
10/23/67	6/30/70	Completed—Published as NCHRP Report 128	1-11
8/1/70	4/30/71	Completed—Published by AASHO	1-11
8/25/69	2/24/72	Report in review stage	1-12
9/16/70	5/15/73	Research in progress	1-12(2)
11/1/71	4/30/75	Research in progress	1-12(3)
4/19/71	3/31/73	Report in review stage	1-13
2/15/72	11/30/72	Report in review stage	1-13(2)
10/15/72	1/14/74	Research in progress	1-14
8/1/72	4/30/74	Research in progress	1-15
6/1/63	11/30/67	Completed—Rep. not to be publ.; summarized in Summary of Progress to June 30, 1968	2-1
7/1/63	8/31/64	Completed—Published as NCHRP Report 18	2-2
6/1/63	8/31/66	Completed—Published as NCHRP Report 47	2-3
6/1/63	8/31/66	Completed—Published as NCHRP Report 33	2-4
6/1/63	8/31/64	Completed—Published as NCHRP Report 13	2-5
6/1/65	12/31/66	Completed—Report included in NCHRP Report 111	2-5
7/1/67	12/31/68	Completed—Report included in NCHRP Report 111	2-5A
8/11/69	8/10/70	Completed—Report included in NCHRP Report 111	2-5A
6/1/63	9/30/66	Completed—Published as NCHRP Report 63	2-6
2/1/64	5/31/66	Completed—Report included in NCHRP Report 111	2-7
5/1/64	8/31/66	Completed—Rep. not to be publ.; summarized in Summary of Progress to June 30, 1967	2-8
11/8/65	1/31/68	Completed—Published as NCHRP Report 75	2-9
11/1/66	4/30/68	Completed—Published as NCHRP Report 80	2-10
1/1/67	7/31/70	Completed—Published as NCHRP Report 122	2-11
2/15/63	2/29/64	Completed—Report not to be published; summarized in Summary of Progress to	3-1
7/2/64	2/28/66	June 30, 1967	
2/15/63	4/30/66	Completed—Published as NCHRP Reports 9, 28, 29	3-2
2/15/63	11/30/65	Completed—Published as NCHRP Report 51	3-3
3/1/63	3/31/65	Completed—Published as NCHRP Report 6	3-4
7/1/65	12/15/66	Completed—Published as NCHRP Report 40	3-4
3/1/63	12/31/65	Completed—Published as NCHRP Reports 3, 32	3-5
7/1/66	7/31/67	Completed—Published as NCHRP Report 73	3-5
8/1/68	12/31/69	Completed—Published as NCHRP Report 124	3-5
4/1/63	8/15/66	Completed—Published as NCHRP Reports 11, 41	3-6
2/1/64	4/30/67	Completed—Published as NCHRP Report 78	3-7
10/14/68	1/15/70	Completed—Published as NCHRP Report 117	3-7
4/1/71	6/30/72	Report in editorial and publication process	3-7
9/1/72	5/31/74	Research in progress	3-7
12/1/63	12/31/64	Completed—Report included in NCHRP Report 50	3-8
4/1/65	1/6/67	Completed—Total project published as NCHRP Report 50	3-8
10/15/66	1/14/68	Completed—Published as NCHRP Report 84	3-9
1/1/66	3/10/67	Completed—Published as NCHRP Report 68	3-10

TABLE 5 (*Continued*)

PROJECT NO.	TITLE	RESEARCH AGENCY	CONTRACT AMOUNT OR CONTRACT COST
	AREA THREE (*Continued*)		
3-11	Optimizing Street Operations Through Traffic Regulations and Control	Peat, Marwick	258,331*
3-12	Development of Information Requirements and Transmission Techniques for Highway Users	Airborne Instr	198,655*
			100,500*
3-13	Guidelines for Medial and Marginal Access Control of Major Roadways		99,956
3-14	Optimizing Flow on Existing Street Networks	Texas A & M	149,916
3-15	Weaving Area Operations Study	Edwards & Kelcey	990,000*
3-16	Freeway Lane Drops	Poly of Brooklyn	300,000
		System Dev Corp	99,789*
3-17	Improving Traffic Operations and Safety at Exit Gore Areas		76,815
3-18(1)	Improved Control Logic for Use with Computer-Controlled Traffic	Penn State U	80,000
3-18(2)	Traffic Control in Oversaturated Street Networks	Stanford Res Inst	298,698
3-19	Grade Effects on Traffic Flow Stability and Capacity	Poly of Brooklyn	100,000
3-20	Traffic Signal Warrants	Midwest Res Inst	200,000
		KLD Associates	120,000
	AREA FOUR: MATERIALS AND CONSTRUCTION—GENERAL MATERIALS		
4-1	Development of Appropriate Methods for Evaluating the Effectiveness of Stabilizing Agents	U of Illinois	$114,991*
4-2	A Study of Degrading Aggregates in Bases and Subbases with Production of Excessive Amounts of and/or Harmful Types of Fines	Purdue U	63,990*
4-3(1)	Development of Methods to Identify Aggregate Particles Which Undergo Destructive Volume Changes When Frozen in Concrete	V P I	20,000*
			23,337*
4-3(2)	Development of Methods to Identify Aggregate Particles Which Undergo Destructive Volume Changes When Frozen in Concrete	Penn State U	56,457*
			49,756*
4-4	Synthetic Aggregates for Highway Uses	Battelle Mem Inst	14,790*
4-5	A Study of the Mechanism Whereby the Strength of Bases and Subbases Is Affected by Frost and Moisture	Michigan Tech U	64,105*
4-6	Protective Coatings for Highway Structural Steel	Steel Str Paint	25,000*
4-7	Fatigue Strength of High-Yield Reinforcing Bars	P C A	100,000
			50,000
4-8	Research Needs Relating to Performance of Aggregates in Highway Construction	V P I	55,254*
4-8(2)	Density Standards for Field Compaction of Granular Bases and Subbases	Clemson U	99,981
4-8(3)	Predicting Moisture-Induced Damage to Asphaltic Concrete	U of Idaho	200,000
4-9	Evaluation of Preformed Elastomeric Pavement Joint Sealing Systems and Practices	Utah St Dept Hy	93,494
4-9	Preformed Elastomeric Pavement Joint Sealing Systems—Field Evaluation Phase	Utah St Dept Hy	125,000
4-10	Promising Replacements for Conventional Aggregates for Highway Use	U of Illinois	50,000*
4-10A	Waste Materials as Potential Replacements for Highway Aggregates	Valley Forge Lab	49,942
	AREA FIVE: TRAFFIC—ILLUMINATION AND VISIBILITY		
5-2(1)	Effects of Illumination on Operating Characteristics of Freeways—Traffic Flow, Driver Behavior, and Accidents	Yale University	124,319*
			21,530*
5-2(2)	Effects of Illumination on Operating Characteristics of Freeways—Driver Response, Visibility, and Visual Discomfort	Ohio State U	81,187*
5-2(3)	Effects of Illumination on Operating Characteristics of Freeways—Driver Discomfort	Inst for Research	37,460*
5-3	Visual Information Needed by the Driver at Night	Ohio State U	100,940*
5-4	Economic Study of Roadway Lighting	Franklin Inst	19,412*
5-5	Nighttime Use of Highway Pavement Delineation Materials	Sw Research Inst	50,000*
			100,000*
5-5A	Development of Optimum Specifications for Glass Beads in Pavement Markings	Penn State U	100,000
5-5B	Pavement Marking Systems for Improved Wet-Night Visibility Where Snowplowing Is Prevalent	Texas A & M	200,000
5-6	Highway Fog		
5-6A	Highway Fog	Cornell Aero Lab	99,955*
5-7	Roadway Delineation Systems	Sperry Rand	95,195
5-8	Warrants for Highway Lighting	Penn State U	469,526*
		Texas A & M	199,627
	AREA SIX: MAINTENANCE—SNOW AND ICE CONTROL		
6-1	Development of Economical and Effective Chemical Deicing Agents to Minimize Injury to Highway Structures and Vehicles	IIT Research Inst	40,000*
6-2	Nonchemical Methods for Preventing or Removing Snow and Ice Accumulations on Highway Structures	Jorgensen & Assoc	25,000*
6-3	Development and Evaluation of Protective Coatings to Prevent Deterioration of Concrete Structures by Deicing Agents	Battelle Mem Inst	58,557*
6-4	Evaluation and Development of Methods for Reducing Corrosion of Reinforcing Steel	Battelle Mem Inst	39,330*
6-5	Study of Physical Factors Influencing Resistance of Concrete to Deicing Agents	U of Illinois	72,500*
6-6	To Evaluate Existing Methods and/or Develop Improved Methods for the Measurement of Certain Properties of Concrete	Ohio State U	69,393*
6-7	Estimation of Disintegration in Concrete Structures	Geotechnics	8,547*
6-7A	Estimation of Disintegration in Concrete Structures	IIT Research Inst	44,614*

START-ING DATE	COMPLE-TION DATE	PROJECT STATUS	PROJECT NO.
9/1/66	9/30/68	Completed—Published as NCHRP Report 110	3-11
10/1/66	12/31/67	Completed—Report included in NCHRP Report 123	3-12
4/1/68	12/1/69	Completed—Report included in NCHRP Report 123	3-12
3/29/71	6/30/72	Report in review stage	3-12
9/1/67	11/30/69	Completed—Published as NCHRP Report 93	3-13
10/1/67	1/10/70	Completed—Published as NCHRP Report 113	3-14
10/1/69	10/31/73	Research in progress	3-15
11/1/69	4/30/71	Completed—Rep. not to be publ.; summarized in Summary of Progress Through 1971	3-16
5/1/72	5/31/73	Research in progress	3-16
1/1/71	3/31/72	Report in review stage	3-17
7/15/71	10/31/73	Research in progress	3-18(1)
9/1/71	3/31/73	Research in progress	3-18(2)
9/1/71	11/30/73	Research in progress	3-19
9/1/72	11/30/73	Research in progress	3-20
6/1/63	10/31/66	Completed—Report not to be published; summarized in Summary of Progress Through June 30, 1968	4-1
2/15/63	11/30/66	Completed—Published as NCHRP Report 98	4-2
3/1/63	9/30/64	Completed—Published as NCHRP Report 12	4-3(1)
7/1/65	3/31/67	Completed—Published as NCHRP Report 65	4-3(1)
3/25/63	1/31/65	Completed—Published as HRB Special Report 80 and NCHRP Report 15	4-3(2)
7/1/65	8/31/67	Completed—Published as NCHRP Report 66	4-3(2)
3/1/63	4/15/64	Completed—Published as NCHRP Report 8	4-4
2/15/63	8/31/65	Completed—Report not to be published; summarized in Summary of Progress Through June 30, 1968	4-5
3/1/65	11/30/66	Completed—Published as NCHRP Reports 74, 74A, 74B	4-6
10/1/67	2/28/70	Completed—Report to be included in Phase II Report	4-7
2/1/71	9/30/72	Report in review stage	4-7
1/1/68	4/30/69	Completed—Published as NCHRP Report 100	4-8
4/1/71	3/31/73	Research in progress	4-8(2)
9/1/71	2/28/74	Research in progress	4-8(3)
10/1/68	6/30/71	Report in review stage	4-9
10/1/72	12/31/77	Research in progress	4-9
10/15/69	3/31/71	Completed—Published as NCHRP Report 135	4-10
9/1/72	11/30/73	Research in progress	4-10A
2/15/63	5/31/66	Completed—Report included in NCHRP Report 60	5-2(1)
2/1/67	7/31/67	Completed—Report included in NCHRP Report 60	5-2(1)
2/15/63	8/31/65	Completed—Report included in NCHRP Report 60	5-2(2)
2/20/63	2/28/66	Completed—Report included in NCHRP Report 60	5-2(3)
9/1/64	3/31/67	Completed—Published as NCHRP Report 99	5-3
7/20/64	8/31/65	Completed—Published as NCHRP Report 20	5-4
3/1/65	12/31/66	Completed—Published as NCHRP Report 45	5-5
7/15/67	9/15/69	Completed—Published as NCHRP Report 85	5-5
5/1/71	4/30/73	Research in progress	5-5A
9/1/71	8/31/74	Research in progress	5-5B
10/2/67	4/30/69	Completed—Published as NCHRP Report 95	5-6
9/1/70	11/30/72	Report in review stage	5-6A
10/1/68	6/30/71	Completed—Published as NCHRP Report 130	5-7
3/16/70	6/15/72	Report in review stage	5-8
2/15/63	9/30/64	Completed—Published as NCHRP Report 19	6-1
2/15/63	2/29/64	Completed—Published as NCHRP Report 4	6-2
3/1/63	2/28/65	Completed—Published as NCHRP Report 16	6-3
3/1/63	4/30/65	Completed—Published as NCHRP Report 23	6-4
3/1/63	8/31/65	Completed—Published as NCHRP Report 27	6-5
3/1/63	2/28/66	Completed—Report not to be published; summarized in Summary of Progress to June 30, 1967	6-6
3/1/63	8/31/64	Contract terminated—no report; research resumed under Project 6-7A	6-7
2/1/65	7/31/66	Completed—Rep. not to be publ.; summarized in Summary of Progress to June 30, 1967	6-7A

TABLE 5 (*Continued*)

PROJECT NO.	TITLE	RESEARCH AGENCY	CONTRACT AMOUNT OR CONTRACT COST
	AREA SIX (*Continued*)		
6-8	Evaluation of Methods of Replacement of Deteriorated Concrete in Structures	Tallamy Assoc	25,000*
6-9	Potential Accelerating Effects of Chemical Deicing Damage by Traffic and Other Environmental-Induced Stresses in Concrete Bridge Decks	U of Illinois	200,000*
6-10	Develop Improved Snow Removal and Ice Control Techniques at Interchanges	Tallamy Assoc	95,000*
6-11	Economic Evaluation of the Effects of Ice and Frost on Bridge Decks	Midwest Res Inst	50,000 50,000
	AREA SEVEN: TRANSPORTATION PLANNING—TRAFFIC PLANNING		
7-1	The Influence of Land Use on Urban Travel Patterns	Louis E. Keefer	62,674* 66,894*
7-2	Traffic Attraction of Rural Outdoor Recreational Areas	IIT Research Inst	24,652* 24,844*
7-3	Weighing Vehicles in Motion	Franklin Inst	73,391*
7-4	Factors and Trends in Trip Lengths	Voorhees & Assoc	89,250* 61,730*
7-5	Predicted Traffic Usage of a Major Highway Facility Versus Actual Usage	Yale University	99,675*
7-6	Multiple Use of Lands Within Highway Rights-of-Way	Barton-Aschman	24,220*
7-7	Motorists' Needs and Services on Interstate Highways	Airborne Instr	99,267*
7-8	User Cost and Related Consequences of Alternative Levels of Highway Service	Stanford Res Inst	99,070
7-9	Development of Models for Predicting Weekend Recreational Traffic	Midwest Res Inst	74,983
	AREA EIGHT: TRANSPORTATION PLANNING—URBAN TRANSPORTATION		
8-1	Social and Economic Factors Affecting Travel	Vogt, Ivers	$ 94,558*
8-2	Factors Influencing Modal Trip Assignment	IIT Research Inst	298,033*
8-3	Individual Preferences for Various Means of Transportation	U of Penn	63,282*
8-4	Criteria for Evaluating Alternative Transportation Plans	Northwestern U	89,900*
8-4A	Criteria for Evaluating Alternative Transportation Plans	U of Illinois	5,000*
8-5	Transportation Aspects of Land-Use Controls	Victor Gruen	25,967* 99,571*
8-6	Individual Preferences for Alternative Dwelling Types and Environments	U of N Carolina	99,897*
8-7	Evaluation of Data Requirements and Collection Techniques for Transportation Planning	Creighton, Hamburg	190,000*
8-7A	Data Requirements and Transportation Planning Procedures in Small Urban Areas	—	—
8-8(1)	The Impact of Highways upon Environmental Values (Study Design)	M I T	29,654*
8-8(2)	The Impact of Highways upon Environmental Values (Study Design)	Daniel, Mann et al	28,950*
8-8(3)	The Impact of Highways upon Environmental Values	M I T	470,000
8-9	Comparative Economic Analysis of Alternative Multimodal Passenger Transportation Systems	Creighton, Hamburg	93,738
8-10	Planning and Design Guidelines for Efficient Bus Utilization of Highway Facilities	Wilbur Smith	149,907
	AREA NINE: MATERIALS AND CONSTRUCTION—BITUMINOUS MATERIALS		
9-1	Asphalt Durability and Its Relation to Pavement Performance	American Oil	50,000* 50,000*
9-2	Asphalt Durability and Its Relation to Pavement Performance—Adhesion	Montana College	107,670
9-3	Evaluation of Pavement Joint and Crack Sealing Materials and Practices	Rensselaer	24,996*
9-4	Minimizing Premature Cracking of Asphaltic Concrete Pavements	Materials R & D	99,560
	AREA TEN: MATERIALS AND CONSTRUCTION—SPECIFICATIONS, PROCEDURES, AND PRACTICES		
10-1	Development of Guidelines for Practical and Realistic Construction Specifications	Miller-Warden	25,000*
10-2	Evaluation of Construction Control Procedures	Miller-Warden	59,750*
10-2A	Evaluation of Construction Control Procedures	Materials R & D	70,945*
10-3	Effects of Different Methods of Stockpiling and Handling Aggregates	Miller-Warden	25,000* 30,000*
10-4	Rapid Test Methods for Field Control of Construction	Clemson U	30,000* 69,320*
10-5	Density and Moisture Content Measurements by Nuclear Methods	Res Triangle Inst	28,801* 59,835*
10-5A	Optimization of Nuclear Density and Moisture Content Measurement Methods	N Carolina State U	49,986
10-6	Measurement of Pavement Thicknesses by Rapid and Nondestructive Methods	IIT Research Inst	108,821*
10-7	Potential Uses of Sonic and Ultrasonic Devices in Highway Construction	Ohio State U	24,310*
10-8	Evaluating Procedures for Determining Concrete Pavement Thickness and Reinforcement Position	Pa Dept of Transp	199,835
10-9	Criteria for Need of Seal Coats for Bituminous Pavements	U of Minnesota	50,000
	AREA ELEVEN: ADMINISTRATION—LAW		
11-1	Rules of Compensability and Valuation in Highway Land Acquisition	U of Wisconsin	84,840*
11-1(1)	Eliminating Enhancement or Diminution Effects on Right-of-Way Valuation	Real Estate Res	5,000*
11-1(2)	Recognition of Benefits to Remainder Property in Highway Valuation	Montano & Assoc	5,000*
11-1(3)	Taxation Aspects of Right-of-Way Acquisition	U of Tulsa	2,500
11-1(4)	Compensation in the Nature of Additives to Market Value	U of Oklahoma	2,500*
11-1(5)	Rules of Discovery and Disclosure in Highway Condemnation Proceedings	Long, Mikkelborg	2,500*
11-1(6)	Valuation and Condemnation Problems of Selected Special Purpose Properties	Edward E. Level	7,500*
11-1(7)	Valuation and Compensability of Noise, Pollution, and Other Environmental Factors	U of Oklahoma	2,500*
11-1(8)	Remainder Damages Caused by Drainage, Runoff, Blasting, and Slides	Harrison Lewis	7,500*

START-ING DATE	COMPLE-TION DATE	PROJECT STATUS	PROJECT NO.
2/15/63	2/29/64	Completed—Published as NCHRP Report 1	6-8
1/1/65	6/15/68	Completed—Published as NCHRP Report 101	6-9
9/1/67	9/30/70	Completed—Published as NCHRP Report 127	6-10
9/1/70	11/30/71	Init. phase completed—rep. to be incl. in Phase II rep.	6-11
9/12/72	3/11/74	Research in progress	6-11
2/1/64	1/31/66	Completed—Published as NCHRP Report 24	7-1
4/1/66	9/30/67	Completed—Published as NCHRP Report 62	7-1
2/1/64	3/15/65	Completed—Report included in NCHRP Report 44	7-2
5/1/65	5/31/66	Completed—Total project published as NCHRP Report 44	7-2
2/1/64	8/31/67	Completed—Published as NCHRP Report 71	7-3
2/1/64	10/31/66	Completed—Published as NCHRP Report 48	7-4
10/23/67	1/10/69	Completed—Published as NCHRP Report 89	7-4
2/1/64	11/30/66	Completed—Published as NCHRP Report 58	7-5
2/1/66	2/28/67	Completed—Published as NCHRP Report 53	7-6
1/1/66	12/31/67	Completed—Published as NCHRP Report 64	7-7
9/1/70	4/15/72	Completed—Published as NCHRP Report 133	7-8
9/1/72	11/30/73	Research in progress	7-9
2/1/64	9/23/66	Completed—Published as NCHRP Report 70	8-1
2/1/64	8/31/66	Completed—Published as NCHRP Report 57	8-2
2/1/64	3/31/65	Completed—Rep. not to be publ.; summarized in Summary of Progress to June 30, 1967	8-3
2/1/65	8/1/67	Completed—Report included in NCHRP Report 96	8-4
10/14/68	1/10/69	Completed—Published as NCHRP Report 96	8-4A
4/1/65	5/31/66	Completed—Published as NCHRP Report 31	8-5
8/7/67	1/15/70	Completed—Published as NCHRP Report 121	8-5
2/14/66	3/13/68	Completed—Published as NCHRP Report 81	8-6
9/13/68	8/28/70	Completed—Published as NCHRP Report 120	8-7
—	—	Contract pending	8-7A
9/16/68	3/14/69	Completed—Study design report not to be published	8-8(1)
9/9/68	3/7/69	Completed—Study design report not to be published	8-8(2)
9/15/69	12/31/73	Initial phase completed—Rep. to be incl. in Phase II rep.; Phase II research in prog.	8-8(3)
9/1/71	1/31/73	Report in review stage	8-9
9/1/71	2/28/73	Report in review stage	8-10
2/1/64	7/31/65	Completed—Report included in NCHRP Report 67	9-1
11/1/65	4/30/67	Completed—Total project published as NCHRP Report 67	9-1
1/1/65	10/31/67	Completed—Rep. not to be publ.; summarized in Summary of Progress Through 1972	9-2
6/1/65	6/30/66	Completed—Published as NCHRP Report 38	9-3
11/1/71	1/31/73	Research in progress	9-4
11/15/63	11/14/64	Completed—Published as NCHRP Report 17	10-1
11/4/63	2/1/66	Completed—Published as NCHRP Report 34	10-2
7/15/66	11/14/67	Completed—Published as NCHRP Report 69	10-2A
10/22/63	4/30/64	Completed—Published as NCHRP Report 5	10-3
10/15/64	10/16/65	Completed—Published as NCHRP Report 46	10-3
2/1/64	2/28/65	Completed—Report included in NCHRP Report 103	10-4
5/1/65	2/28/67	Completed—Published as NCHRP Report 103	10-4
1/15/64	1/31/65	Completed—Published as NCHRP Report 14	10-5
4/1/65	10/7/66	Completed—Published as NCHRP Report 43	10-5
2/1/68	1/31/70	Completed—Published as NCHRP Report 125	10-5A
2/1/64	10/31/66	Completed—Published as NCHRP Report 52	10-6
2/1/64	3/31/65	Completed—Published as NCHRP Report 25	10-7
3/2/70	5/31/73	Research in progress	10-8
11/1/69	1/31/73	Initial phase completed—Rep. to be incl. in Phase II rep.; Phase II research in prog.	10-9
1/1/65	4/30/67	Completed—Published as NCHRP Report 104	11-1
9/2/68	2/28/69	Completed—Published as NCHRP Report 114	11-1(1)
10/1/68	3/31/69	Completed—Published as NCHRP Report 88	11-1(2)
9/16/68	4/30/69	No final report—Project terminated	11-1(3)
12/1/68	5/31/69	Completed—Rep. not to be publ.; summarized in Summary of Progress Through 1972	11-1(4)
9/15/68	4/14/69	Completed—Published as NCHRP Report 87	11-1(5)
9/2/68	11/28/69	Completed—Published as NCHRP Report 92	11-1(6)
10/1/68	3/31/69	Completed—Rep. not to be publ.; summarized in Summary of Progress Through 1972	11-1(7)
10/15/68	1/15/70	Completed—Published as NCHRP Report 134	11-1(8)

TABLE 5 (*Continued*)

PROJECT NO.	TITLE	RESEARCH AGENCY	CONTRACT AMOUNT OR CONTRACT COST
	AREA ELEVEN (*Continued*)		
11-1(9)	Valuation and Condemnation Problems Involving Trade Fixtures	Edward L. Snitzer	5,000*
11-1(10)	Compensability and Valuation Aspects of Residential Displacement in Highway Programs	Ross, Hardies et al.	5,000*
11-1(11)	Valuation Elements of Joint Development Projects, Including Air Rights	Real Estate Res	5,000*
11-2	Theory and Practice in Inverse Condemnation	Reg & Urban Plan	15,000*
11-3	Valuation and Legal Implications of Scenic, Conservation, and Roadside Easements	Sutte, Jr. & Assoc	25,000*
11-3(1)	Public Control of Roadside Advertising Signs for Highway Beautification	Sutte, Jr. & Assoc	20,000*
11-3(2)	Public Control of Junkyards for Highway Beautification	Real Estate Res	13,300*
11-4	Elimination of Wide Divergence in Right-of-Way Valuation	Am Inst Rl Est App	24,959*
11-5	Valuation of Air Space	Daniel, Mann et al	49,800
	AREA TWELVE: DESIGN—BRIDGES		
12-1	Deformation of Steel Beams Related to Permitted Highway Bridge Overloads	U of Missouri	50,000
12-2	Distribution of Wheel Loads on Highway Bridges	Iowa State U	79,512*
12-3	Development of Waterproof Roadway Joints for Bridges	Sw Research Inst	149,895*
12-4	Thermal Characteristics of Highway Bridges	Sw Research Inst	102,400*
12-5	Protection of Steel in Prestressed Concrete Bridges	U of Denver	173,255*
12-6	Prediction of Permanent Camber of Bridges	U of Missouri	85,000
12-7	Effects of Weldments on Fatigue Strength of Steel Beams	Lehigh University	199,023* 200,000
12-8	Bridge Rail Service Requirements as a Basis for Design Criteria	Texas A & M	30,000 70,000
12-9	Elastomeric Bearing Research	Battelle Mem Inst	84,800*
12-10	Analysis and Design of Bridge Bents	PCA	297,900
12-11	Waterproof Membranes for Protection of Concrete Bridge Decks	Materials R & D	206,034
12-12	Welded Steel Bridge Members Under Variable-Cycle Fatigue Loadings	US Steel	300,000
12-13	Cathodic Protection for Reinforced Concrete Bridge Decks	USS Eng & Consult	174,699
12-14	Subcritical Crack Growth in Steel Bridge Members	US Steel	99,923
12-15	Detection and Repair of Fatigue Cracking in Highway Bridges	Lehigh U	100,000
	AREA THIRTEEN: MAINTENANCE—EQUIPMENT		
13-1	Equipment Rental Rates	Ernst & Ernst	$ 22,800*
	AREA FOURTEEN: MAINTENANCE—MAINTENANCE OF WAY AND STRUCTURES		
14-1	Upgrading of Unit Maintenance Cost Index and Development of Interstate Maintenance Requirements	Tallamy Assoc	205,128*
14-2	Techniques for Reducing Roadway Occupancy During Routine Maintenance Activities	Byrd, Tallamy et al	200,000
14-3	Improved Pavement-Shoulder Joint Design	Georgia Tech	99,754
	AREA FIFTEEN: DESIGN—GENERAL DESIGN		
15-1	Guardrail Design	Cornell Aero Lab	19,723*
15-1(2)	Guardrail Performance and Design	Sw Research Inst	280,000* 100,000*
15-2	Design to Control Erosion in Roadside Drainage Channels	U of Minnesota	95,000
15-3	Rational Structural Analysis and Design of Pipe Culverts	Northwestern U	49,937*
15-4	Estimating Runoff Rates from Small Rural Watersheds	Travelers Res Cen	299,902*
15-5	Dynamic Characteristics of Heavy Highway Vehicles	Gen Mot Corp	135,000*
15-6	Development of Criteria for Safer Luminaire Supports	Texas A & M	150,000
	AREA SIXTEEN: DESIGN—ROADSIDE DEVELOPMENT		
16-1	Effects of Deicing Compounds on Vegetation and Water Supplies	V P I	217,300
16-2	Evaluation of Research on Roadside Development	Western States	100,000
16-3	Erosion Control During Highway Construction	To Be Determined	
	AREA SEVENTEEN: TRAFFIC—SAFETY		
17-1	Development of Improved Methods for Reduction of Traffic Accidents	Cornell Aero Lab	247,847*
17-2	Methods for Evaluating Highway Safety Improvements	ORI	29,973
17-2A	Methods for Evaluating Highway Safety Improvements	Jorgensen & Assoc	97,134
	AREA EIGHTEEN: MATERIALS AND CONSTRUCTION—CONCRETE MATERIALS		
18-1	Revibration of Retarded Concrete for Continuous Bridge Decks	U of Illinois	103,895*
18-2	Use of Polymers in Highway Concrete	Lehigh U	300,000
	AREA NINETEEN: ADMINISTRATION—FINANCE		
19-1	Budgeting for State Highway Departments	Ernst & Ernst	45,000*
19-2(1)	Develop Performance Budgeting System to Serve Highway Maintenance Management	Booz·Allen & Ham.	6,000*
19-2(2)	Develop Performance Budgeting System to Serve Highway Maintenance Management	Ernst & Ernst	6,000*
19-2(3)	Develop Performance Budgeting System to Serve Highway Maintenance Management	Jorgensen & Assoc	6,000*
19-2(4)	Develop Performance Budgeting System to Serve Highway Maintenance Management	Jorgensen & Assoc	220,000*
19-3	Economic Effects of Changes in Legal Vehicle Weights and Dimensions on Highways	Wilbur Smith	96,728
	AREA TWENTY: SPECIAL PROJECTS		
20-1	Highway Research Information Service	HRB	455,000*
20-2	Research Needs in Highway Transportation	Tallamy—Smith	98,760*

STARTING DATE	COMPLETION DATE	PROJECT STATUS	PROJECT NO.
3/15/69	12/1/69	Completed—Published as NCHRP Report 94	11-1(9)
3/15/69	9/15/69	Completed—Published as NCHRP Report 107	11-1(10)
2/24/69	8/25/69	Completed—Rep. not to be publ.; summarized in Summary of Progress Through 1972	11-1(11)
2/1/65	6/30/66	Completed—Published as NCHRP Report 72	11-2
11/1/66	12/15/67	Completed—Published as NCHRP Report 56	11-3
10/1/68	12/31/69	Completed—Published as NCHRP Report 119	11-3(1)
9/2/68	2/28/70	Completed—Published as NCHRP Report 112	11-3(2)
7/1/69	2/28/71	Completed—Published as NCHRP Report 126	11-4
10/1/70	5/31/72	Report in editorial and publication process	11-5
2/1/65	6/30/67	Report to be included in Project 12-6 report	12-1
6/1/66	12/31/68	Completed—Published as NCHRP Report 83	12-2
12/15/65	3/14/69	Completed—Report being made available only to sponsors	12-3
12/15/65	3/31/68	Completed—Rep. not to be publ.; summarized in Summary of Progress Through 1969	12-4
9/15/66	11/15/68	Completed—Published as NCHRP Report 90	12-5
2/1/67	1/31/69	Report in editorial and publication process	12-6
10/1/66	1/31/70	Completed—Published as NCHRP Report 102	12-7
7/1/70	12/31/72	Report in editorial and publication process	12-7
3/1/68	2/28/69	Completed—Published as NCHRP Report 86	12-8
1/2/70	6/30/71	Report in editorial and publication process	12-8
9/1/67	1/31/70	Completed—Published as NCHRP Report 109	12-9
1/1/70	12/31/73	Research in progress	12-10
8/1/70	1/31/73	Report in review stage	12-11
10/1/70	9/30/74	Research in progress	12-12
10/1/72	6/30/74	Research in progress	12-13
10/1/72	6/30/74	Research in progress	12-14
10/1/72	12/31/74	Research in progress	12-15
2/1/65	1/31/66	Completed—Published as NCHRP Report 26	13-1
3/1/65	3/31/67	Completed—Published as NCHRP Report 42	14-1
10/1/70	3/31/73	Research in progress	14-2
9/15/72	9/14/74	Research in progress	14-3
12/15/65	6/14/66	Completed—Published as NCHRP Report 36	15-1
7/1/67	8/31/70	Completed—Published as NCHRP Reports 54, 115	15-1(2)
5/1/70	12/31/71	Completed—Published as NCHRP Reports 118, 129	15-1(2)
7/1/66	6/30/73	Initial phase published as NCHRP Report 108; Phase II research in progress	15-2
10/1/67	12/31/68	Completed—Published as NCHRP Report 116	15-3
9/1/67	3/16/70	Completed—Published as NCHRP Report 136	15-4
8/15/67	1/10/69	Completed—Published as NCHRP Report 105	15-5
9/1/67	8/31/68	Completed—Published as NCHRP Report 77	15-6
3/1/66	4/30/72	Initial phase published as NCHRP Report 91; Phase II report in review stage	16-1
10/1/67	3/31/69	Completed—Published as NCHRP Report 137	16-2
—	—	Project in developmental processes	16-3
2/1/66	5/31/68	Completed—Published as NCHRP Report 79	17-1
1/10/72	6/20/72	Contract terminated—no report; res. to be resumed under Project 17-2A	17-2
—	—	Contract pending	17-2A
9/1/67	12/1/69	Completed—Published as NCHRP Report 106	18-1
10/1/72	9/30/75	Research in progress	18-2
9/5/67	9/4/68	Completed—Refer to Table 9 for publication	19-1
9/2/68	10/31/68	Completed—Working plan not to be published	19-2(1)
9/2/68	10/31/68	Completed—Working plan not to be published	19-2(2)
9/2/68	10/31/68	Completed—Research continued as Project 19-2(4)	19-2(3)
2/1/69	11/30/71	Completed—Published as NCHRP Report 131	19-2(4)
9/15/70	6/14/72	Report in editorial and publication process	19-3
3/16/64	10/31/67	Completed—Informal publication only; Service is operational	20-1
4/1/66	12/31/67	Completed—Published as NCHRP Report 55	20-2

TABLE 5 (*Continued*)

PROJECT NO.	TITLE	RESEARCH AGENCY	CONTRACT AMOUNT OR CONTRACT COST
	AREA TWENTY (*Continued*)		
20-3	Optimizing Freeway Corridor Operation Through Traffic Surveillance, Communication, and Control	Texas A & M	419,000 200,540†
20-3A	Optimizing Freeway Corridor Operation Through Traffic Surveillance, Communication, and Control	U of Michigan	505,642 20,000††
20-3B	Optimizing Freeway Corridor Operation Through Traffic Surveillance, Communication, and Control—Summary Reporting	Patrick J. Athol	50,000
20-4	Public Preference for Future Individual Transportation	Chilton Research National Analysts	195,260* 83,911*
20-5	Synthesis of Information Related to Highway Problems	HRB	200,000§§
20-6	Right-of-Way and Legal Problems Arising out of Highway Programs	HRB	65,000‡
20-7	AASHO Standing Committee on Engineering Policies Research	Texas A & M	100,000§
20-8	Interactive Graphic Systems for Highway Design	Control Data	49,672*
20-9	Socioeconomic Consequences of Right-of-Way Acquisition Induced Resident Dislocation	RMC, Inc	199,944
20-10	The Costs and Benefits of Separating Pedestrians and Vehicles	To Be Determined	
20-11	Toward Environmental Benefit/Cost Analysis—Measurement Methodology	Poly of Brooklyn	100,000
	AREA TWENTY-ONE: SOILS AND GEOLOGY—TESTING AND INSTRUMENTATION		
21-1	Instrumentation for Measurement of Moisture	Res Triangle Inst	35,027*
21-2	Instrumentation for Moisture Measurement—Bases, Subgrades, and Earth Materials (Sensor Development)	Sw Research Inst	64,976
21-2(2)	Instrumentation for Moisture Measurement—Bases, Subgrades, and Earth Materials (Sensor Development)	SUNY Buffalo	29,953
	AREA TWENTY-TWO: DESIGN—VEHICLE BARRIER SYSTEMS		
22-1	Concepts for Improved Traffic Barrier Systems	Walter W. White	25,000
22-2	Traffic Barrier Performance and Design	Sw Research Inst	125,000

* Final contract cost.
† NCHRP funds obligated under the $314,340 four-way agreement among the National Academy of Sciences, Michigan Department of State Highways, Wayne County, and the City of Detroit.
†† NCHRP funds obligated under the $70.000 five-way agreement among the National Academy of Sciences, Michigan Department of State Highways, Wayne County, the City of Detroit, and the University of Michigan.
§ Continuing activity supported at the annual amount shown.
§§ Continuing activity supported at the annual amount shown beginning with FY '72.
‡ Continuing activity with average annual expenditures in the amount shown.

START-ING DATE	COMPLE-TION DATE	PROJECT STATUS	PROJECT NO.
12/15/66	1/31/69	Reports in review stage	20-3
1/1/67	12/31/68		20-3
11/20/68	5/31/71	Report in review stage	20-3A
1/1/69	12/31/69		20-3A
7/1/72	11/30/73	Research in progress	20-3B
5/2/67	1/21/69 (CRS)	Completed—Published as NCHRP Reports 49, 82	20-4
5/2/67	1/2/68 (NA)	Completed—Published as NCHRP Reports 49, 82	20-4
12/15/67	§§	Research in progress: Topic reports published as NCHRP Syntheses 1 through 15	20-5
11/1/68	‡	Research in progress: Refer to Table 9 for publications	20-6
12/2/68	§	Research in progress	20-7
9/1/70	7/31/71	Completed—Rep. not to be publ.; summarized in Summary of Progress Through 1972	20-8
8/1/72	10/31/74	Research in progress	20-9
—	—	Project deferred; awaiting results of FHWA research	20-10
9/1/72	10/30/73	Research in progress	20-11
8/25/69	2/24/71	Report in editorial and publication process	21-1
2/1/72	1/31/74	Research in progress	21-2
4/1/72	9/30/73	Research in progress	21-2(2)
10/1/70	12/31/71	Completed—Rep. not to be publ.; summarized in Summary of Progress Through 1972	22-1
1/1/72	6/30/73	Research in progress	22-2

TABLE 6

AGENCY DISTRIBUTION OF FY '63 THROUGH FY '73 PROJECTS

TYPE OF AGENCY	PROJECTS AND CONTINUATIONS NO.	%
Educational institutions	83	40
Research institutes	56	28
Industry, consultants, and trade associations	62	31
Professional societies and service organizations	0	0
State highway departments	2	1
Special transportation and other governmental agencies	0	0
All	203*	100

* Does not include Projects 16-3 and 20-10 (FY '73).

advantage of all opportunities to increase the odds for acquiring useful research results and to increase the probability that useful results will find their way into practice more quickly. Beyond the sponsor's first weighting of the odds by setting the goals for a program of applied research dedicated to solving pressing operational problems, the NCHRP tries to further weight the odds favorably by concentrating on:

- Establishing the agency and personnel qualifications that are mandatory if the goals are to be achieved. Emphasis is placed on the importance of a record of successful past performance in endeavors similar to those to be undertaken. Further, it is also stipulated that proposals are not acceptable if they do not contain specific statements as to how the contemplated results can be used to improve practice.

- Utilizing persons who are not only experts in the particular problem area but who also have a complete understanding of the needs of the practitioners to define the research problem and its objectives in the form of a precise project statement on which fully responsive research proposals can be based. Many of these experts are drawn from the highway departments.

- Exercising extreme care in the process of selecting research agencies to insure not only that the proposed research plan is the best possible in addressing the specifics of the objectives but that it also culminates in the best promise for providing the practitioner with a product that is both usable and readily implementable.

- Establishing—on the basis of staff and advisory group review of and suggested modifications to the research plan —a clear meeting of the minds as to what specifically is expected from the research and the personnel carrying it out in order to meet the needs of the practicing engineer.

- Acquiring an amplified research plan that is intended to detail comprehensively the approved research plan and to include a specific schedule of events for the major tasks. This document is used by the staff in the day-to-day surveillance of the project's progress and by the advisory group as required.

- Carrying out project surveillance sufficient to keeping the research in line with the approved research plan, constantly keeping the researchers aware of the needs of the practicing engineer, and insuring that all project developments through final reporting center around these needs.

- Requiring research reports in a format that is designed specifically to first meet the needs of the busy highway administrator and the practicing engineer. Different treatment is given to the material that would be of interest to other researchers.

NCHRP Reporting of Research Results

In an applied research program such as the NCHRP, the sponsor rightfully expects not only results that are accurate but also findings that can be readily put into practice. This means that the final research reports must be presented in language understandable to both the highway administrator and the highway engineer and in such format as to permit easy assimilation. Too many of today's research reports are frequently so clouded by obscure language and format that the reader must spend precious time and effort in translating them into concise and readily usable working documents.

Research agencies for the NCHRP are required to report their results in a form that succinctly summarizes the findings for the busy highway administrator and likewise informs the highway engineer as to the application of the findings. These objectives are accomplished through a "Summary of Findings," and a chapter on "Interpretation, Appraisal, and Application of Results." The detailed research techniques and analyses in which a researcher would be interested are presented in appendices and do not have to be labored through to extract the findings. The Program has a document titled *Style and Organization of Interim and Final Reports,* that serves as guidance to the researcher in his writing so that maximum use by the sponsors may be obtained.

Prior to publication, extraordinary measures are taken to insure that useful research results are made immediately available to the appropriate operations personnel in the highway departments. One means consists of forwarding to them copies of the research agency drafts of final reports. According to the urgency of the particular circumstances, these drafts may be either uncorrected or corrected on the basis of an acceptance review. Several copies of unedited drafts of the agency reports are retained until formal publication in either of the two regular NCHRP series (Reports or Syntheses of Highway Practice) and are available, on a loan basis, to others having an interest in the research. Once published in their entirety, the drafts are destroyed.

After publication in the NCHRP series, each report or synthesis is sent immediately to the chief administrative officer of each highway department. Then, through the

Board's selective distribution system, copies go automatically to about 100 libraries, Highway Research Board representatives in the state highway departments, educational institutions, liaison representatives, appropriate panels and committees of the Board, and individual members who have selected publications in the particular subject area of the report. As a further means of disseminating the research reports, announcements of their availability are made to the trade press. Each of these reports contains a staff-prepared foreword that directs the attention of the busy reader to the persons who would be most interested in the results and, also, to how the results fit into present knowledge and practice. Also, during the conduct of the work, periodic progress reports are prepared by the staff and sent to each of the highway departments as a measure of providing a current awareness of on-going work. In addition, the Board's Technical Activities Staff personnel follow the progress of the work throughout its conduct and consequently are able to discuss application of the research results with the highway engineers during their various state highway department visits. Furthermore, AASHO has provided the NCHRP with annual opportunities for staff and project researchers to go before the various committees of the Association to present the findings of their particular research and the usefulness of these findings to the practicing highway engineer. Research findings not published in the NCHRP series are summarized in a subsequent *NCHRP Summary of Progress* report, issued annually each January. On an interim basis, the findings are sometimes reported in a *Research Results Digest,* described next.

Another means for bringing research findings before the practicing engineer was instituted in December 1968 with the first issue of *NCHRP Research Results Digest*—a series of flyers being published at frequent intervals. These Digests are being issued in the interest of providing an early awareness of the research results emanating from projects in the NCHRP. By making these results known as they are developed and prior to publication of the final reports in the regular NCHRP series, it is hoped that their early use in practice will be encouraged. For the most part, each Digest is intended to be very brief in summarizing specific findings—they do not deal with research methodology—and require the reader to expend very little time in determining how the research results may be of use to him. The basic format is couched in terms of the problem and the solution to it, the findings, and applications. Operations personnel—particularly the Liaison Representatives for Research in the highway departments—should find them of direct assistance in serving the intermediary, or interpretive, position between research and operating personnel, for each Digest speaks directly to the vital factors of:

- Whether the research stands alone or whether it has to be combined with results from other research in order to be useful.
- Whether the results are defined explicitly enough to permit direct application to practice.
- Whether the results have to be translated into the working tools with which the practicing engineer is familiar.
- Whether the research findings have been evaluated sufficiently to make some reasonable determination of the probability of their success when applied to practice.

In recent years there have been several opportunities for the Program and various AASHO committees to work together to structure the research findings into the best possible form for immediate use by the practicing engineer. Such joint efforts are highly desirable and represent the ultimate in the steps that the Program can take to weight the odds in favor of implementation of the findings. Beyond that point, only final reporting remains, and it is up to the sponsor to implement the findings. Without steps in this direction, research with gold-plated results may just as well have been totally unsuccessful—the end result is the same. Fortunately, AASHO and the FHWA have taken steps to develop a system that should lead ultimately to the sponsor's adequate consideration of all research results. Only if the results get around and are used can it be said that AASHO is fulfilling its objective of providing solutions to problems of interest to the majority of the state highway departments.

In summary, then, it should be evident that the NCHRP normally possesses only indirect means for promoting implementation of research results; there is little opportunity for more direct discourse with the sponsor by which implementation may be promoted. Every possible opportunity is therefore taken all along the way to capitalize on the indirect means to the fullest extent. There has been steady improvement as regards the usefulness of NCHRP products, and this situation is expected to maintain its trend as a result of increased Program stability gained from experience. It is hoped that there will be a corresponding rise of user interest that will be reflected by increased utilization of NCHRP research results.

EXAMPLES OF UTILIZATION OF NCHRP RESEARCH RESULTS

Many instances have come to light as regards the use of research results from NCHRP projects. There are undoubtedly many other uses of results that are unknown to the Program. In the interest of all potential users, the Program will be grateful for any information on actual application of results and associated cost savings. This will be reported as below with the hope that widespread interest will result on the part of the member departments of AASHO and that, consequently, research results will find their way more quickly into policies, practices, procedures, specifications, and standards of the highway departments.

EXAMPLES OF UTILIZATION OF NCHRP RESULTS *

NCHRP PROJECT	NCHRP PUBLICATION	USER	HOW USED
1-1	Reports 2, 2A	Illinois Div. of Hwys., Bur. of Res. and Devel.	In studies of existing pavements and of the rehabilitated AASHO Road Test project at Ottawa. Particular use made of recommendations for experimental designs, measurement programs, and data processing analysis.
1-2	Report 7	New York Dept. of Transp.	To develop a flexible pavement performance equation; in use as of June 1968.
		Tallamy, Byrd, et al.	In study of highway maintenance quality levels for Ohio Dept. of Hwys.
1-5(2)	Report 76	North Dakota State Highway Dept.	Major equipment purchase was based on successful use of similar equipment in conduct of project.
1-7	Report 37	Nat'l. Hwy. Safety Bur.	In preparation of a *Highway Safety Program Manual* for issuance to the States.
		92nd Congress, 1st Sess.	House of Representatives subcommittee hearings on highway safety and skidding.
1-8	Agency final report	Consultant for USN and USAF	Development of a new approach to pavement design for heavy aircraft loadings; used for redesign of the Salt Lake City runway to accommodate B747 aircraft and in design of the runway, taxiways, and aprons at Air Force Plant No. 42 near Palmdale, Calif., where the design load is one million pounds (gross) from the B2707 (SST) configuration.
1-9	Report 61	California Div. of Hwys.	In evaluation of proposed State legislation regarding use of studded tires.
1-10	Agency final report	Consultant for USN and USAF	See Project 1-8.
1-11	Agency report	U.S. Forest Service	In preparation of an Engineering Technical Report evaluating several commonly accepted pavement design methods, as to their applicability for the design of pavement systems for Forest Service roads.
		AASHO	Partly published as *AASHO Interim Guide for Design of Pavement Structures, 1972*
1-12	—	92nd Congress, 1st Sess.	House of Representatives subcommittee hearings on highway safety and skidding.
1-12(2)	—	92nd Congress, 1st Sess.	See Project 1-12.
1-12(3)	—	92nd Congress, 1st Sess.	See Project 1-12.
2-5	Reports 13, 111	One State (unknown)	To replace outdated material in AASHO book, *Urban Freeway Design.*
2-5A	Report 111	AASHO	In draft of proposed AASHO publication, *A Policy on Arterial Highways in Urban Areas.*
		Woodrow W. Rankin, I.T.E.	In preparing textbook on traffic engineering.
2-6	Report 63	E. L. Grant and W. Grant Ireson	In textbook, *Principles of Engineering Economy.*
3-2	Reports 9, 29	Illinois Div. of Hwys., Bur. of Traffic	In a FAI 80 Motorist Communication project. Also, more emphasis is being placed on the influence of pedestrians on signal timing, because signals in the small cities are almost always in the CBD where there are many pedestrians.
3-4	Reports 6, 40	California Div. of Hwys.	Source of background information for highway and law enforcement officials facing problem decisions on location of disabled or stopped vehicles.

EXAMPLES OF UTILIZATION OF NCHRP RESULTS (*Continued*)

NCHRP PROJECT	NCHRP PUBLICATION	USER	HOW USED
3-5	Reports 3, 32, 73, 124	Dist. of Columbia, Dept. of Hwys. and Traffic	Incremental travel cost technique applied to a comprehensive determination of the existing effectiveness of operation in the D.C. traffic signal system. Annual incremental travel costs in the D.C. system were estimated and used in a benefit/cost analysis of traffic signal system improvement alternatives.
		Minnesota Dept. of Hwys.	Steps taken toward implementation of the delay difference offset technique in an existing signal network.
		California Div. of Hwys.	Source of information to supplement and improve the effectiveness with which the Division can carry out its program of reducing delay to the motorist. Also of value in designing innovative signals; in fact, the Division engaged the principal investigator on a consulting basis to help simulate different levels of traffic for a project under design in Riverside County.
	Agency final report	Goodell, Grivas and Assoc.	Obtained contract to use model described in report on a network in Detroit.
3-7	Reports 78, 117 and "Illustrative Recording of Traffic Noise"	Hwy. Depts., FHWA offices, universities, consulting firms, County Bd. of Educ.	Demand for the tape has been large, and loan copies have been circulated widely.
			Although the principal use of the tape has been educational in nature, one County Board of Education was so impressed with the noise differential between the open and closed window situation that consideration was given to installation of air conditioning and storm windows for school buildings adjacent to freeways.
		Georgia State Hwy. Dept.	Noise design guide used in design of the urban freeway system.
		Minnesota Legislature	For demonstration purposes in hearings by House Transportation Committee, and Senate Highways and Natural Resources and Environment Committees. Both Senate committees took favorable action on a Truck Noise Control bill patterned after the California law.
		Virginia Dept. of Hwys.	To evaluate noise for several proposed highways and to make subsequent explanations to the public on the impact of the noise on the community. One instance involved I-195, a six-lane depressed highway in a residential area of Richmond. Using the computer program from *Report 78,* peak-hour traffic was used to project the noise levels; comparisons were made with actual readings taken in the area. Another case involved projecting noise levels on I-66 in the vicinity of Washington, D.C., to determine if they would be within an acceptable limit. Revisions were made in the cross sections where the estimates exceed the acceptable limit. The Department estimates that almost $18,000 was saved by doing the evaluation work in-house, rather than contracting it. Annual savings of $50,000 to $75,000 have been forecast in the instance of standard evaluations of major projects. Valuable knowledge has been gained concerning the strengths and weaknesses of the research results; once this information is disseminated, implementation by other States should be made easier.

EXAMPLES OF UTILIZATION OF NCHRP RESULTS (*Continued*)

NCHRP PROJECT	NCHRP PUBLICATION	USER	HOW USED
		Arizona cons. firm	In design and location of a 4.5-mile segment of I-10 (Papago Freeway) traversing a high-density area of downtown Phoenix. Recommendations made are expected to substantially reduce the noise levels in the areas adjacent to the Freeway.
		Natl. Assn. of Homebuilders	In development of a *Builders' Acoustical Manual* that includes guidelines for prediction of site noise due to traffic.
		Missouri State Hwy. Comm.	Highway traffic noise simulation program used to establish noise projections on new project designs.
		Federal Highway Administration	In developing highway noise level standards PPM 90-2, "Interim Noise Standards and Procedures for Implementing Section 109(I) 23 U.S.C."
	Report 117	Howard, Needles, Tammen & Bergendoff	The model for predicting highway traffic noise was validated under contract to a state highway department.
		Express Hwy. Res. Foundation (Japan)	Abridgment (8 pp.) published in April 1972 issue of *Expressways and Automobiles* (in Japanese).
		Colorado Dept. of Highways	A projected noise study is based on a U.S. DOT program that was developed directly from this report, which is considered to represent the best study procedure from available empirical and theoretical research on highway noise.
3-8	Report 50	Orange Co. (Calif.) Traffic Eng. Council	Extensive use as the best available source of information for preparation of warrants for the installation of protective devices at rail-grade crossings.
		Illinois Div. of Hwys., Bur. of Design	In a continuing program toward grade crossing safety, with particular use seen for the portion dealing with crossings where flashing light signals—with or without gates—are not warranted.
3-9	Report 84	California Div. of Hwys.	Recommendations being used on the Freeway Surveillance and Control Project (Los Angeles), involving expenditure of about $8 million in three years.
3-12	Report 123	Transp. Systems Center	Information on fixed highway signing principles was particularly helpful in providing control signals to pilots at Kennedy International Airport (New York).
3-13	Report 93	City of Waco, Tex.	Plans to incorporate in subdivision and zoning regulations many of the controls recommended as a means of attempting to protect facility capacity and safety.
4-3	Reports 12, 15, 65, and 66	ASTM	Basis for development of C671, "Tentative Method of Test for Critical Dilation of Concrete Specimens Subject to Freezing," and C682, "Resistance of Aggregates to Freezing."
5-4	Report 20	AASHO Stdg. Comm. on Engrg. Policies	Input (with Report 77, Proj. 15-6) to the March 1969 publication, *Informational Guide to Roadway Lighting*.
5-7	—	Ohio Dept. of Hwys.	Source of current and complete information on individual delineation techniques.
6-1	Report 19	California Div. of Hwys.	Source material and bibliography simplified literature search and saved much valuable time. Results incorporated in planning and design of new projects.
6-2	Report 4	California Div. of Hwys.	See Project 6-1.

EXAMPLES OF UTILIZATION OF NCHRP RESULTS (*Continued*)

NCHRP PROJECT	NCHRP PUBLICATION	USER	HOW USED
6-3	Report 16	California Div. of Hwys.	See Project 6-1.
		Natl. Flaxseed Processors Assn.	Advertising (*Civil Eng.*, Feb. 1966) highlighting research results in stating ". . . considering both the economy and performance, the best results by far were obtained by vegetable oil, and particularly linseed oil solutions.
6-4	Report 23	Iowa State Hwy. Comm.	Constructed a bridge with galvanized reinforcing bars in one-half of the deck. This follows the recommendations to the effect that more field evaluation is required of zinc, nickel, and asphalt-epoxy coatings.
6-5	Report 27	California Div. of Hwys.	See Project 6-1.
6-8	Report 1	California Div. of Hwys.	See Project 6-1.
		U.S. Park Serv.	Techniques used by consulting engineering firm for deck repair of Memorial Bridge, Washington, D.C., depended heavily on reported results.
6-10	Agency reports	California Div. of Hwys.	In preparation of plans for two sections of US50 from Riverton to the Nevada State line. Design consideration given to those factors considered vital to increased safety and reduced maintenance at interchanges under the adverse conditions of snow and ice.
7-4	Report 89	Illinois Dept. of Transp., Bur. of Planning	Findings have been found useful, and practice has been modified to conform with them.
7-7	Report 64	Ohio Dept. of Hwys.	Implemented several recommendations pertaining to rest areas with maps and other information of interest to motorists, signing conformity, service patrols, patrol aircraft, and medicopter service.
8-3	Agency final report	Arizona Hwy. Dept.	Source material for decisions based on consumer sensitivity to the various factors considered in trip making.
9-3	Report 38	Ford Motor Co.	Saved countless hours of search and survey by state-of-the-art section on highway joint and crack sealing materials and methods. Useful in further understanding various design, construction, and maintenance problems, in analyzing specific failures, and in adapting future developments in highways to their industrial and other roadway problems.
10-1	Report 17	North Dakota State Univ.	Basic text for a course in statistical quality control taught to both undergraduates and a sizeable number of engineers, the majority of the latter being highway department employees.
		Illinois Div. of Hwys., Bur. of Materials	In conjunction with FHWA sigma bank, and data developed by our field testing, to develop special provisions covering statistical acceptance of bituminous concrete pavement.
10-2	Report 34	Illinois Div. of Hwys., Bur. of Materials	In conjunction with supplementary materials, as a basis for recommending and/or limiting stockpiling methods to be included in the policy being developed for aggregate inspection and acceptance.
10-6	Report 52	Illinois Div. of Hwys., Bur. of Res. and Devel.	Considering a trial of recommendation for use of nuclear pellet technique for measuring pavement thickness.

EXAMPLES OF UTILIZATION OF NCHRP RESULTS (*Continued*)

NCHRP PROJECT	NCHRP PUBLICATION	USER	HOW USED
11-1(6)	Report 92	New Mexico State Hwy. Comm.	In settling negotiations for purchase of an airport.
11-3	Report 56	Indiana State Hwy. Comm., Land Ac. Div.	Rated as "excellent." Requested extra copies for use in development of new work in area of responsibility.
		Illinois Div. of Hwys., Bur. of Rt.-of-Way	Most of the principles set forth have been in practice. Land Economic Study unit will conduct a study according to the report recommendation for one method of analysis of the value of scenic easements.
12-2	Report 83	California Div. of Hwys.	Own research project on "Analysis, Design and Behavior of Highway Bridges" used both basic knowledge and example of a well-devised rational approach to further simplify the proposed formulas and criteria recommended as revisions to the AASHO Specifications, and to consolidate and authenticate the proposed criteria by further model and prototype verification of analytically obtained values.
12-5	Report 90	California Div. of Hwys.	Confirmed the Division's present practices, gave reassurance that its long-term investment in prestressed concrete structures is sound, and answered the question as to practicability of protective coatings.
12-7	Report 102	AASHO	Fatigue specification recommendations are being adopted as part of the latest interim specifications and will become standard practices as soon as released.
		Naval Ship Res. and Devel. Lab.	Limited portions used in a technical report entitled "Some Observations on the Fatigue Behavior of Specimens and Structures."
		Illinois Dept. of Transp., Bur. of Design	Findings have been found useful, and practice has been modified to conform with them.
12-8	Report 86	Canadian Stds. Assn.	Committee on Design of Highway Bridges used results in updating standards for bridge railing loads.
13-1	Report 26	Delaware State Hwy. Dept.	In a study of highway maintenance management, Advanced Management Planning, Inc., recommended use as a guide in establishing equipment rental rates.
14-1	Report 42	Minnesota Dept. of Hwys.	Of considerable assistance to the investigators in the Maintenance Program Budget Pilot Study, which includes a determination of the sets of road characteristics to which quality and quantity standards codes should be assigned.
		Washington State Hwy. Comm.	In development of a unit maintenance expenditure index for the State.
		Ohio Dept. of Hwys.	In a study to develop a forecast of maintenance needs for the 1970–80 decade and compare it with the trends in highway maintenance needs for the U.S. as a whole and for the Northeast region in particular.
15-1	Report 36	Commercial firm	In formulating a design for a new fiberglass guardrail system.
15-1(2)	Report 54	Federal and State agencies	In planning, design, construction, maintenance, replacement of guardrails and median barriers.
		American Iron and Steel Inst.	Recommendations on standardization of guardrail hardware by the Highway Task Force of the Institute's Sheet Committee to include use of the flat washer illustrated on page 29 of *Report 54*.

EXAMPLES OF UTILIZATION OF NCHRP RESULTS (*Continued*)

NCHRP PROJECT	NCHRP PUBLICATION	USER	HOW USED
		Illinois Div. of Hwys.	Included in highway design policies and standards by Bur. of Design. New Bur. of Maintenance standards for guardrail and median barriers adapted from report. Bur. of Traffic comments highlight *Design Manual* or *Highway Standards* areas that could be improved by the findings; the warranting of trial installations of various types of median barriers, for reasons of both safety and economy; and the value of certain information as a tool to determine whether to remove or upgrade existing installations.
		Nevada Dept. of Hwys.	In evaluating acceptability of the Department's design criteria and standards.
	Report 115	Illinois Dept. of Transp., Bur. of Design	Findings have been found useful, and practice has been modified to conform with them.
	Report 118	New York State Dept. of Transp.	As a vital supplement to a recently prepared design manual covering policies, procedures, and standards. Design guide refers to report for further information.
15-2	Report 108	Connecticut Dept. of Transp.	On trial basis, used the design technique developed for channels lined with riprap. Major relocation of a stream and tributaries having a design flood discharge of 3,900 cfs from a drainage area of 7.3 square miles was involved. Saving from use of riprap instead of paving was estimated to be more than $90,000. Evaluation of the effectiveness of the treatment is continuing, especially observation of behavior during and after any significant storms.
		Wisconsin Dept. of Transp.	Channel design procedure applied to ditches along the Lake Wissota—Cadott Road in Chippewa County. These were previously subject to erosion, but none has occurred since use of riprap according to the procedure.
15-6	Report 77	AASHO Stdg. Comm. on Engr. Policies	Input (with Report 20, Proj. 5-4) to the March 1969 publication, *Informational Guide to Roadway Lighting.*
		California Div. of Hwys.	Instrumental in setting the standards for California and aiding in developing the most satisfactory breakaway base. The California research, without that done under NCHRP, reportedly would have cost well over $100,000 to develop or affirm preliminary designs of this type.
16-1	Report 91	California Div. of Hwys.	Appendix D ("Effects of Salts on Plant Biota") is the most complete dissertation on soil salinity and salt-tolerant plants in the Division's reference files.
		U.S. Government	As a primary reference in formulating the National Environmental Policy Act of 1969 and Executive Order 11514 on "Protection and Enhancement of Environmental Quality."
17-1	Report 79	Robley Winfrey	In development of a college textbook, *Economic Analysis for Highways.*
20-1	(HRIS)	Many diverse agencies	The Highway Research Information Service is known to be used widely by a number of organizations in addition to state highway departments. Recognition has been given to the periodic issues of *Highway Research in Progress* as being very useful and of great value to many other governmental agencies.

EXAMPLES OF UTILIZATION OF NCHRP RESULTS (*Continued*)

NCHRP PROJECT	NCHRP PUBLICATION	USER	HOW USED
20-2	Report 55	Illinois Div. of Hwys., Bur. of Res. and Devel.	A committee within the Illinois Highway Research Council, having the assignment of developing a system of establishing research priorities for the Division's program, the method outlined for structuring research programs.
20-3	—	California Div. of Hwys.	Although not yet published, results from the second year of research are being used as background for installing surveillance and control systems and in planning alternative methods of improving operations on the Los Angeles Area freeway system.
20-5	Synthesis 4	California Div. of Hwys.	Serves as a basic document in the continuing development of Division practices and procedures to cope with the problem, as well as a guide for those lines of research that will yield the highest return, and is reported as: "Unquestionably the finest that has been published on the bridge deck deterioration problem."
		U.S. Dept. of Transp.	In preparation of *Instructional Memorandum 4-2-70.*
	Synthesis 5	Center for Public Works Studies and Experimentation (Spain)	Translated into Spanish as an "Information Bulletin" of the Transport and Soil Mechanics Laboratory.
	Synthesis 7	92nd Congress, 1st Sess.	See Project 1-12.
20-6	Res. Results Digest 11	Maryland State Roads Comm.	In a case before the September 1969 term of the State Court of Appeals.
	Res. Results Digest 11 and others	Colorado Dept. of Hwys.	Used on several occasions involving condemnation cases and other legal matters. Digests noted as being extremely helpful in view of their discussions of current problems and consequent saving of legal staff time.
	Res. Results Digest 3	Secretary of Transportation	Included in toto in 1970 Annual Report to the Congress in respect to progress made in the administration of the highway relocation assistance program as enacted under the Federal-Aid Highway Act of 1968.
	Res. Results Digests	Virginia Atty. Genl. Office	As an aid to maintaining a current awareness of legal research of an original nature, as a basis for further research by personnel of the Office, and as a point of departure for reviews of settled law.
20-7	—	92nd Congress, 1st Sess.	Task 4, "Lateral Accelerations and Lateral Tire-Pavement Forces in a Vehicle Traversing Curves Relating to Available Pavement Skid-Resistant Measures." See Project 1-12.

* Project and publication titles, as well as project status, are given in Table 5.

TABLE 7

PUBLISHED REPORTS OF THE NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Rep. No.	Title, Project, Pages, Price
—*	A Critical Review of Literature Treating Methods of Identifying Aggregates Subject to Destructive Volume Change When Frozen in Concrete and a Proposed Program of Research—Intermediate Report (Proj. 4-3(2)), 81 p., $1.80
1	Evaluation of Methods of Replacement of Deteriorated Concrete in Structures (Proj. 6-8), 56 p., $2.80
2	An Introduction to Guidelines for Satellite Studies of Pavement Performance (Proj. 1-1), 19 p., $1.80
2A	Guidelines for Satellite Studies of Pavement Performance, 85 p.+9 figs., 26 tables, 4 app., $3.00
3	Improved Criteria for Traffic Signals at Individual Intersections—Interim Report (Proj. 3-5), 36 p., $1.60
4	Non-Chemical Methods of Snow and Ice Control on Highway Structures (Proj. 6-2), 74 p., $3.20
5	Effects of Different Methods of Stockpiling Aggregates—Interim Report (Proj. 10-3), 48 p., $2.00
6	Means of Locating and Communicating with Disabled Vehicles—Interim Report (Proj. 3-4), 56 p. $3.20
7	Comparison of Different Methods of Measuring Pavement Condition—Interim Report (Proj. 1-2), 29 p., $1.80
8	Synthetic Aggregates for Highway Construction (Proj. 4-4), 13 p., $1.00
9	Traffic Surveillance and Means of Communicating with Drivers—Interim Report (Proj. 3-2), 28 p., $1.60
10	Theoretical Analysis of Structural Behavior of Road Test Flexible Pavements (Proj. 1-4), 31 p., $2.80
11	Effect of Control Devices on Traffic Operations—Interim Report (Proj. 3-6), 107 p., $5.80
12	Identification of Aggregates Causing Poor Concrete Performance When Frozen—Interim Report (Proj. 4-3(1)), 47 p., $3.00
13	Running Cost of Motor Vehicles as Affected by Highway Design—Interim Report (Proj. 2-5), 43 p., $2.80
14	Density and Moisture Content Measurements by Nuclear Methods—Interim Report (Proj. 10-5), 32 p., $3.00
15	Identification of Concrete Aggregates Exhibiting Frost Susceptibility—Interim Report (Proj. 4-3(2)), 66 p., $4.00
16	Protective Coatings to Prevent Deterioration of Concrete by Deicing Chemicals (Proj. 6-3), 21 p., $1.60
17	Development of Guidelines for Practical and Realistic Construction Specifications (Proj. 10-1), 109 p., $6.00
18	Community Consequences of Highway Improvement (Proj. 2-2), 37 p., $2.80
19	Economical and Effective Deicing Agents for Use on Highway Structures (Proj. 6-1), 19 p., $1.20
20	Economic Study of Roadway Lighting (Proj. 5-4), 77 p., $3.20
21	Detecting Variations in Load-Carrying Capacity of Flexible Pavements (Proj. 1-5), 30 p., $1.40
22	Factors Influencing Flexible Pavement Performance (Proj. 1-3(2)), 69 p., $2.60
23	Methods for Reducing Corrosion of Reinforcing Steel (Proj. 6-4), 22 p., $1.40
24	Urban Travel Patterns for Airports, Shopping Centers, and Industrial Plants (Proj. 7-1), 116 p., $5.20
25	Potential Uses of Sonic and Ultrasonic Devices in Highway Construction (Proj. 10-7), 48 p., $2.00
26	Development of Uniform Procedures for Establishing Construction Equipment Rental Rates (Proj. 13-1), 33 p., $1.60
27	Physical Factors Influencing Resistance of Concrete to Deicing Agents (Proj. 6-5), 41 p., $2.00
28	Surveillance Methods and Ways and Means of Communicating with Drivers (Proj. 3-2), 66 p., $2.60
29	Digital-Computer-Controlled Traffic Signal System for a Small City (Proj. 3-2), 82 p., $4.00
30	Extension of AASHO Road Test Performance Concepts (Proj. 1-4(2)), 33 p., $1.60
31	A Review of Transportation Aspects of Land-Use Control (Proj. 8-5), 41 p., $2.00
32	Improved Criteria for Traffic Signals at Individual Intersections (Proj. 3-5), 134 p., $5.00
33	Values of Time Savings of Commercial Vehicles (Proj. 2-4), 74 p., $3.60
34	Evaluation of Construction Control Procedures—Interim Report (Proj. 10-2), 117 p., $5.00
35	Prediction of Flexible Pavement Deflections from Laboratory Repeated-Load Tests (Proj. 1-3(3)), 117 p., $5.00
36	Highway Guardrails—A Review of Current Practice (Proj. 15-1), 33 p., $1.60
37	Tentative Skid-Resistance Requirements for Main Rural Highways (Proj. 1-7), 80 p., $3.60
38	Evaluation of Pavement Joint and Crack Sealing Materials and Practices (Proj. 9-3), 40 p., $2.00
39	Factors Involved in the Design of Asphaltic Pavement Surfaces (Proj. 1-8), 112 p., $5.00
40	Means of Locating Disabled or Stopped Vehicles (Proj. 3-4(1)), 40 p., $2.00
41	Effect of Control Devices on Traffic Operations (Proj. 3-6), 83 p., $3.60
42	Interstate Highway Maintenance Requirements and Unit Maintenance Expenditure Index (Proj. 14-1), 144 p., $5.60
43	Density and Moisture Content Measurements by Nuclear Methods (Proj. 10-5), 38 p., $2.00
44	Traffic Attraction of Rural Outdoor Recreational Areas (Proj. 7-2), 28 p., $1.40
45	Development of Improved Pavement Marking Materials—Laboratory Phase (Proj. 5-5), 24 p., $1.40
46	Effects of Different Methods of Stockpiling and Handling Aggregates (Proj. 10-3), 102 p., $4.60
47	Accident Rates as Related to Design Elements of Rural Highways (Proj. 2-3), 173 p., $6.40
48	Factors and Trends in Trip Lengths (Proj. 7-4), 70 p., $3.20
49	National Survey of Transportation Attitudes and Behavior—Phase I Summary Report (Proj. 20-4), 71 p., $3.20
50	Factors Influencing Safety at Highway-Rail Grade Crossings (Proj. 3-8), 113 p., $5.20
51	Sensing and Communication Between Vehicles (Proj. 3-3), 105 p., $5.00

* Highway Research Board Special Report 80.

TABLE 7 (*Continued*)

Rep. No.	*Title, Project, Pages, Price*
52	Measurement of Pavement Thickness by Rapid and Nondestructive Methods (Proj. 10-6), 82 p., $3.80
53	Multiple Use of Lands Within Highway Rights-of-Way (Proj. 7-6), 68 p., $3.20
54	Location, Selection, and Maintenance of Highway Guardrails and Median Barriers (Proj. 15-1(2)), 63 p., $2.60
55	Research Needs in Highway Transportation (Proj. 20-2), 66 p., $2.80
56	Scenic Easements—Legal, Administrative, and Valuation Problems and Procedures (Proj. 11-3), 174 p., $6.40
57	Factors Influencing Modal Trip Assignment (Proj. 8-2), 78 p., $3.20
58	Comparative Analysis of Traffic Assignment Techniques with Actual Highway Use (Proj. 7-5), 85 p., $3.60
59	Standard Measurements for Satellite Road Test Program (Proj. 1-6), 78 p., $3.20
60	Effects of Illumination on Operating Characteristics of Freeways (Proj. 5-2), 148 p., $6.00
61	Evaluation of Studded Tires—Performance Data and Pavement Wear Measurement (Proj. 1-9), 66 p., $3.00
62	Urban Travel Patterns for Hospitals, Universities, Office Buildings and Capitols (Proj. 7-1), 144 p., $5.60
63	Economics of Design Standards for Low-Volume Rural Roads (Proj. 2-6), 93 p., $4.00
64	Motorists' Needs and Services on Interstate Highways (Proj. 7-7), 88 p., $3.60
65	One-Cycle Slow-Freeze Test for Evaluating Aggregate Performance in Frozen Concrete (Proj. 4-3(1)), 21 p., $1.40
66	Identification of Frost-Susceptible Particles in Concrete Aggregates (Proj. 4-3(2)), 62 p., $2.80
67	Relation of Asphalt Rheological Properties to Pavement Durability (Proj. 9-1), 45 p., $2.20
68	Application of Vehicle Operating Characteristics to Geometric Design and Traffic Operations (Proj. 3-10), 38 p., $2.00
69	Evaluation of Construction Control Procedures—Aggregate Gradation Variations and Effects (Proj. 10-2A), 58 p., $2.80
70	Social and Economic Factors Affecting Intercity Travel (Proj. 8-1), 68 p., $3.00
71	Analytical Study of Weighing Methods for Highway Vehicles in Motion (Proj. 7-3), 63 p., $2.80
72	Theory and Practice in Inverse Condemnation for Five Representative States (Proj. 11-2), 44 p., $2.20
73	Improved Criteria for Traffic Signal Systems on Urban Arterials (Proj. 3-5), 55 p., $2.80
74	Protective Coatings for Highway Structural Steel (Proj. 4-6), 64 p., $2.80
74A	Protective Coatings for Highway Structural Steel—Literature Survey (Proj. 4-6), 275 p., $8.00
74B	Protective Coatings for Highway Structural Steel—Current Highway Practices (Proj. 4-6), 102 p., $4.00
75	Effect of Highway Landscape Development on Nearby Property (Proj. 2-9), 82 p., $3.60
76	Detecting Seasonal Changes in Load-Carrying Capabilities of Flexible Pavements (Proj. 1-5(2)), 37 p., $2.00
77	Development of Design Criteria for Safer Luminaire Supports (Proj. 15-6), 82 p., $3.80
78	Highway Noise—Measurement, Simulation, and Mixed Reactions (Proj. 3-7), 78 p., $3.20
79	Development of Improved Methods for Reduction of Traffic Accidents (Proj. 17-1), 163 p., $6.40
80	Oversize-Overweight Permit Operation on State Highways (Proj. 2-10), 120 p., $5.20
81	Moving Behavior and Residential Choice—A National Survey (Proj. 8-6), 129 p., $5.60
82	National Survey of Transportation Attitudes and Behavior—Phase II Analysis Report (Proj. 20-4), 89 p., $4.00
83	Distribution of Wheel Loads on Highway Bridges (Proj. 12-2), 56 p., $2.80
84	Analysis and Projection of Research on Traffic Surveillance, Communication, and Control (Proj. 3-9), 48 p., $2.40
85	Development of Formed-in-Place Wet Reflective Markers (Proj. 5-5), 28 p., $1.80
86	Tentative Service Requirements for Bridge Rail Systems (Proj. 12-8), 62 p., $3.20
87	Rules of Discovery and Disclosure in Highway Condemnation Proceedings (Proj. 11-1(5)), 28 p., $2.00
88	Recognition of Benefits to Remainder Property in Highway Valuation Cases (Proj. 11-1(2)), 24 p., $2.00
89	Factors, Trends, and Guidelines Related to Trip Length (Proj. 7-4), 59 p., $3.20
90	Protection of Steel in Prestressed Concrete Bridges (Proj. 12-5), 86 p., $4.00
91	Effects of Deicing Salts on Water Quality and Biota—Literature Review and Recommended Research (Proj. 16-1), 70 p., $3.20
92	Valuation and Condemnation of Special Purpose Properties (Proj. 11-1(6)), 47 p., $2.60
93	Guidelines for Medial and Marginal Access Control on Major Roadways (Proj. 3-13), 147 p., $6.20
94	Valuation and Condemnation Problems Involving Trade Fixtures (Proj. 11-1(9)), 22 p., $1.80
95	Highway Fog (Proj. 5-6), 48 p., $2.40
96	Strategies for the Evaluation of Alternative Transportation Plans (Proj. 8-4), 111 p., $5.40
97	Analysis of Structural Behavior of AASHO Road Test Rigid Pavements (Proj. 1-4(1)A), 35 p., $2.60
98	Tests for Evaluating Degradation of Base Course Aggregates (Proj. 4-2), 98 p., $5.00
99	Visual Requirements in Night Driving (Proj. 5-3), 38 p., $2.60
100	Research Needs Relating to Performance of Aggregates in Highway Construction (Proj. 4-8), 68 p., $3.40
101	Effect of Stress on Freeze-Thaw Durability of Concrete Bridge Decks (Proj. 6-9), 70 p., $3.60
102	Effect of Weldments on the Fatigue Strength of Steel Beams (Proj. 12-7), 114 p., $5.40
103	Rapid Test Methods for Field Control of Highway Construction (Proj. 10-4), 89 p., $5.00
104	Rules of Compensability and Valuation Evidence for Highway Land Acquisition (Proj. 11-1), 77 p., $4.40

TABLE 7 (*Continued*)

Rep. No.	*Title, Project, Pages, Price*
105	Dynamic Pavement Loads of Heavy Highway Vehicles (Proj. 15-5), 94 p., $5.00
106	Revibration of Retarded Concrete for Continuous Bridge Decks (Proj. 18-1), 67 p., $3.40
107	New Approaches to Compensation for Residential Takings (Proj. 11-1(10)), 27 p., $2.40
108	Tentative Design Procedure for Riprap-Lined Channels (Proj. 15-2), 75 p., $4.00
109	Elastomeric Bearing Research (Proj. 12-9), 53 p., $3.00
110	Optimizing Street Operations Through Traffic Regulations and Control (Proj. 3-11), 100 p., $4.40
111	Running Costs of Motor Vehicles as Affected by Road Design and Traffic (Proj. 2-5A and 2-7), 97 p., $5.20
112	Junkyard Valuation—Salvage Industry Appraisal Principles Applicable to Highway Beautification (Proj. 11-3(2)), 41 p., $2.60
113	Optimizing Flow on Existing Street Networks (Proj. 3-14), 414 p., $15.60
114	Effects of Proposed Highway Improvements on Property Values (Proj. 11-1(1)), 42 p., $2.60
115	Guardrail Performance and Design (Proj. 15-1(2)), 70 p., $3.60
116	Structural Analysis and Design of Pipe Culverts (Proj. 15-3), 155 p., $6.40
117	Highway Noise—A Design Guide for Highway Engineers (Proj. 3-7), 79 p., $4.60
118	Location, Selection, and Maintenance of Highway Traffic Barriers (Proj. 15-1(2)), 96 p., $5.20
119	Control of Highway Advertising Signs—Some Legal Problems (Proj. 11-3(1)), 72 p., $3.60
120	Data Requirements for Metropolitan Transportation Planning (Proj. 8-7), 90 p., $4.80
121	Protection of Highway Utility (Proj. 8-5), 115 p., $5.60
122	Summary and Evaluation of Economic Consequences of Highway Improvements (Proj. 2-11), 324 p., $13.60
123	Development of Information Requirements and Transmission Techniques for Highway Users (Proj. 3-12) 239 p., $9.60
124	Improved Criteria for Traffic Signal Systems in Urban Networks (Proj. 3-5) 86 p., $4.80
125	Optimization of Density and Moisture Content Measurements by Nuclear Methods (Proj. 10-5A), 86 p., $4.40
126	Divergencies in Right-of-Way Valuation (Proj. 11-4), 57 p., $3.00
127	Snow Removal and Ice Control Techniques at Interchanges (Proj. 6-10), 90 p., $5.20
128	Evaluation of AASHO Interim Guides for Design of Pavement Structures (Proj. 1-11), 111 p., $5.60
129	Guardrail Crash Test Evaluation—New Concepts and End Designs (Proj. 15-1(2)), 89 p., $4.80
130	Roadway Delineation Systems (Proj. 5-7), 349 p., $14.00
131	Performance Budgeting System for Highway Maintenance Management (Proj. 19-2(4)), 213 p., $8.40
132	Relationships Between Physiographic Units and Highway Design Factors (Proj. 1-3(1)), 161 p., $7.20
133	Procedures for Estimating Highway User Costs, Air Pollution, and Noise Effects (Proj. 7-8), 127 p., $5.60
134	Damages Due to Drainage, Runoff, Blasting, and Slides (Proj. 11-1(8)), 24 p., $2.80
135	Promising Replacements for Conventional Aggregates for Highway Use (Proj. 4-10), 53 p., $3.60
136	Estimating Peak Runoff Rates from Ungaged Small Rural Watersheds (Proj. 15-4), in press
137	Roadside Development—Evaluation of Research (Proj. 16-2), 78 p., $4.20

Synthesis of Highway Practice

No.	*Title*
1	Traffic Control for Freeway Maintenance (Proj. 20-5, Topic 1), 47 p., $2.20
2	Bridge Approach Design and Construction Practices (Proj. 20-5, Topic 2), 30 p., $2.00
3	Traffic-Safe and Hydraulically Efficient Drainage Practice (Proj. 20-5, Topic 4), 38 p., $2.20
4	Concrete Bridge Deck Durability (Proj. 20-5, Topic 3), 28 p., $2.20
5	Scour at Bridge Waterways (Proj. 20-5, Topic 5), 37 p., $2.40
6	Principles of Project Scheduling and Monitoring (Proj. 20-5, Topic 6), 43 p., $2.40
7	Motorist Aid Systems (Proj. 20-5, Topic 3-01), 28 p., $2.40
8	Construction of Embankments (Proj. 20-5, Topic 9), 38 p., $2.40
9	Pavement Rehabilitation—Materials and Techniques (Proj. 20-5, Topic 8), 41 p., $2.80
10	Recruiting, Training, and Retaining Maintenance and Equipment Personnel (Proj. 20-5, Topic 10), 35 p., $2.80
11	Development of Management Capability (Proj. 20–5, Topic 12), 50 p., $3.20
12	Telecommunications Systems for Highway Administration and Operations (Proj. 20–5, Topic 3–03) 29 p., $2.80
13	Radio Spectrum Frequency Management (Proj. 20–5, Topic 3–03) 32 p., $2.80
14	Skid Resistance (Proj. 20-5, Topic 7), 66 p., $4.00
15	Statewide Transportation Planning—Needs and Requirements (Proj. 20-5, Topic 3-02), in press

TABLE 8

UNPUBLISHED REPORTS OF THE NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM [a]

PROJECT SUMMARIES IN *SUMMARY OF PROGRESS REPORT* FOR PERIOD ENDING				
JUNE 30 1967	JUNE 30 1968	DEC. 31 1969	DEC. 31 1971	DEC. 31 1972
1-2	2-1	12-4	3-16	9-2
2-8	4-1			11-1(4)
3-1	4-5			11-1(7)
6-6				11-1(11)
6-7A				20-8
8-3				22-1

[a] See Table 5 for project titles. For information on obtaining copies of research agency reports write to University Microfilms, Inc., 300 North Zeeb Road, Ann Arbor, Michigan 48103.

AWARD-WINNING RESEARCH UNDER NCHRP

Several projects have been honored to date as outstanding contributions to the field of highway safety and have received Metropolitan Life Awards for Research in Accident Prevention from the National Safety Council. They are:

- NCHRP Project 1-7, "Development of Interim Skid-Resistance Requirements for Highway Pavement Surfaces." In 1968 this project, reported as *NCHRP Report 37,* "Tentative Skid-Resistance Requirements for Main Rural Highways," received the Award of Merit ($500).

- NCHRP Project 3-8, "Factors Influencing Safety at Highway-Rail Grade Crossings." In 1969 this project, reported as *NCHRP Report 50,* "Factors Influencing Safety at Highway-Rail Grade Crossings," received top honors—the Award of Honor ($1,000).

- NCHRP Project 2-3, "Analysis of Motor Vehicle Accident Data as Related to Highway Classes and Design Elements." Also in 1969 this project, reported as *NCHRP Report 47,* "Accident Rates as Related to Design Elements of Rural Highways," placed second and received the Award of Merit ($500).

Other projects prominent in various other classes of awards are:

- NCHRP Project 20-3, "Optimizing Freeway Corridor Operation Through Traffic Surveillance, Communication, and Control." In 1969 a paper based on this project received Honorable Mention under the Past President's Award, Institute of Traffic Engineers.

- NCHRP Project 9-1, "Asphalt Durability and Its Relation to Pavement Performance." In 1969 a paper based on this project, reported in *NCHRP Report 67,* "Relation of Asphalt Rheological Properties to Pavement Durability," received the W. J. Emmons Annual Award of the Association of Asphalt Paving Technologists as the best paper at the annual meeting.

TABLE 9

NCHRP RESEARCH RESULTS DIGESTS [a]

DIGEST NO.	PROJ. NO.	TITLE
3 [b]	20-6	Relocation Assistance Under Chapter Five of the 1968 Federal-Aid Highway Act
6 [b]	20-6	Standing to Sue for Purposes of Securing Judicial Review of Exercise of Administrative Discretion in Route Location of Federal-Aid Highways
11 [b]	20-6	Valuation Changes Resulting from Influence of Public Improvements
14	12-3	Waterproof Expansion Joints for Bridges
19 [b]	20-6	Advance Acquisition Under the Federal-Aid Highway Act of 1968
20 [b]	19-1	Budgeting for State Highway Departments
22 [b]	20-6	Valuation in Eminent Domain as Affected by Zoning
25 [b]	20-6	Federal Environmental Legislation and Regulations as Affecting Highways
30	4-7	Fatigue Strength of High-Yield Reinforcing Bars
31 [b]	20-6	Proposed Legislation to Authorize Joint Development of Highway Rights-of-Way
32 [b]	20-6	Changes in Existing State Law Required by the Uniform Relocation Assistance and Real Property Acquisition Policies Act of 1970
34	1-10	Flexible Pavement Design and Management—Systems Formulation and Materials Characterization
35	4-9	Evaluation of Preformed Elastomeric Pavement Joint Sealing Systems and Practices
38	1-12(2)	Locked-Wheel Pavement Skid Tester Correlation and Calibration Techniques
39 [b]	20-6	Legal Effect of Representations as to Subsurface Conditions
40 [b]	20-6	Appeal Bodies for Highway Relocation Assistance
41 [b]	20-6	Trial Strategy and Techniques to Exclude Noncompensable Damages and Improper Valuation Methods in Eminent Domain Cases
42 [b]	20-6	Supplemental Condemnation: A Discussion of the Principles of Excess and Substitute Condemnation
43	22-2	Evaluation of Breakaway Cable Terminals for Guardrails

[a] See Table 5 for project titles. Numbers missing from the series have been superseded by published reports. Digests are provided at a nominal cost depending on quantity. Make request to Program Director, NCHRP, Highway Research Board, 2101 Constitution Avenue, Washington, D. C. 20418.

[b] Final publication.

SUMMARY

The National Cooperative Highway Research Program is a unique contract research effort designed to respond quickly and efficiently to the needs of the state highway departments through the solution of the pressing transportation problems. Although the Highway Research Board administers the Program, the research content is solely the prerogative of the American Association of State Highway Officials and the participating member state highway departments. The Program is one of applied (rather than basic) research, and every possible effort is made to help administrators and engineers put the findings to early use. Program policy insures maximum exposure of the research while in progress in the hope that research results will, in fact, more quickly find their way into practice in the form of policies, procedures, specifications, and standards of the state highway departments.

PROGRESS BY PROJECT

AREA 1: PAVEMENTS

Project 1-1(1) FY '63

Development of Procedures for Comparing the AASHO Road Test Findings with Performance of (1) Existing Pavements and (2) Newly Constructed Experimental Pavements

Research Agency: Highway Research Board
Principal Invest.: Dr. Paul E. Irick
Effective Date: March 1, 1963
Completion Date: February 29, 1964
Funds: $42,800

Guidelines were established for the study of existing and new experimental pavements in the satellite research program. Definitions were provided for pavement units and behavior, traffic factors, and environmental factors. Recommendations were made for experimental designs and requirements for collecting adequate data.

The final report has been published in two volumes as:

NCHRP Report 2, "An Introduction to Guidelines for Satellite Studies of Pavement Performance";

NCHRP Report 2A, "Guidelines for Satellite Studies of Pavement Performance."

Report 2 contains a brief presentation of the essentials of the research, whereas Report 2A contains the details.

Project 1-1(2) FY '64

Guidelines for Extending the Findings of the AASHO Road Test—Implementation Phase

Research Agency: Highway Research Board
Principal Invest.: Dr. Paul E. Irick
Effective Date: March 1, 1964
Completion Date: August 31, 1965
Funds: $11,356

In follow-up to the development of NCHRP Report 2A, the intent of this continuation was to establish means for advising and assisting the various satellite programs in the use of the guidelines, techniques, and standards for data acquisition, procedures for data processing, and methods for updating the original guidelines in light of the findings of other research in Area One.

For counseling with project personnel, the following Project Advisory Committee was appointed: J. H. Havens, Chairman, Kentucky Department of Highways; R. F. Baker, Bureau of Public Roads; F. H. Scrivner, Texas Transportation Institute; and V. L. Anderson, Purdue University.

A recommendation was made by this committee that the Bureau of Public Roads should undertake the implementation of the guidelines rather than attempt to do this in this research project, and that the Highway Research Board could assist, if needed, in the area of data analysis. Such assistance was deemed unnecessary; therefore, this project has been closed out.

Project 1-2 FY '63

Comparison of Different Methods for Evaluating Pavement Conditions

Research Agency: Purdue University
Principal Invest.: Prof. E. J. Yoder
Prof. B. E. Quinn
Effective Date: February 15, 1963
Completion Date: February 28, 1965
Funds: $29,957

This project was authorized to evaluate the effectiveness of various objective measurement techniques for obtaining data on road surface properties for use in the prediction of pavement serviceability ratings. Initially, a comparison was made between existing types of "road-roughness" measuring equipment. Such devices as the BPR roughometer, the AASHO slope profilometer, and the CHLOE profilometer were involved in the comparison study.

Research has been completed, and the project report published as:

NCHRP Report 7, "Comparison of Different Methods of Measuring Pavement Condition."

Because the initial research resulted in sufficient data to permit calculation of elevation power spectra, the work was extended to consider specifically the problems associated with using these spectra as criteria of pavement condition. The report on the power spectra work will not be published in the regular NCHRP series, but a summary was included in the "Summaries of Unpublished Reports," *Summary of Progress to June 30, 1967.* A paper on this work has also been published in *Highway Research Record No. 189.*

Project 1-3(1) FY '63 and FY '64

Factors Influencing Pavement Performance—Regional

Research Agency: Purdue University
Principal Invest.: Prof. K. B. Woods
Prof. E. J. Yoder
Prof. R. D. Miles
Dr. C. W. Lovell, Jr.
Effective Date: February 15, 1963
Completion Date: September 30, 1967
Funds: $45,982

The degree of influence of various factors commonly assumed to affect pavement performance has not been suitably evaluated to allow translation of test results from one geographic area to another. The objectives of this project were to identify factors that influence pavement performance, to determine the relative effect of each factor, and to correlate pavement design and performance with factors common to a number of regions of the United States.

A regional classification system, using 97 physiographic units and covering the 48 contiguous states, was adapted from the system originally developed by K. B. Woods and C. W. Lovell, Jr., and published in the *Highway Engineering Handbook,* McGraw-Hill, New York (1960). The highway factors analyzed by physiographic unit were: (1) availability of aggregates, (2) soil origin and texture, (3) high volume change soils, (4) potentially poor subgrade support conditions, and (5) frost-susceptible soils.

The research has been completed, and the project report has been published as:

NCHRP Report 132, "Relationships Between Physiographic Units and Highway Design Factors."

Project 1-3(2) FY '63

Factors Influencing Pavement Performance—Local

Research Agency: Northwestern University
Principal Invest.: Dr. R. L. Kondner
Effective Date: September 1, 1963
Completion Date: September 30, 1964
Funds: $19,850

In contrast with other research concerned with organizing regions into like groupings of sufficient size to permit the applications of the principles of meteorology, pedology, and geology to the identification of significant factors influencing pavement performance, this study was directed to the establishment of significant trends between flexible pavement response and various factors such as axle load, number of load applications, and thickness of pavement components. Performance data from the AASHO Road Test and other similar experiments were examined, and observed behavioral trends were expressed mathematically for consideration of the possibility of incorporating performance, expressed in terms of the present serviceability index (PSI), in flexible pavement design procedures.

This research has been completed, and the results have been published as:

NCHRP Report 22, "Factors Influencing Flexible Pavement Performance."

Project 1-3(3) FY '64

Factors Influencing Pavement Performance

Research Agency: University of California
Principal Invest.: Dr. H. B. Seed
Prof. C. L. Monismith
Effective Date: April 1, 1964
Completion Date: October 31, 1965
Funds: $19,800

The reported analyses of AASHO Road Test data describe to a limited degree the independent reactions of the various components of the pavement structure to the imposed test conditions. The analyses treat very conclusively the reaction of the entire pavement sections to these test conditions. The degree of influence of various factors commonly assumed to affect pavement performance has not been suitably evaluated, however, to allow translation of performance test results from one area to another. It is desirable that all of these factors be studied and evaluated in an attempt to determine order of importance and relative effect on pavement design.

As experience has demonstrated that heavy-duty asphalt pavements experience fatigue cracking under repetitions of heavy load, this research was initiated to develop procedures for predicting pavement deflections on the basis of the results from controlled repeated-load tests on materials comprising the pavement sections and within the framework of existing layered system theory.

Research has been completed, and the results have been published as:

NCHRP Report 35, "Prediction of Flexible Pavement Deflections from Laboratory Repeated-Load Tests."

Project 1-4(1) FY '63

Extension of Road Test Performance Concepts

Research Agency: Georgia Institute of Technology
Principal Invest.: Dr. A. S. Vesic
Leonard Domaschuk
Effective Date: October 1, 1963
Completion Date: September 30, 1964
Funds: $10,000

This research involved a critical review of existing hypotheses and the development of new hypotheses of flexible pavement performance as related to fundamental principles of engineering mechanics and material science. New hypotheses of flexible pavement performance as related to design were sought and tested with available data from the AASHO Road Test and elsewhere.

Research has been completed, and the results have been published as:

NCHRP Report 10, "Theoretical Analysis of Structural Behavior of Road Test Flexible Pavements."

Project 1-4(1)A FY '64

Extension of Road Test Performance Concepts

Research Agency: Duke University
Principal Invest.: Dr. A. S. Vesic
Effective Date: February 1, 1965
Completion Date: September 30, 1966
Funds: $19,924

This research was concerned with existing theories of structural behavior of rigid pavements. Available data on deflections, stresses, and observed structural failures of rigid pavements during the AASHO Road Test were collected and critically reviewed. Rational correlations were developed for existing theories of mechanical behavior of rigid pavements.

The project report has been published as:

NCHRP Report 97, "Analysis of Structural Behavior of AASHO Road Test Rigid Pavements."

Project 1-4(2) FY '64

Extension of Road Test Performance Concepts

Research Agency:	Purdue University
Principal Invest.:	Dr. M. E. Harr
Effective Date:	February 1, 1964
Completion Date:	January 31, 1966
Funds:	$12,243

There exist in the literature many theories that attempt to describe, from a mechanistic point of view, the action and reaction of pavements subjected to various loading. In general, they represent solutions to particular problems which, because of the high cost of performance testing, have never been thoroughly evaluated. In the light of the findings of the AASHO Road Test, a comprehensive overview of all theories is needed to determine relationships which are necessary and sufficient for a broad and adequate description of pavement performance. To pursue this problem, this research study was authorized to examine existing hypotheses and to develop new hypotheses of pavement performance as related to fundamental principles of engineering mechanics and materials science, and alternately to test these hypotheses with data from any other available source.

This research has been completed, and the project report has been published as:

NCHRP Report 30, "Extension of AASHO Road Test Performance Concepts."

Project 1-5 FY '64

Detecting Variations in Load-Carrying Capacity of Flexible Pavements

Research Agency:	Cornell Aeronautical Laboratory
Principal Invest.:	Dr. N. M. Isada
Effective Date:	January 15, 1964
Completion Date:	July 15, 1965
Funds:	$49,011

A need exists for an accurate method which will indicate the relative load-carrying capacity of pavements when compared with capacities during fall or other seasons so that restrictions in load limits can be more objectively applied. It is desirable that such a method be rapid and simple in operation and nondestructive to the pavement.

This research approached the objectives in terms of investigating the displacement response of flexible pavements to impulsive loadings as a measure of the seasonal changes in the elastic properties. The findings have been published as:

NCHRP Report 21, "Detecting Variations in Load-Carrying Capacity of Flexible Pavements."

Project 1-5(2) FY '67

Detecting Seasonal Changes in Load-Carrying Capabilities of Flexible Pavements

Research Agency:	Texas A & M University Research Foundation
Principal Invest.:	F. H. Scrivner W. M. Moore
Effective Date:	September 1, 1966
Completion Date:	June 30, 1968
Funds:	$52,000

Frost, temperature, moisture, and other environmental factors influence the seasonal changes in strength of flexible pavements, particularly during the spring thaw periods in the northern areas of the country. A simple, rapid, and nondestructive procedure is needed for determining the relative load-carrying capabilities of pavements during all seasons of the year. The objectives of this study were to evaluate methods of meeting this need and to develop techniques and guidelines for field use of the most promising procedure. As a result of the evaluation, the Lane-Wells Dynaflect equipment was selected for field evaluation and recommended for field operation.

Research has been completed, and the project report has been published as:

NCHRP Report 76, "Detecting Seasonal Changes in Load-carrying Capabilities of Flexible Pavements."

Project 1-6 FY '64

Standard Measurements for Satellite Program—Measurement Team

Research Agency:	Texas A & M University Research Foundation
Principal Invest.:	F. H. Scrivner
Effective Date:	March 31, 1964
Completion Date:	January 31, 1967
Funds:	$61,353

This research related to establishing measurement teams equipped, staffed, and trained to make common denominator measurements on the projects in any proposed satellite research program and to insure continuity of these measurements during the life of such a program.

The measurement program considered minimal for a nationwide coordinated satellite program was outlined in the guidelines prepared under NCHRP Project 1-1, but the guidelines did not specify actual items of test equipment nor describe team personnel requirements or procedures in detail. In addition, it did not attempt to define

the testing program for the measurement teams in terms of frequency of visits to individual projects or schedules of measurements within projects.

Research has been completed, and the project report has been published as:

NCHRP Report 59, "Standard Measurements for Satellite Road Test Program."

Project 1-7 FY '65

Development of Interim Skid-Resistance Requirements for Highway Pavement Surfaces

Research Agency:	The Pennsylvania State University
Principal Invest.:	Prof. W. E. Meyer
Effective Date:	June 15, 1965
Completion Date:	December 15, 1966
Funds:	$24,815

This study was conducted to satisfy an immediate need for determining minimum service values of skid resistance. These values are interim in nature, as much additional research on the skid problem is needed. The high speeds and rapid accelerations and decelerations of modern vehicles result in pavement surfaces which were once considered skid resistant, but are now deficient in this respect. The problem lies not only in providing surfaces which are adequately skid resistant, but also in the development of standard measurement equipment and procedure. The specific objectives of this research were to (1) develop a state-of-knowledge report on skid measurement techniques and coefficients for highway pavements, (2) recommend interim design values and minimum service values for skid resistance of wet pavements in terms of safety and economy for different methods of measurements, and (3) outline a long-range program to provide verification or refinement of the recommended values.

Research has been completed, and the project report has been published as:

NCHRP Report 37, "Tentative Skid-Resistance Requirements for Main Rural Highways."

Project 1-8 FY '65

Factors Involved in the Design of Asphalt Pavement Surfaces

Research Agency:	Materials Research & Development
Principal Invest.:	F. N. Finn
Effective Date:	January 1, 1965
Completion Date:	February 28, 1966
Funds:	$23,255

Research is needed to improve the methods currently being used to design both asphalt concrete mixtures and thicknesses for flexible pavement surfaces. It is necessary that design methods take into consideration the many factors that affect surface-course performance and the function of the surface course in performance of the total structure of the pavement. A knowledge of all these interrelationships is necessary to the achievement of optimum performance, durability, and economy of the pavement. This research was authorized to identify the factors fundamental to comprehensive design of asphalt surface courses; to appraise the state of knowledge concerning both the recognition of and accounting for these factors in design; and to recommend areas in which new test methods and research are needed if currently used test methods are inadequate to provide the necessary information concerning the fundamental factors.

Research has been completed, and the project report has been published as:

NCHRP Report 39, "Factors Involved in the Design of Asphaltic Pavement Surfaces."

Project 1-9 FY '67

Evaluation of Studded Tires

Research Agency:	Cornell Aeronautical Laboratory
Principal Invest.:	F. R. Haselton
Effective Date:	October 1, 1966
Completion Date:	June 30, 1967
Funds:	$24,998

There is a need to evaluate the effectiveness of studded tires, which apparently cause accelerated pavement wear during the period when the surfaces are free of snow and ice. Wear is likely to be greater at signalized intersections and under repeated turning, braking, and acceleration conditions. The resulting increased maintenance cost must be balanced against the gains in safety attributable to the studded tires.

Research has been completed, and the project report has been published as:

NCHRP Report 61, "Evaluation of Studded Tires—Performance Data and Pavement Wear Measurement."

Project 1-10 FY '67 and FY '69

Translating AASHO Road Test Findings—Basic Properties of Pavement Components

Research Agency:	Materials Research and Development	
Principal Invest.:	B. A. Vallerga	
	F. N. Finn	
	Dr. W. R. Hudson	
	Dr. Keshavan Nair	
Effective Dates:	Sept. 12, 1966	Dec. 1, 1968
Completion Dates:	Mar. 11, 1968	Dec. 31, 1970
Funds:	$99,803	$103,291

A wealth of useful design and performance information resulted from the AASHO Road Test; however, means do

not now exist for reliably translating this information to other localities throughout the United States. This research concentrated on improving the understanding of the significant basic properties of pavement systems and components and their relationships to design and performance, with due regard to locality and environment. The specific objectives of the research were (1) development of descriptions of significant basic properties of materials used in road structures, (2) development of procedures for measuring these properties in a manner applicable to pavement design and evaluation, and (3) development of procedures for pavement design, utilizing the measured values of the basic properties, which would be applicable to all locations, environments, and traffic loadings.

During the initial phase of research, it was determined that measurement of basic properties of materials and components significant to pavement performance is a highly complex problem requiring (a) development of new testing equipment, (b) considerable laboratory data collection, and (c) substantial field evaluation. It was also recognized that the pavement design decision-making processes involve factors other than the structural ability of a pavement to support predicted traffic loadings (e.g., maintenance strategies, user considerations, and long-term economics). Progress was made toward project objectives and a project report was received at the completion of the initial phase. It will not be published, but the findings will be incorporated into the report for Phase II of the study.

In recognition of the problem that new procedures for pavement design, applicable for all materials and pavement types and for all climatic conditions, could not be developed and verified within available time and funds, the Phase II research concentrated on flexible pavements. Project efforts were divided into two major subdivisions—material characterization and systems formulation. A procedure, including the necessary laboratory equipment, has been developed for characterization of materials in terms of stress/strain relationships representative of loading and environmental conditions to which they are likely to be subjected as components of a pavement. The methodology is illustrated by its application to the characterization of an asphaltic concrete, a granular base, and a cohesive subgrade soil. An operational pavement systems model (SAMP 5) has been formulated that organizes the over-all influencing factors, such as materials characteristics, construction techniques, maintenance requirements, and economics, within a suitable framework for flexible pavement design and management. A computer program has been prepared using 58 to 100 input variables and information from the *AASHO Interim Guide for the Design of Pavement Structures* as the structural subsystem.

Research has been completed. The essential findings of the study have been published in NCHRP Research Results Digest 34.

The project report is in the NCHRP editorial and publication process as two separate volumes covering the "materials characterization" and "systems formulation" portions of the study.

Project 1-10A FY '72

Systems Approach to Pavement Design—Implementation Phase

Research Agency:	Texas A & M Univ Research Foundation
Principal Invest.:	R. L. Lytton W. F. McFarland
Effective Date:	March 1, 1972
Completion Date:	December 31, 1973
Funds:	$100,000

Pavements are extremely complex physical systems involving the interaction of numerous variables. Their performance is influenced by such factors as material properties, environment, traffic loading, construction practices, and maintenance activities. The pavement design process must consider all of these influencing factors, plus other constraints imposed by management.

Methods are needed for considering the effect of the interaction of the numerous variables during the over-all pavement design process. An operational pavement systems model (SAMP5), including a computer program using up to 100 input variables, developed during work on NCHRP Project 1-10, appears to be one approach to meeting this need. For the method to be fully implementable, detailed descriptions for user guides, input forms, and data feedback storage systems are needed.

The primary objective of this project is the further development of the SAMP5 program to field application stage and its pilot testing in one or more state highway departments. It is anticipated that this will involve the following:

1. Finalize the SAMP5 working system as a pavement design and management tool, including the preparation of detailed descriptions for user guides, input forms, data feedback storage systems, etc.
2. Conduct a sensitivity analysis of SAMP5 to determine research needs in each of the subsystems.
3. Pilot test SAMP5, including a sensitivity analysis, in one or more state highway departments using the current pavement structural design procedure of the test state(s) as the structural subsystem.
4. Revise the working system as necessary in accordance with the experience gained during pilot testing.

Pilot implementation of the SAMP 5 procedure is being conducted in cooperation with the Kansas, Louisiana, and Florida highway departments. Data have been collected for several example problems. The cooperating states have suggested several modifications, including provisions for variable unit costs, nonlinear traffic growth, and pavement skid resistance. Better guidelines for determining pavement salvage values were also suggested. Considerable effort will be devoted to revising the computer program in response to these suggestions. After further development of the user guides and the data feedback system, the revised program will be used by the cooperating highway agencies in the design decision-making process on actual problems and the feasibility of implementing the procedure will be evaluated.

Project 1-11 FY '68

Evaluation of AASHO Interim Guides for Design of Pavement Structures

Research Agency:	Materials Research & Development	
Principal Invest.:	C. J. Van Til	
	B. F. McCullough	
Effective Dates:	Oct. 23, 1967	Aug. 1, 1970
Completion Dates:	June 30, 1970	Apr. 30, 1971
Funds:	$63,720	$20,205

In the AASHO Interim Guides for the Design of Flexible and Rigid Pavement Structures, distributed in 1962, it was emphasized that the guides were ". . . interim in nature and subject to adjustment based on experience and additional research." Since that time no evaluation has been made of the experience accumulated by the State highway departments as reflected by current design procedures. An immediate need exists for a review and evaluation of these procedures for the purpose of updating the guides. Accordingly, the specific objectives of this research were (1) to collect, review, and summarize current State highway department pavement design procedures, and (2) to develop proposed revisions to the AASHO Interim Guides for the Design of Pavement Structures based on an evaluation of the results of the first objective.

To achieve the objectives, information on current pavement design procedures was collected from 50 state highway departments, the District of Columbia, and Puerto Rico. This was analyzed along with the original AASHO Road Test data and the findings of other research work in the problem area. For the purpose of providing State highway departments with maximum benefits from the project, a continuation contract was executed with the agency with the objective of drafting revised Guides based on suggested revisions contained in the project report.

Research has been completed, and the project reports have been published as:

NCHRP Report 128, "Evaluation of AASHO Interim Guides for Design of Pavement Structures"
and
"AASHO Interim Guide for Design of Pavement Structures," published by the American Association of State Highway Officials, Washington, D. C.

Project 1-12 FY '70

Determination of Pavement Friction Coefficients Required for Driving Tasks

Research Agency:	The Franklin Institute
Principal Invest.:	Eugene Farber
Effective Date:	August 25, 1969
Completion Date:	February 24, 1972
Funds:	$299,990

Increases in traffic density, vehicle speed, and engine horsepower contribute to the rise in number and the severity of highway accidents resulting in thousands of deaths and billions of dollars in property damage each year. It is recognized that the highway accident problem is very complex, involving relationships between the highway, vehicle, driver, traffic, weather, and other variables. Extensive research is needed in all of the various aspects of this problem.

This project statement speaks to the particular portion of the over-all highway accident problem dealing with the frictional coupling of the vehicle tire and the pavement surface. Although tentative minimum skid resistance requirements have been recommended for main rural highways, there currently exists a definite need for the development of a valid basis for determining both minimum and desirable service values of skid resistance for any class of highway, taking into consideration such variable factors as driver and vehicle characteristics, traffic, weather, and highway geometry.

The ultimate objective of research in this problem area is to provide highway agencies with the methods and procedures for determining both the minimum skid resistance values for a pavement necessary to insure adequate vehicle control during normal driving conditions and the desirable skid resistance values for a pavement that will result in reasonable control during emergency or panic situations. The specific objectives of this project are to:

1. Develop an approach for determining driver behavior under normal driving conditions and emergency or panic situations.
2. Conduct driver behavior studies and develop a procedure for determining frictional needs of traffic for any given condition or situation.
3. Using the procedure developed under objective 2, recommend minimum service values of skid resistance for general classes of highways and traffic conditions.

Research has been completed. A tape switch system has been developed for instrumenting a roadway site and determining longitudinal and lateral accelerations of vehicles passing through the site. A total of 24 intersection, curve, and interchange ramp sites were instrumented and data were collected to demonstrate the ability of the tape switch system for measuring vehicle maneuvers. By analysis of vehicle skid data on several different pavement surfaces, empirical relationships between longitudinal accelerations (driver demand) and pavement skid resistance (frictional needs of traffic) were developed for roadway sites where braking is the prevalent vehicle maneuver. A procedure is recommended for using these empirical relationships to determine minimum skid resistance requirements for intersections and other roadway sites where braking occurs. Further research is planned to provide field evaluation of this procedure. Inadequate correlation was found to exist between lateral acceleration and the ability of a vehicle/tire combination to corner on pavements with several different levels of skid resistance. Consequently, further research is necessary to develop procedures for determining minimum skid resistance requirements for highway curves and other roadway sites where cornering and combinations of cornering and braking are prevalent vehicle maneuvers.

The preliminary draft report is being revised by the agency.

Project 1-12(2) FY '71

Locked-Wheel Pavement Skid Tester Correlation and Calibration Techniques

Research Agency: The Pennsylvania State University
Principal Invest.: W. E. Meyer
R. R. Hegmon
Effective Date: September 16, 1970
Completion Date: May 15, 1973
Funds: $319,000

Increases in traffic density, vehicle speed, and engine horsepower contribute to the rise in the number and severity of highway accidents, resulting in thousands of deaths and billions of dollars in property damage each year. It is recognized that the highway accident problem is very complex, involving relationships among the highway, vehicle, driver, traffic, weather, and other variables. Extensive research is needed in all of the various aspects of this problem.

Project 1-12 speaks to the particular portion of the over-all highway accident problem dealing with the frictional coefficients required for coupling of the vehicle tire and the pavement surface. Implementation of the results of Project 1-12 will depend on the ability to measure the skid resistance of a pavement surface with a reasonable degree of reliability. A basic step is the adoption of a consistent method of test for such measurements. Presently, at least 30 state highway departments are using locked-wheel skid testers that substantially conform to ASTM Method E-274-69 to determine the skid numbers for pavement surfaces, and a number of additional states plan to purchase similar devices. It has been demonstrated that the results obtained by use of two or more of this type of tester often differ significantly. These differences cannot be resolved by information currently available from correlation studies. A concentrated effort is required to determine the causes of the differences and to develop procedures for either their elimination or their reconciliation.

The specific objective of this project is the development and verification of methods for improving the ability to measure the skid properties of pavement surfaces with skid testers constructed in general conformance with ASTM Method E-274-69.

The research consists of the following:

Phase A:

1. On the basis of current information, analyze the test and equipment factors that influence the variations in skid values by skid testers conforming to ASTM Method M-274-69, for the purpose of estimating their relative significance.
2. Develop means for eliminating and/or reconciling these variations.
3. Provide limited or pilot-test-type verification of the proposed means.

Phase B:

4. Verify the Phase A findings involving a representative number of skid testers conforming to ASTM Method E-274-69.
5. Evaluate and recommend criteria and techniques for calibrating skid testers conforming to ASTM Method E-274-69.

Initial contacts were made with 54 agencies known to be operating locked-wheel pavement skid testers to collect all possible information about the test equipment and to obtain test data for further analysis. A mathematical model of a locked-wheel skid tester was prepared for a computer analysis of the influence of the various parameters on measurements. It incorporated such parameters as suspension systems, test tire, road roughness, and hitch position. An experimental program is also being conducted to examine repeatability of skid resistance measurements as affected by operator, data-evaluation techniques, lateral position, speed, and temperature. A small skid-test comparative study involving six testers was conducted in cooperation with the National Bureau of Standards. The data collected will provide input for both this project and the NBS work, sponsored by the Federal Highway Administration.

Phase A objectives have been achieved and an interim report has been accepted. The essential findings from the interim report have been published in NCHRP Research Results Digest 38, "Locked-Wheel Pavement Skid Tester Correlation and Calibration Techniques."

Research on Phase B of the study is in progress. A comprehensive correlation program involving 12 skid testers from various parts of the country was planned and conducted. The data collected during the correlation program are being analyzed to determine the ability of the recommendations developed under Phase A to reduce variations in skid resistance measurements made with locked-wheel skid testers.

Project 1-12(3) FY '72

Requirements for Wear-Resistant and Skid-Resistant Highway Pavement Surfaces

Research Agency: Materials Research & Development
Principal Invests.: C. J. Van Til
B. J. Carr
Effective Date: November 1, 1971
Completion Date: April 30, 1975
Funds: $249,651

The highway accident problem is complex, involving relationships between the highway, vehicle, driver, traffic, weather, and other variables. Extensive research is needed in all the various aspects of this problem. NCHRP Project 1-12 pertains to one particular portion of the over-all highway accident problem of determining the pavement frictional coefficients required for any given set of conditions. Project 1-12(2) pertains to the concentrated effort to determine the causes of differences that currently exist in measuring the skid resistance of a pavement surface with a

reasonable degree of reliability by using skid testers constructed in general compliance with ASTM Method E-274-69. With completion of Projects 1-12 and 1-12(2), highway departments will have better means for determining desirable skid resistance service levels and for reliably measuring the skid resistance of pavement surfaces.

Traffic density and the use of winter traction aids contribute to accelerated polishing and wear of highway pavement surfaces. The resulting loss of surface texture reduces tire-pavement friction. Channelized traffic can also produce wheelpath depressions or ruts that may be detrimental to vehicle control and and permit ponding of water with adverse safety effects, such as splashing, ice formation, and increased potential for hydroplaning.

In the interest of highway safety, it is essential that economical and effective procedures be provided for correcting polished or worn surfaces and that new pavement surfaces be designed and constructed to retain acceptable levels of resistance to wear and polishing.

The specific objectives of this project are:

Phase I:

1. Identify and evaluate, on the basis of previous and current research and experience, any procedures intended to result in the construction of improved wear- and skid-resistant pavement surfaces and the correction of worn or polished surfaces.
2. Develop recommendations for the implementation of the procedures identified under objective 1 that are found to be suitable for immediate practical application.
3. Identify and describe possibilities for new and innovative procedures for the construction of highly wear- and skid-resistant pavement surfaces and for correction of worn or polished surfaces.
4. Prepare recommendations for an experimental program to evaluate the promising procedures identified under objective 1 and the new and innovative procedures identified under objective 3 that are found to need further study.

Phase II

5. Conduct the experimental program prepared under objective 4.
6. Develop recommendations for the implementation of the procedures found by the experimental program to be suitable for practical application.

During the initial stages of the study, a comprehensive literature review was undertaken and an annotated bibliography containing approximately 550 items dealing with the various aspects of pavement wear and polishing was prepared. Skid-resistant and wear-resistant pavement surfaces have been classified by function, form, and description for use as remedial treatment of existing pavements and for new construction. Surfaces or treatments suitable for immediate practical application have been identified and recommendations have been prepared for implementation of these surfaces.

A preliminary draft interim report covering Phase I has been submitted for acceptance review. Work on Phase II is expected to begin early in 1973.

Project 1-13 FY '72

Effects of Studded Tires on Highway Safety

Research Agency: Cornell Aeronautical Laboratory
Principal Invest.: Kenneth Perchonok
Effective Date: April 19, 1971
Completion Date: March 31, 1973
Funds: $200,000

The growing use of studded tires has been based largely on claims for greater highway safety. Many highway departments, aware of accelerated pavement damage caused by studded tires, have instituted studies designed to measure the damage and evaluate the associated costs. There is need for sound factual information concerning the overall effects of studded tires on highway safety to facilitate decisions relating to their continued use.

The specific objective of this project is to measure, by study of accidents, accident records, accident investigations, or other appropriate means, the effect of studded tire use on the incidence and severity of accidents occurring under winter driving conditions. Analysis is to include consideration of exposure of vehicles with and without studded tires to accident occurrence.

When research was initiated, the agency had just completed a study in Minnesota on the effect of studded tire use on accidents under winter driving conditions. Because of such limitations as the difficulty in eliminating the drivers' influence and the small sample size, the findings of the previous Minnesota study could not be expressed quantitatively with a significant degree of confidence. The original plan for this research proposed a similar project to benefit from the experience gained during the previous Minnesota work and to use a much larger number of accident reports. By the time research was under way a few months, it became apparent that the use of studded tires would not be permitted in Minnesota, necessitating a modification of the research plan. It also provided a unique opportunity for study of the effects of studded tires on highway safety in a manner that will result in far more definitive findings than would be possible without elimination of their use.

The research plan for accomplishing the project objective was modified to permit conduct of a before-and-after-type study to determine the effect of studded tire use on the incidence and severity of accidents under winter driving conditions. In the program, road condition, vehicle type, and injury information were obtained for each police-reported accident occurring during the normal studded tire seasons of 1970-71 and 1971-72. Each driver was then contacted by mail to determine tire type at the time of the accident and the tire type characteristically used by the driver to determine whether each person should be considered a studded-tire-driver type or nonstudded-tire-driver type. Analysis of these data has permitted an evaluation of the effect of eliminating studded tires in Minnesota on

the number of accidents and resultant injuries. The effect of not permitting the use of tire studs was measured by comparing the change in the number of accidents and injuries for studded tire drivers with studded tires one winter and without studded tires the second winter after correcting for annual effects and effects other than the elimination of the use of studs by assuming that the accident rate for nonstudded tire drivers would generally reflect the influence of the other factors.

To provide greater generality of findings, a study similar to the Minnesota study, but covering only the situation where studded tires are permitted, was included using Michigan data.

The final report has been received and is in the review stage.

Project 1-13(2) FY '72

Effects of Studded Tires on Highway Safety—Non-Winter Driving Conditions

Research Agency: University of Michigan
Principal Invest.: Dr. John A. Green
Effective Date: February 15, 1972
Completion Date: November 30, 1972
Funds: $39,450

Pavement wear by studded tires is suspected of causing an unnatural placement of vehicles in traffic lanes by drivers attempting to avoid worn channels, of increasing the hydroplaning potential by water entrapment in the ruts, of reducing skid resistance, and of having an adverse effect on steering. Studded tires are known to cause premature loss of pavement markings. Quantitative information is needed on these, and other, stud-related influences on highway safety that should be considered in reaching rational decisions regarding the over-all value of studded tires. Some information of this kind may now exist, but much more undoubtedly needs to be assembled if decisive determinations are ever to be made. This project is a first step in obtaining the needed data.

The objectives of this study were to synthesize current knowledge about studded tires related to their non-winter driving safety effects and to use this synthesis to formulate a plan for determining the magnitude of these non-winter safety effects where this information cannot be derived with assurance from existing data.

The study was divided into the following four major tasks:

1. A review of currently available information.
2. Qualitative and, where appropriate, quantitative modeling of the important safety effects.
3. Preparation of experimental plans for exploring areas where present knowledge is lacking and for validating, if necessary, those effects that are clearly indicated by current information.
4. Preparation of a final report documenting the findings of the first three tasks in a form that will be useful to officials and other members of the highway safety community in understanding the present problem and in guiding future investigation.

Project work has been completed, and has offered some insight into the magnitude of the further investigational work required to quantify the many stud-related influences on highway safety. The project report has been received and is in the review stage.

Project 1-14 FY '73

Influence of Combined Highway Grade and Horizontal Alignment on Skidding

Research Agency: University of Michigan
Principal Invest.: Paul Fancher
Effective Date: October 15, 1972
Completion Date: January 14, 1974
Funds: $70,000

A variety of factors have contributed to the rise in number and severity of highway accidents, with attendant loss of life, injury, and property damage. It is recognized that the highway accident problem is an extremely complex one, involving all aspects of the system. Thus, continuing research is needed on all facets of the problem.

At present, "A Policy on Geometric Design of Rural Highways" (AASHO, 1965) treats combinations of vertical and horizontal alignment in a general and relatively nonspecific manner. Although a detailed treatment is afforded to horizontal alignment alone and a similar treatment is given vertical alignment alone, a significant information gap exists on combined alignments. Because the combined alignment condition is common, and because certain combinations of alignments have been identified as a probable causative factor in skidding accidents, the study of these combinations is most appropriate.

This project deals with the particular portion of the overall accident problem involving vehicle operation on highway sections containing the combination of horizontal alignment and vertical alignment—that is, cornering on a downgrade or an upgrade. In this situation, there is strong evidence from accident experience that highway, vehicle, and tire design, as well as operational factors—such as speed and surface condition—affect the onset of skidding. Furthermore, these several variables interact in such a way that a comprehensive parametric examination is required to define the relative importance of the separate variables.

The objective of the research is to develop tentative guidelines for highway geometrics and pavement surface characteristics to ensure adequate vehicle control during anticipated maneuvers on highway sections containing the combination of horizontal alignment and upgrade and downgrade vertical alignment.

The specific objectives are to:

1. Examine analytically the roadway and vehicle factors that influence the safe operation of modern passenger auto-

mobiles on highway sections containing a combination of horizontal alignment and vertical alignment, with emphasis on the downgrade horizontal curvature condition. Specifically, the following parameters and variables are to be included in this analysis:

(a) Roadway:
  (1) Grades.
  (2) Superelevation rate and runoff.
  (3) Radius and type of horizontal alignment.
  (4) Pavement surface properties and conditions.
  (5) Drainage.
(b) Vehicle and operation characteristics:
  (1) Operating speeds and lateral acceleration.
  (2) Braking and longitudinal acceleration.
  (3) Weight, geometry, suspension, and related factors.
  (4) Tire characteristics and conditions.

High-level mathematical simulation techniques for analyzing the operation of automobiles with varying vehicle parameters under roadway conditions have been developed through research in other programs and verified by full-scale tests. Due to this fact—coupled with the limited available funds for Project 1-14—the development of new models is not anticipated during this project.

2. Determine those combinations of speed, roadway geometrics, and pavement conditions that define the onset of skidding for modern passenger automobiles.

3. Evaluate the results of Objectives 1 and 2 by one or more of the following methods:
(a) Comparison with accident experience and roadway characteristics.
(b) Physical simulation.
(c) Field studies.
(d) Other.

4. Suggest measures for alleviating skidding accidents on highway sections containing a combination of horizontal and vertical alignment and prepare recommended additions or modifications to current AASHO design policy to accommodate anticipated vehicle maneuvers on this type of highway section.

Research has been initiated with the preparation of a detailed work plan. A computerized turnpike accident data file is being analyzed to identify relationships between combined curvature and grade and accident experience.

Project 1-15 FY '73

Design of Continuously Reinforced Concrete Pavements for Highways

Research Agency:	University of Texas at Austin
Principal Invest.:	Dr. B. F. McCullough
	Dr. W. R. Hudson
Effective Date:	August 1, 1972
Completion Date:	April 30, 1974
Funds:	$149,985

Since 1959, about 10,000 miles of equivalent two-lane CRCP have been built or placed under contract. These pavements are performing adequately; however, on some projects, problems have occurred that reflect a need for defining more quantitatively the relationships among the design variables that affect performance. These problems generally appear to be associated with irregular crack spacing, erratic crack patterns, excessive crack widths, and excessive deflections. They manifest themselves as isolated areas of premature distress in the forms of (1) steel failure at transverse cracks, (2) edge pumping, (3) spalling at transverse cracks, and (4) failure of the concrete. To overcome these problems and to realize the total potential from CRCP, design procedures more precise than the current procedures based on limited and incomplete performance data are needed.

The specific objectives of this project are to:

1. Review presently available methods for designing continuously reinforced concrete highway pavements to determine those design variables that require further refinement or inclusion. The final manuscript of a synthesis, "Guidelines for Design and Construction of Continuously Reinforced Concrete Pavement," being prepared under NCHRP Project 20-5, became available in late summer 1972 for inclusion in the review.

2. Utilize in-service pavements and laboratory studies (past or proposed) to relate design variables to performance considering traffic loads, deflections, material properties, environment, and slab support.

3. Develop more precise design procedures for continuously reinforced concrete pavement systems.

AREA 2: ECONOMICS

Project 2-1 FY '63 and FY '64

Criteria for Highway Benefit Analysis

Research Agency:	University of Washington
Principal Invest.:	Prof. R. G. Hennes
Effective Date:	June 1, 1963
Completion Date:	November 30, 1967
Funds:	$101,948

This project provided estimates of the relevance of different types of benefit and cost data to decisions in highway location. Basic guides for priorities, guidelines for data collection, and basic information related to taxation were developed.

An interdisciplinary approach to the problem was undertaken by the Departments of Civil Engineering, Political Science, Business Administration, Economics, and Sociology of the University of Washington.

The final report will not be published. A summary of the contents of this report has been published in "Summaries of Unpublished Reports," *Summary of Progress Through June 30, 1968.*

Project 2-2 FY '63

Guidelines for the Determination of Community Consequences

Research Agency: University of Washington
Principal Invest.: Prof. Edgar M. Horwood
Effective Date: July 1, 1963
Completion Date: August 31, 1964
Funds: $48,873

This project was concerned with identifying and predicting community consequences arising from highway improvements. It was designed to seek out both favorable and unfavorable consequences and involved evaluation of existing economic impact studies, developing of guidelines for highway agencies to follow in these studies, and the outlining of urgent aspects of this problem needing detailed research.

The Urban Planning and Civil Engineering Departments combined their talents and analyzed more than 600 research reports and other writings. The final report presented an analysis of bypasses, circumferentials, and radial freeway impact effects. The utility of these studies as well as expressed gaps in knowledge was also discussed.

This research has been completed, and the results have been published as:

NCHRP Report 18, "Community Consequences of Highway Improvement."

Project 2-3 FY '63 and FY '64

Analysis of Motor Vehicle Accident Data as Related to Highway Classes and Design Elements

Research Agency: Cornell Aeronautical Laboratory
Principal Invest.: Dr. J. K. Kihlberg
Effective Date: June 1, 1963
Completion Date: August 31, 1966
Funds: $155,972

The objective of the study was to determine the relationship of motor vehicle accidents to highway design elements. The study consisted of two phases: Phase 1 was a one-year study to determine accident and severity rates for various highway types; Phase 2 was a two-year study to extend these rates to various geometric elements of the highway.

Phase 1 was accomplished with highway and accident data from California, Louisiana, and Ohio. The highway data were the highway networks divided into a multitude of short segments, each of known length, each with a known ADT, and each homogeneous with respect to number of lanes, access control, and median. Data of the accidents that had occurred on a particular highway segment were affixed to that segment. By grouping the highway data according to highway type and ADT, the various accident and severity rates could be computed.

Phase 2 used highway and accident data from Ohio, Connecticut, and Florida. The highway network of each State was subdivided into segments, each 0.3 mile long, each with known ADT, each homogeneous with respect to number of lanes, access control, and median, and each containing known geometric elements (curvature, gradient, intersections, and structures). As in Phase 1, accidents were affixed to the highway segments at the site of occurrence. Proper grouping allowed calculation of accident and severity rates (within each State) for the various geometric elements.

The project report has been published as:

NCHRP Report 47, "Accident Rates as Related to Design Elements of Rural Highways."

Project 2-4 FY '63 and FY '64

The Value of Highway Travel Time, Comfort, Convenience, and Uniform Driving Speed

Research Agency: Texas A & M University Research Foundation
Principal Invest.: Dr. W. G. Adkins
Effective Date: June 1, 1963
Completion Date: August 31, 1966
Funds: $77,100

Various methods that have been proposed to evaluate time savings accruing to highway vehicles are reviewed in this report, and two selected models were used to analyze Interstate Commerce Commission data on commercial highway carriage for the year 1962. Values of time saving in dollars per hour were derived for nine geographical regions as designated by the Interstate Commerce Commission for cargo vehicles and for intercity buses. Detailed methodology of the cost-savings model is presented so that other researchers can make similar estimates under known local conditions. Also, an updating technique has been developed and the 1962 costs were projected to 1965 utilizing equipment costs and driver wages and benefit indexes to develop multipliers. The assumptions of this technique and the limitations of applying the derived results are discussed.

The final report for this project has been published as:

NCHRP Report 33, "Values of Time Savings of Commercial Vehicles."

Project 2-5 FY '63 and FY '64

Running Cost of Motor Vehicles as Affected by Highway Design and Traffic

Research Agency:	The Catholic University of America	
Principal Invest.:	Dr. Paul J. Claffey	
Effective Dates:	June 1, 1963	June 1, 1965
Completion Dates:	Aug. 31, 1964	Dec. 31, 1966
Funds:	$49,998	$51,265

In this project, the motor vehicle running costs were developed for use in evaluating user costs related to proposed highway improvements and traffic regulations. These costs were determined from actual vehicle field tests as well as from the available literature.

A research report presenting the results of the first year's work was received and has been published as:

NCHRP Report 13, "Running Cost of Motor Vehicles as Affected by Highway Design."

This report relates the fuel consumption cost of a typical passenger vehicle to various roadway geometrics and operating characteristics as measured by more than 4,000 test runs in the field. It describes the development of a precise fuel meter used to collect the data. Brief studies are reported on oil consumption, maintenance, tire wear, and depreciation costs as they are affected by highway and traffic conditions.

During the second phase of research, fuel and time consumption data were collected for a second passenger vehicle, a transit bus, a tractor semitrailer, a single-unit truck, and a diesel truck. A special fuel meter for measuring the fuel consumption of diesel trucks was developed.

The results of this project have been combined with the results of Projects 2-5A and 2-7. The findings of the combined research effort have been published as:

NCHRP Report 111, "Running Costs of Motor Vehicles as Affected by Road Design and Traffic."

Project 2-5A FY '65 and FY '67

Running Cost of Motor Vehicles as Affected by Highway Design and Traffic

Research Agency:	Paul J. Claffey and Associates	
Principal Invest.:	Dr. Paul J. Claffey	
Effective Dates:	July 1, 1967	Aug. 11, 1969
Completion Dates:	Dec. 31, 1968	Aug. 10, 1970
Funds:	$35,000	$30,665

The original 2-5 project was continued with the principal investigator as the contracting agency to obtain more detailed data on running costs of motor vehicles in order to eliminate certain gaps that exist in the information available on this subject. The results of the earlier work on Project 2-5 and Project 2-7 have been combined with the additional results of this phase of the project into a single comprehensive final report. The effects that variations in gradient, road surface, speed change frequency, and traffic volumes have on the running costs of passenger cars, pickup trucks, two-axle six-tire trucks, and tractor-trailer combinations are included in the final report and information is provided on the operating expenditures of fuel and oil consumption, maintenance and depreciation, tire wear, and accidents. Condensed graphs of the findings of the fuel consumption and tire wear studies are presented. Each is designed to provide fuel and tire wear cost for various combinations of road design elements and speed change conditions for a given running speed. Also included are families of curves of fuel consumption and tire wear for the eleven test vehicles used in the study and data on the maintenance costs of passenger cars and trucks relative to travel distance, together with average oil consumption rates for operation on dust-free pavements in free-flowing traffic, on dusty roads in free-flowing traffic, and on high-type pavements under restrictive traffic conditions. Several appendices detail a comparative analysis of fuel consumption of diesel and gasoline trucks, determination of the excess fuel consumed by passenger car passing maneuvers, an investigation of devices for the measurement of tire wear, development of equipment for the measurement of vehicle fuel consumption, and an annotated bibliography on highway motor vehicle operating costs.

The final report for this project has been combined with those from Projects 2-5 and 2-7 and published as:

NCHRP Report 111, "Running Costs of Motor Vehicles as Affected by Road Design and Traffic."

Project 2-6 FY '63 and FY '64

Warranted Levels of Improvement for Local Rural Roads

Research Agency:	Stanford University
Principal Invest.:	Prof. C. H. Oglesby
Effective Date:	June 1, 1963
Completion Date:	September 30, 1966
Funds:	$40,000

This project was concerned with the setting of economic standards for the construction and maintenance of local rural roads. Prevailing rural design standards and practices were examined in depth, and user benefits were weighed against cost. Economic and social consequences to local residents, businesses, and communities were studied also and related to the proposed rural road improvements. Operating costs on two-lane roads of various widths were analyzed.

Data were assembled or developed on construction and maintenance costs, on vehicle operations and their associated costs, and on accident expectancies and their costs. These costs were related to various roadbed widths and surface types for straight roads with unimpaired sight distance and traffic volumes of 400 vehicles per day or less.

The research has been completed, and the results have been published as:

NCHRP Report 63, "Economics of Design Standards for Low-Volume Rural Roads."

Project 2-7 FY '64 and FY '65

Road User Costs in Urban Areas

Research Agency:	The Catholic University of America
Principal Invest.:	Dr. Paul J. Claffey
Effective Date:	February 1, 1964
Completion Date:	May 31, 1966
Funds:	$99,376

The purpose of this research was to provide data on road user costs as classified by arterial type, operating speed, traffic composition, and delay factors. Basic tables applicable for planning and for selecting arterial street and highway systems from the various alternates in urban areas were developed.

The final report contains information on fuel and time consumption rates of a passenger vehicle, two trucks, and a bus operating on various types of urban facilities under various levels of service. Some study was devoted to determining motor vehicle accident costs and oil and maintenance costs which can be attributed to urban driving conditions. Tire wear data were collected for freeway and urban arterial comparisons.

The results presented in the project report have been combined with the results of Projects 2-5 and 2-5A and published as:

NCHRP Report 111, "Running Costs of Motor Vehicles as Affected by Road Design and Traffic."

Project 2-8 FY '64

Estimation and Evaluation of Diverted and Generated (Induced) Traffic

Research Agency:	Northwestern University
Principal Invest.:	Prof. W. L. Garrison
Effective Date:	May 1, 1964
Completion Date:	August 31, 1966
Funds:	$40,000

Traffic volumes on new or improved highway facilities are found to increase more than can be attributed to normal growth of existing traffic. This extraordinary traffic increase is composed of two components, diverted and generated. In making analyses of highway improvement consequences, such diverted and generated traffic must be taken into account. At the present time, sufficient information is not available concerning characteristics of this type of traffic.

The final report has been received and reviewed for acceptance. It will not be published, but is available from the Highway Research Board on loan. A summary of the contents of this report is included under "Summaries of Unpublished Reports," *Summary of Progress to June 30, 1967.*

Project 2-9 FY '66

Effect of Highway Landscape Development on Nearby Property

Research Agency:	The Franklin Institute
Principal Invest.:	Joel N. Bloom
Effective Date:	November 8, 1965
Completion Date:	January 31, 1968
Funds:	$149,103

The intent of this research is to study how highway landscape development affects nearby property on a nationwide basis. This study determines the comparative effects of different basic types of landscape treatments in regard to property values, land use compatibility, and general acceptability. Factors relative to the problem include geometric design as well as plantings, fencing, slope blending, and screening applications.

A pilot study was conducted in the Philadelphia area to test the research techniques. Measurements of headlight annoyance, noise, vibration, air pollution, and concealment were made and correlated to the highway design and landscape treatment, property valuation, and attitude data obtained from household interviews. Field studies have continued in New York, Connecticut, Pennsylvania, Maryland, Ohio, and California. Statistical tests were conducted to determine if an economic effect could be determined. Regression analyses were made to illustrate the effects that landscapes and landforms have on noise level reduction. Correlation analyses were made to show the relations among landform, landscape, disturbance, interview data, and the value of properties adjacent to highways.

The report will assist highway engineers and landscape architects in developing designs that will reduce highway noise levels to an acceptable range for adjacent residents. The research results have been published as:

NCHRP Report 75, "Effect of Highway Landscape Development on Nearby Property."

Project 2-10 FY '67

Future Needs for Oversize-Overweight Permit Operation on State Highways

Research Agency:	Roy Jorgensen and Associates
Principal Invest.:	Ralph D. Johnson
Effective Date:	November 1, 1966
Completion Date:	April 30, 1968
Funds:	$99,655

The purpose of this study was to evaluate the extent of current and future activities of oversize-overweight vehicles in relation to the highway transport situation. Because of the physical and economic aspects of oversize-overweight vehicles with regard to present and future highway needs, it is timely that basic information be developed.

A survey was conducted in each State to determine the location of permit files and the magnitude of these records. A 3 percent sample of all the permit records for 1966 in all the contiguous States was coded and punched into cards for statistical analyses. This amounted to a sample of 60,139 permits, which represents an estimated 2,160,000 permits issued in 1966.

Data were also collected from the Heavy-Specialized Carriers and the Oil Field Haulers through the American Trucking Associations concerning movements made during the summer of 1967. The Mobile Home Manufacturers' Association provided statistics on shipments, and the Defense Department contributed data on their special movements.

Detailed analysis was conducted using automatic data processing statistical programs. Future trends in industries reliant upon permits for movement of certain commodities were projected to 1975. The research results have been published as:

NCHRP Report 80, "Oversize-Overweight Permit Operation on State Highways."

Project 2-11 FY '67

Summary and Evaluation of Economic Consequences of Highway Improvements

Research Agency: Highway Research Board
Principal Invest.: Robley Winfrey
Effective Date: January 1, 1967
Completion Date: July 31, 1970
Funds: $110,000

This project reviewed the reports submitted on economics in NCHRP, as well as information from other sources, and prepared the results in a form that may be used directly by engineers, economists, and others who wish to make highway economic studies.

The research was conducted in four phases: (a) to present the background and principles of engineering economy and economic analysis; (b) to present the findings of Projects 2-1 to 2-9, together with supplementary data from other sources, in an organized form for use in benefit-cost studies and other economic analyses; (c) to identify gaps in the information available and needed research to fill these gaps; and (d) to make an introductory study of probable future trends in the technology of economic analysis.

The project report has been published as:

NCHRP Report 122, "Summary and Evaluation of Economic Consequences of Highway Improvements."

AREA 3: OPERATIONS AND CONTROL

Project 3-1 FY '63 and FY '64

Development of Criteria for Evaluating Traffic Operations

Research Agency:	Cornell Aeronautical Laboratory	
Principal Invest.:	Jaime F. Torres	
Effective Dates:	Feb. 15, 1963	July 2, 1964
Completion Dates:	Feb. 29, 1964	Feb. 28, 1966
Funds:	$78,965	$79,913

This research project provided an investigation into the application of criteria based on travel time, driver comfort, safety, and vehicle running costs. The linear combination of these factors weighted by an appropriate set of cost coefficients quantified the operational performance. A procedure was studied which would provide estimates of the four components based on measurements of traffic volume and an inventory of roadway characteristics. Travel time, volume, and roadway inventory data were collected from several cities and analyzed. Estimating relationships were derived for many classes of urban arterials, whereby travel time can be obtained from the measurement of volume and a knowledge of the street characteristics. A survey vehicle was equipped to monitor skin resistance, heart pulse, and respiration of two subjects in traffic while steering, brake, throttle, and speed were being recorded to study driver comfort. Accident data in the Buffalo area were analyzed and related to the safety factor and vehicle running costs were estimated through the use of speed distributions for a sample of streets.

The final report on this research will not be published; however, loan copies are available from the Highway Research Board. A summary of the report is available in *Highway Research Record No. 211* and also in the *NCHRP Summary of Progress to June 30, 1967.*

Project 3-2 FY '63 and FY '64

Surveillance Methods and Ways and Means of Communicating with Drivers

Research Agency: Cornell Aeronautical Laboratory
Principal Invest.: Morton I. Weinberg
Effective Date: February 15, 1963
Completion Date: April 30, 1966
Funds: $246,756

This project, which was concerned with the development, practice, and evaluation of various methods of surveillance and means of communicating with drivers, took advantage of the several surveillance systems available in the United States to further its research.

The report of the first phase of research described a predictive model to provide warning of impending congestion, study of a ramp advisory signal, and use of an airborne observer for traffic control. It has been published as:

NCHRP Report 9, "Traffic Surveillance and Means of Communicating with Drivers."

In the second phase of the project the researchers developed the mathematical logic to predict the effects from unexpected blockages on a freeway and validated the model on the John C. Lodge Freeway in Detroit. Also included was an evaluation of an airborne surveillance and control system. The results of this phase have been published as:

NCHRP Report 28, "Surveillance Methods and Ways and Means of Communicating with Drivers."

In the third phase of the project a computer-controlled signal system for a typical urban complex was synthesized, including control logic and equipment requirements. The results of this phase have been published as:

NCHRP Report 29, "Digital-Computer-Controlled Traffic Signal System for a Small City."

Project 3-3 FY '63 and FY '64

Sensing and Communication Between Vehicles

Research Agency: The Ohio State University
Principal Invest.: Dr. Thomas H. Rockwell
Dr. Joseph Treiterer
Effective Date: February 15, 1963
Completion Date: November 30, 1965
Funds: $163,190

This project involved establishment of the operating requirements of a communication system designed to enable

better communications between vehicles on expressway-type facilities.

Evaluation and comparative examinations of four inter-vehicular communication systems were completed. These involved both night and day study of car-following for no signal display, for the conventional brake light, for the tri-light system denoting brake and accelerator action and an acceleration information display of horizontal rows of green and red lights to indicate the magnitude of the vehicle's acceleration or deceleration. Studies of lane changing decisions were also made. Taxonomies of functional groupings of conceptual rear-end visual display components were studied for the various signal systems previously tested. A prototype infrared sensing system was developed and tested to indicate distance and relative velocities between vehicles. Field studies of traffic dynamics were analyzed to determine the data which should be transferred by the sensing and communication system to increase traffic volume and improve safety and speed of traffic flow. Model development studies were made to quantitatively evaluate possible improvements which may be obtained through improved communication between vehicles.

The final report has been published as:

NCHRP Report 51, "Sensing and Communication Between Vehicles."

Project 3-4 FY '63, FY '64, and FY '66

Means of Locating Disabled or Stopped Vehicles and Methods of Communication with a Central Location

Research Agency:	Airborne Instruments Laboratory	
Principal Invest.:	Fred Pogust	
Effective Dates:	March 1, 1963	July 1, 1965
Completion Dates:	March 31, 1965	Dec. 15, 1966
Funds:	$78,517	$49,474

This study was directed toward evaluation of the nature and extent of the problem and describing the need for communication as well as the benefits of locating disabled vehicles. An additional task was researching the ways that information about disabled or stopped vehicles may be used.

An interim report has been published as:

NCHRP Report 6, "Means of Locating and Communicating with Disabled Vehicles."

Following the comprehensive review of the nature, extent, and characteristics of the stopped vehicle problem conducted during the first year of research, the researchers continued to investigate the feasibility of a detector system. A roadside vehicle detector system was developed using a silicon photo-voltair diode as the roadside receiving unit and signalling was performed by a vehicle-mounted relay-type interrupting device which modulates infrared-emitting diodes. A prototype system was built, tested, and demonstrated to the advisory panel.

The final report has been published as:

NCHRP Report 40, "Means of Locating Disabled or Stopped Vehicles."

Project 3-5 FY '63, FY '64, FY '66, and FY '69

Improved Criteria for Designing and Timing Traffic Signal Systems

Research Agency:	Planning Research Corp.		
Principal Invest.:	F. A. Wagner, Jr.		
Effective Dates:	3/1/63	7/1/66	8/1/68
Completion Dates:	12/31/65	7/31/67	12/31/69
Funds:	$123,030	$48,155	$93,717

In many cases, improving the safety and efficiency of existing road and street systems is dependent on the improvement of traffic control signals. Experience with conventional methods of timing traffic signals has repeatedly shown that they do not take into account all of the variables. Conventional methods give no assurance that the final result is the most efficient system, or even that the system is operating at peak efficiency.

The over-all objective of the research was to determine the most efficient method of timing traffic signals for isolated intersections, arterial highways, and grid networks of city streets. The research was accomplished in three phases.

The first phase involved methods of signal timing for the isolated intersection. Utilizing a sophisticated digital computer traffic-simulation model, new control techniques were developed and compared with existing control methods for the isolated intersection. A promising new control technique determines the duration of green time for each signal phase, based on the queue length of the various lanes just as the signal turns green. This mode of control was field tested at an intersection in the Chicago area, and its operational efficiency was compared empirically with the existing volume-density controller and a fixed-time method of control. In addition, special studies were conducted to evaluate the effectiveness of turn controls and equalization of delay.

The results of the first phase of research have been published as:

NCHRP Report 3, "Improved Criteria for Traffic Signals at Individual Intersections—Interim Report," and

NCHRP Report 32, "Improved Criteria for Traffic Signals at Individual Intersections."

The second phase involved development and comprehensive, closely controlled, scientific testing of several advanced concepts for operating traffic-signal systems on urban arterial streets. The results indicate that a significant degree of improvement in traffic operation is possible through application of advanced control methods. This phase has been completed and the final report has been published as:

NCHRP Report 73, "Improved Criteria for Designing and Timing Traffic Signal Systems—Urban Arterials."

The third phase, involving network signal operations, started in August 1968. The objective of the third phase was to simulate and field test promising signal-control logic that will produce improved signal timings for a grid network of traffic signals. With the assistance of cooperating agencies test networks were located in Los Angeles and San Jose. The San Jose computerized traffic signal network contained 46 signalized intersections, and the Los Angeles

network contained 26 signalized intersections. The following signal-timing methods were evaluated using simulation techniques and through actual field tests: (1) existing control; (2) Delay-Difference Method, Preferred Arterials Plan; (3) Delay-Difference Method, Volume Priority Plan; (4) Delay-Difference Method, Mixed Cycle Plan; (5) SIGOP Plan; (6) Combination Method Plan.

The final report has been published as:

NCHRP Report 124, "Improved Criteria for Traffic Signal Systems in Urban Networks."

Project 3-6 FY '63, FY '64, and FY '66

Effect of Regulatory Devices on Intersectional Capacity and Operation

Research Agency:	De Leuw, Cather & Company
Principal Invest.:	Ronald Pfefer
Effective Date:	April 1, 1963
Completion Date:	August 15, 1966
Funds:	$153,175

This project was for the purpose of identifying the effect of specified traffic regulatory devices on intersection capacity and operations and on systems of traffic facilities. The effects of stop and yield signs were investigated as they apply to capacity, traffic operations, safety, driver acceptance, and the traffic operations of the area of influence.

The initial phase of research has been published as:

NCHRP Report 11, "Effect of Control Devices on Traffic Operation."

The report examines efficient methods of intersection study and derives some preliminary relationships concerning the operations of intersections with YIELD and two-way STOP control and their street system effects.

During the second phase of research, field data were collected at STOP- and YIELD-sign locations in the areas of Chicago, San Francisco, New York, and Toronto. Analyses were made to select criteria for intersection controls and develop a method for applying them. Programs and procedures were developed to integrate and analyze the field data collected during the first phase. Detailed traffic-control-devices questionnaires were analyzed from States, cities, and counties throughout the country.

The final report has been published as:

NCHRP Report 41, "Effect of Control Devices on Traffic Operations."

Project 3-7 FY '64, '65, '67, '72, and '74

Establishment of Standards for Highway Noise Levels

Research Agency:	Bolt Beranek and Newman			
Principal Invest:	Andrew Kugler			
Effective Dates:	2/1/64	10/14/68	4/1/71	9/1/72
Completion Dates:	4/30/67	1/15/70	6/30/2	5/31/74
Funds:	$144,920	$69,930	$49,927	$299,050

This project is concerned with the evaluation of noise levels of the various classes of highways and the effectiveness of controlling highway noise through highway design features as well as the reduction of noise production by means of legislation and vehicle regulation. Questions relating to highway noise levels and their effect on adjacent land users frequently arise in urban highway planning and design.

The Phase I research involved the selection of the most appropriate means and units for measuring and evaluating highway noise. Measures of noise levels were collected from past studies, and additional field studies were made as necessary. A simulation model has been developed to determine the noise created by highway traffic, and objective limits for noise produced by various classes of vehicles have been determined. The research agency reported gratifying success with the use of judgments of photographs to elicit reactions to highway noise. These attitude expressions were found to be important modifiers of response to the noise stimulus. The results of the Phase I research have been published as:

NCHRP Report 78, "Highway Noise—Measurement, Simulation, and Mixed Reactions."

The Phase II research started on October 14, 1968. Its objective was to prepare a highway design noise manual for the practicing highway engineer. The design guide is practically oriented to provide the highway designer with the tools necessary to make meaningful decisions regarding highway design with respect to traffic noise. In addition, a magnetic tape recording was produced to demonstrate basic elements of highway noise and to present examples illustrating changes in traffic noise.

Studies of the noise produced by freely flowing traffic were completed, and an analytic technique for predicting traffic noise levels was developed. Extensive studies were undertaken to determine highway noise design criteria. The development was along three principal lines: (1) task interference such as speech communication, sleep, and TV/radio uses, (2) general annoyance, and (3) intrusive versus ambient levels. Speech interference criteria were adopted as a basis for setting an upper design limit for allowable traffic noise. The results of the Phase II research have been published as:

NCHRP Report 117, "Highway Noise—A Design Guide for Highway Engineers."

The objective of the Phase III research was to conduct a thorough measurement program on various noise reduction treatments under a variety of traffic and environmental conditions. This research developed a tie between field data and analytic approaches so that the performance of noise reduction treatments may be more accurately predicted.

The agency completed a field measurement program in which the necessary data on the noise abatement characteristics of the selected noise reduction measures were collected. For each study site, a comprehensive measurement plan was developed. The sites selected for study included evaluation of elevated and depressed highway configuration, shielding barriers, and roadside structures.

The measurement program identified the contribution of traffic parameters, traffic noise reduction measure charac-

teristics, and environmental and ground conditions on the over-all noise reduction characteristics of each test site. Measurements were taken simultaneously at various distances from the noise source at different heights above the ground to obtain a spatial description of the noise abatement characteristics. During the first part of 1972, the investigators analyzed the data collected at the test sites and formulated analytic and laboratory models. The results of the Phase III research will be published in 1973.

The Phase IV research started on September 1, 1972. Its objectives are to: summarize the present state-of-the-art for controlling the noise-producing properties of the individual mechanical components of motor vehicles that lead to the composite noise produced by motor vehicles on highways; assess the technological and economic feasibility of reduction of traffic noise that will enable highway officials to seek federal and local legislation that might redistribute the burden of noise control; and improve procedures for highway noise control that will allow the designer to more realistically assess the highway noise problem.

The agency is conducting a state-of-the-art review of vehicle noise-source evaluation and prediction for over-the-road vehicles for the purpose of quantifying individual noise-source characteristics of identifiable vehicle subsystems. The noise-reduction potential for each subsystem will be defined to establish feasible composite noise reduction for over-all vehicle noise. The agency is defining the present state-of-the-art for incorporation of practical noise control measures in highway design. The practicality, acoustical effectiveness, and cost effectiveness of noise control measures utilized at the community level will be assessed.

During the first part of 1973, the investigators will be developing estimated costs to achieve noise reductions previously defined and traffic noise source models that allow for regional variations in noise source levels. The criteria for these variations will be based on such human functions as speech, sleep, and annoyance.

Project 3-8 FY '64 and FY '65

Factors Influencing Safety at Highway-Rail Grade Crossings

Research Agency:	Alan M. Voorhees & Associates	
Principal Invest.:	David W. Schoppert	
	Dan W. Hoyt	
Effective Dates:	Dec. 1, 1963	Apr. 1, 1965
Completion Dates:	Dec. 31, 1964	Jan. 6, 1967
Funds:	$17,171	$74,250

This study was directed toward the interpretation and analysis of currently available highway-rail grade-crossing data in the United States.

The initial research reviewed previous work in this area and developed a mathematical model for predicting accidents, and this was tested with accident data obtained from Minnesota, Oregon, and Virginia. A warrant was developed based on the cost of providing protective devices and the cost of possible accident savings.

Later work involved the development and testing of improved grade-crossing protective devices and several experimental devices were studied by the agency. A human factors study was completed. Several important sources of data were found that facilitated the research associated with the development of the accident predictive model as well as refinement of the proposed criteria for grade-crossing protection. Data acquired from Stanford University included 18 years of data at 617 crossings and data acquired from the Ohio Department of Highways included all accidents occurring at 1,000 rural grade crossings. From the Interstate Commerce Commission the investigators obtained more than 15,000 grade-crossing accident reports spanning a five-year period.

The project report has been published as:

NCHRP Report 50, "Factors Influencing Safety at Highway-Rail Grade Crossings."

Project 3-9 FY '66

Analysis and Projection of Research on Traffic Surveillance, Communication, and Control

Research Agency:	Roy Jorgensen and Associates
Principal Invest.:	Karl Moskowitz
Effective Date:	October 15, 1966
Completion Date:	January 14, 1968
Funds:	$23,760

The purpose of this study was to review the results of NCHRP Projects 3-2, 3-3, and 3-4, together with the accomplishments of other recently completed research in this area in the United States and abroad, and to determine the state of the art and set forth guidelines regarding the proposed future research efforts to be conducted in this area.

The investigators visited other researchers to collect progress reports and unpublished information. On-site observations were made on the major freeway surveillance and control facilities currently in operation.

The project report has been published as:

NCHRP Report 84, "Analysis and Projection of Research on Traffic Surveillance, Communication, and Control."

Project 3-10 FY '66

Application of Vehicle Operating Characteristics to Geometric Design and Traffic Operations

Research Agency:	Cornell Aeronautical Laboratory
Principal Invest.:	Morton I. Weinberg
	Dr. Kenneth J. Tharp
Effective Date:	January 1, 1966
Completion Date:	March 10, 1967
Funds:	$41,520

This research was directed at identifying the motor vehicle characteristics that are related to highway geometric design and traffic control operations. The objective was to determine the relationships between the vehicle and its

operating environment. Vehicle characteristics were reviewed, and where appropriate highway design criteria were suggested.

Elements of geometric design and traffic operations presented in the basic design and policy manuals were analyzed to determine how vehicle characteristics are being utilized. A rational approach was made to determine, expand, or modify the existing criteria. The results of the review revealed those vehicle characteristics which should be known and used in designing and operating streets and highways. For vehicle characteristics which are presently unknown or where information is outdated, methods of obtaining data and methods of using this information in geometric design and traffic operations were recommended.

The final report has been published as:

NCHRP Report 68, "Application of Vehicle Operating Characteristics to Geometric Design and Traffic Conditions."

Project 3-11 FY '67

Optimizing Street Operations Through Traffic Regulations and Control

Research Agency:	Peat, Marwick, Mitchell & Co.
Principal Invest.:	James H. Kell
Effective Date:	September 1, 1966
Completion Date:	September 30, 1968
Funds:	$258,331

This research was directed to applying the best traffic regulation and control techniques to an area of typical urban streets and evaluating results. Innovations that may be expected to improve operational efficiency were explored. The cities of Sunnyvale and Redwood, Calif., were selected as the cooperating demonstration test cities. The research emphasis was placed on a quantified evaluation of the effect of traffic regulation and control techniques on the central business districts of these cities.

A base-condition traffic operations profile was established for each city and used for subsequent comparisons as changes in traffic regulations and control were implemented and evaluated through a series of test stages. Operational techniques ranging from relatively simple, but effective, signal timing to extensive left-turn prohibitions and one-way operations, were evaluated. Angle parking, no-stopping towaway, and unbalanced traffic flow were also evaluated throughout an area of urban streets. Average speeds, stops, delays, and a variety of other measures were used to determine the relative magnitude of operational efficiency on an areawide basis. Business performance, public acceptance, and driver observance were also measured for each combination of traffic improvement techniques.

As this research study included the significant areas of business performance and public opinion, greater insight was gained into the political feasibility of a proposed traffic change. The study findings substantiated the theory that no major traffic improvement plan can be implemented, regardless of the extent to which it may serve the public interest, unless it meets with the support of the general public, especially that of the business community.

The final report has been published as:

NCHRP Report 110, "Optimizing Street Operations Through Traffic Regulations and Control."

Project 3-12 FY '67 and FY '68

Development of Information Requirements and Transmission Techniques for Highway Users

Research Agency:	Airborne Instruments Laboratory		
Principal Invest.:	M. A. Warskow	G. F. King	G. F. King
Effective Date:	10/1/66	4/1/68	3/29/71
Completion Date:	12/31/67	12/1/69	6/30/72
Funds:	$198,655	$100,500	$99,956

The objective of the over-all research problem was the development of a well-defined information system for the highway user. The system represents all conditions with which the driver is routinely, occasionally, and rarely confronted.

Through the technique of task analysis, a body of information needs was found, the satisfaction of which enables drivers to perform the driving task safely, conveniently, efficiently, and comfortably. Principal factors were defined which organize the needs into functional groups, delineate the interactions between them, and identify the criteria for selecting and transmitting needs to be satisfied. The extent to which the visual channel can be used successfully and where and how supplemental communication techniques can be used successfully were investigated. Analysis of the driving task disclosed that the operations that a driver performs can be characterized in terms of a hierarchy. It was found that a demanding priority (primacy) exists in satisfying information needs, and it was concluded that satisfying the primacy of information needs is basic to the design of a highway information system. A procedure was developed for the systematic application of these principles to actual highway situations in accordance with basic information system requirements. In addition, current sign use was investigated, particularly the night legibility problem, to determine problem areas in sign application criteria. Mathematical analyses were presented on the probability of sign blockage by trucks, and the effect of lateral displacement of signs. A sign design procedure to incorporate the findings with regard to sign use was outlined. The test site for the project was located in North Carolina.

The first and second phase research has been completed, and the project report has been published as:

NCHRP Report 123, "Information Requirements and Transmission Techniques for Highway Users."

Although engineers have certain established concepts and standards regarding highway guide signing, additional research, identified as Phase III of this project, was conducted to determine whether or not these present standards provide the information required to guide motorists

properly on their journeys. This research involved critical highway signing in and around urban areas and included inner-city signing, beltway signing, and junction signing for arterial routes and freeways.

A team of traffic engineers and human factor specialists investigated the specific problem of guide signing in urban areas. The specific configurations of the problem were investigated by a number of methodologies and potential solutions were identified. A laboratory empirical evaluation investigated the appropriateness of some of these solutions.

An investigation of the state of the art of urban guidance revealed that, although some individual system elements had received considerable attention, very little work had been done on a system-wide basis. Furthermore, no organized body of complaints, or of any other data, existed that could serve as a basis for analysis of specific problems as perceived by the driver. The available material, obtained through a literature search as well as through a series of technical discussions, was organized and analyzed and a set of applicable constraints was identified.

A detailed examination of the *Manual on Uniform Traffic Control Devices* was made in order to delineate the existing system of urban guidance and to identify problems inherent in the system and its implementation. Synthesis of all information and data obtained showed that the major and most frequently encountered problems in urban guidance fell into five distinct categories:

1. Trip planning and trip plan execution.
2. Getting on and off freeways and expressways.
3. Navigating the conventional road network.
4. System forgiveness (i.e., recovery from being lost).
5. System implementation (size, legibility, maintenance).

A number of potential existing solutions were identified and a number of new potential solutions generated. This effort concentrated on the arterial aspects of the problem, which were found to be most severe. Specifications for the most important of these identified solutions were cast in the form of a set of specific recommendations. These solutions deal mostly with matters of sign legibility, adequacy of arterial identification, advance notice of forthcoming arterial intersection, and increased use of trailblazing. A number of these solutions were subjected to empirical evaluation using a simulated navigational exercise.

The research has been completed and a revised final report is being prepared for publication consideration. Once approved, copies of the unedited draft will be available for loan.

Project 3-13 FY '68

Guidelines for Medial and Marginal Access Control of Major Roadways

Research Agency: Texas A & M University Research Foundation
Principal Invest.: Dr. Vergil G. Stover
Effective Date: September 1, 1967
Completion Date: November 30, 1969
Funds: $149,916

A need exists for guides in selecting the degree of access control for a specific project and for selecting the type, location, and width of median and median openings and the design and frequency of entrances to be associated with the degree of access control. Current practice represents wide variation in judgment, and indicates the need for better understanding of the functions and use of medial and marginal access control.

Factors considered in the research were: accident frequency and severity; cost of physical construction and right-of-way to accomplish access control; legal considerations; traffic patterns; service to the highway user; motor vehicle operating costs; travel time and costs; land use; convenience of access to abutting property; property values; and provision for future needs for access control and for changing traffic characteristics, user requirements, or land use.

The street and highway network of a local area, urban region, state, and nation should adequately provide for the conflicting functions of land access (local traffic) and longer trips (through traffic). The various sections of the more important roadways providing a similar service should be of similar design and have similar treatment of access. Further, they should be connected in a rational manner so as to provide continuity throughout the administrative jurisdiction. The research recommended that:

1. Functional classification should be adopted as the basis for the application of access control.

2. Each administrative agency should develop and adopt a master highway plan of existing and proposed facilities, indicating the functional classification of each facility for its jurisdiction. A policy on the degree of access control to be exercised on each functional class should be adopted simultaneously.

3. Standards should be developed and adopted for each functional class and applied uniformly on all facilities within each class.

4. Policy and standards relating to intersections with other public streets and roads should be based on intersection spacing criteria and not on the location or existence of cross streets. Policy and standards relating to the provision of private driveways to higher classifications of roadways should be based on spacing criteria rather than on property ownership pattern.

5. Driveway permits should be issued for and limited to service for a particular type of land use and specific development; should the development be materially changed or the parcel converted to a different land use the permit should automatically terminate and a new permit should be required.

6. Procedures should be established to obtain greater coordination between traffic personnel and planning personnel in the review of requests for zoning changes and building permits. The entire site development plan should be reviewed and acted on in the consideration of a driveway request. In any case, building permits should not be issued independent of driveway permits.

The project report has been published as:

NCHRP Report 93, "Guidelines for Medial and Marginal Access Control on Major Roadways."

Project 3-14 FY '68

Optimizing Flow on Existing Street Networks

Research Agency:	Edwards & Kelcey
Principal Invest.:	Walter E. Pontier
Effective Date:	October 1, 1967
Completion Date:	January 10, 1970
Funds:	$990,000

This project investigated the benefits to traffic flow in downtown areas which can be achieved by application of traffic engineering measures. Experimentation to quantify the effect of road improvements was carried on in two study areas—the downtown portions of Louisville, Ky., and Newark, N.J. Data developed for control and analysis of these experiments were subjected to statistical evaluation to describe those controlling conditions which influence measurements in the downtown area and to develop meaningful relationships which describe the quality of traffic flow, attaining a level of service definition for downtown streets. Methods were developed for application of the results of this research to streets of other areas.

Thirty-seven experiments were conducted to quantify the effect of traffic engineering measures. These experiments can be grouped into six major categories, as follows: Directional control and lane use, curb lane controls, channelization, signal controls, inclement weather effects, and bus operation.

Consideration of the limitations of a direct capacity-volume approach to analysis of downtown traffic flows led to investigations of developing other means for quantifying and describing traffic flow of a downtown area. These included studies of acceleration noise, mean velocity gradient, and travel time, together with several elements related to travel time such as delay time, average speed, running speed, number of stops, and the number of saturated cycles at signalized intersections. These analyses indicated that a comprehensive analysis of travel time was the best medium for understanding and classifying traffic flow in the downtown area. Using the voluminous travel time and intersection study data accumulated on the project, regression analyses were performed to demonstrate the relationships which exist between various elements of travel time. It was also demonstrated that these relationships are fairly constant for arterial streets of the two study areas, in spite of their widely differing characteristics. The delay ratio—the ratio of delay time to total travel time—was developed and used in a level-of-service definition for arterial roadways of the downtown area.

A statistical evaluation of flow data described the variance and distribution of many elements of traffic flow. This study also described the effect of seasonal, daily, and hourly variations of traffic flow, developing information for control of surveys in the downtown areas.

A network analysis study was conducted to evaluate various models for use in analysis of downtown area traffic flows. As a result of this study, Newell's Intersection Model was selected for use in estimating delays at an intersection. Validation tests were performed and the model was accepted for this use. This Signal Analog Model was developed for use in studying offset relationships between adjacent signals. This model, together with conventional time-space diagramming techniques and the SIGOP program, was used in developing the offset relationships between adjacent signals. The major benefit experienced from use of this model was that the network offset relationships are made visible to the designer in three dimensions, so that the effect of any adjustment may be immediately seen at adjacent intersections.

A fine-grain Network Assignment Model was developed for the downtown Newark study area, using the Bureau of Public Roads assignment system. This model was calibrated and found to be useful for analysis of the functional use of downtown streets. This model is comparable in accuracy to similar models commonly used for analysis of urban area traffic problems.

The Network Assignment Model may be used to determine the over-all efficiency of the network. The over-all average travel speed developed from total trip time and total trip mileage outputs of the network can be used to develop a network level of service. It is anticipated that the network level of service may become a useful measure for determining priorities for the allocation of funds in relation to need.

The final report has been published as:

NCHRP Report 113, "Optimizing Flow on Existing Street Networks."

As part of the project a film, "Relief for Tired Streets," was produced. It demonstrates the results that can be obtained by applying sound traffic engineering practices to our nation's urban traffic problems. Loan copies of the film may be obtained through the NCHRP.

Project 3-15 FY '70

Weaving Area Operations Study

Research Agency:	Polytechnic Institute of Brooklyn
Principal Invest.:	Dr. Louis J. Pignataro
Effective Date:	October 1, 1969
Completion Date:	October 31, 1973
Funds:	$300,000

Design criteria for weaving sections on multilane controlled-access highways require revision and updating, taking into account such variables as roadway geometrics, composition of traffic, volumes of mainline vehicles, and volumes of weaving vehicles.

The objective of this research is to analyze and evaluate the procedures recommended in Chapters 7 and 8 of the *1965 Highway Capacity Manual.* Based on the findings the agency is to develop improved techniques for the analysis and design of weaving sections.

The major accomplishments of the study to date are presented in a report covering the first phase of research.

The report is available on a loan basis and includes results of the following analyses:

1. Adequacy of the *Highway Capacity Manual* (HCM) Chapter 7 procedure as a model of the weaving process.
2. Underlying distinctions between the three methodologies of HCM Chapters 7 and 8 (A-C and D-E procedures) applied to weaving situations.
3. Accuracy of the three HCM procedures in predicting levels of service, lane 1 volumes, truck presence in lane 1, and qualities of flow.
4. Consistency of the three HCM procedures in predicting levels of service.
5. Development of a new algorithm for weaving section design and analysis because of inadequacies found in the analyses of items 1 through 4.
6. Development of a Study Program, designed to accomplish complete calibration of the procedure of item 5, and further investigate the effect of weaving parameters.

Principal data collection efforts have been concentrated in the area of furthering the calibration of the algorithm developed during the first phase of research. Data have been collected to eliminate deficiencies in the flow ranges defined by levels of service A, B, and C. Because the proposed algorithm defines centers, rather than boundaries, calibration has become complex and the major thrust in data collection has been directed mainly on levels of service B and C. To ensure a data base covering the fullest possible range of useful lengths, data have been collected for sections ranging from 500 to 3,000 ft in length.

Project 3-16 FY '70

Freeway Lane Drops

Research Agency:	System Development Corp.	
Principal Invest.:	Antranig V. Gafarian	
Effective Date:	Nov. 1, 1969	May 1, 1972
Completion Date:	Apr. 30, 1971	May 31, 1973
Funds:	$99,789	$76,815

It is necessary in some circumstances to change the number of lanes on a freeway. When this change is a reduction in the number of lanes, it results in a "mainline lane drop."

Many variables affect the operating conditions and safety of the various lane drop configurations. Sound criteria for the selection of the proper lane drop design for various traffic and freeway geometric conditions are needed.

Accordingly, the objectives of Phase I were:

1. From field data determine the effectiveness of existing mainline lane drops from the standpoint of safety and traffic operations.
2. Determine the effects of the significant parameters associated with various levels of safety and traffic service.
3. Recommend configurations for lane drops based on the findings of objectives 1 and 2. In this context "configurations" includes distance from the nearest upstream and downstream ramps.

In this research project, three lane drop sites with different geometric configurations were comprehensively evaluated to determine the effects on traffic operations and safety. More than 90 min of aerial film was collected and reduced to produce time histories (trajectories) of the distance, lane position, and velocity of each vehicle passing through the lane drop region. These trajectories were then analyzed to determine space mean speeds and traffic flow by lanes at a number of locations upstream and downstream of the lane drop, and to identify those pairs of vehicles whose relative speeds and separation distances indicated an unsafe condition.

A useful product of this research was the modification of an aerial photographic data collection and reduction system to allow study of the complex interaction of traffic at lane drops, and the development of program routines that compute accurate estimates of the speeds and flows by lane throughout the lane drop area. These routines develop a detailed analytical description of the disruptions in traffic service caused by geometric features such as lane drops.

The data reduction systems and the analysis routines are applicable to the study of configurations other than lane drops, such as exit and entrance ramps, interchanges, and auxiliary lanes.

The report on the initial phase of this research will not be published; however, loan copies are available from the NCHRP Program Director. A summary of the Phase I report was included in "Summary of Progress Through 1971."

Research is being continued with the specific objective of developing a set of lane drop guidelines based on the analysis of descriptive data and traffic operations information from many existing lane drops. Existing design policies for locating lane drop sites will be compared with detailed data on traffic operations at representative lane drop sites.

Progress through December 31, 1972, included the preparation and submission of an interim report for review. This report summarizes the design guidelines obtained from the survey of the state highway departments and the preliminary analysis of the in-place lane drop sites visited.

Project 3-17 FY '71

Improving Traffic Operations and Safety at Exit Gore Areas

Research Agency:	The Pennsylvania State University
Principal Invest.:	James I. Taylor
Effective Date:	January 1, 1971
Completion Date:	March 31, 1972
Funds:	$80,000

Frequency of accidents is usually higher at freeway exit gore areas than at other freeway locations. These accidents tend to be severe at exit gore areas because of factors that include highway fixtures and topographic features. Observations at exit gore areas indicate erratic driving behavior that may be due to deficiencies in driver decision making, information transfer, geometric design, and traffic control devices.

This research project addressed itself to the problem of erratic maneuvers, such as backing-up and stopping in the gore area, that occur with alarming frequency at freeway exit areas. Specifically, it was directed toward answering three basic questions: What factors cause motorists to make erratic maneuvers at exit gore areas? What remedial devices can be employed to reduce their occurrence at existing sites? And, what changes in design and traffic control criteria can be recommended that will minimize the problem at future sites? The results of this study provide answers to these questions, and the findings can be used by traffic and design engineers to enhance the safety and traffic operations at freeway exit facilities.

Initially, a state-of-the-art summary was prepared from a thorough review of past and current research in six related areas: Geometric design, traffic characteristics, accidents, human factors, signing, and delineation. The summary is presented as a series of "lessons learned" in each of the six categories. Another product of the research review is an annotated bibliography that will be useful for continuing research.

Nine exit sites, incorporating different geometric features, were examined for erratic maneuvers during the course of this project. The observed "before" erratic maneuver rates ranged from a low of 0.4 percent (i.e., 4 out of every 1,000 vehicles) to a high of more than 9 percent of the vehicles exiting from the freeway.

Analyses of the patterns of the erratic maneuvers themselves and on-site driver interviews were used to determine causative factors of these maneuvers. The results indicate that more than one factor is usually present at any one site and that these factors vary from site to site.

Remedial measures were installed at eight sites and evaluated on the basis of reductions in erratic maneuvers. Results of these studies show that the frequency of these hazardous maneuvers can be reduced at existing sites through the application of standard traffic control devices. At a number of study sites, improved signing did reduce driver confusion, resulting in safer operations. In a supplemental study, significant improvement in the use of the deceleration lane, as well as reduced nighttime erratic maneuvers, were obtained through improved gore area delineation employing post delineators and raised pavement markers. Also, at two sites improvements were noted with the addition of interchange illumination.

Recommendations concerning changes in traffic control measures and design criteria were developed through the case study approach.

The research has been completed and the final report will be published in the regular NCHRP report series. In the interim, loans copies of the unedited final draft are available on request to the NCHRP Program Director.

Project 3-18(1) FY '71

Improved Control Logic for Use with Computer-Controlled Traffic

Research Agency: Stanford Research Institute
Principal Invest.: Dr. Dale W. Ross
Effective Date: July 15, 1971
Completion Date: October 31, 1973
Funds: $298,698

During the past few years, a large number of general-purpose digital-computer-controlled traffic signal systems have been installed. Although the potential of these systems to improve operations and to increase capacity has been demonstrated, there still exists a sizeable gap between the inherent hardware capabilities, and the know-how (software) necessary to use these systems at optimum efficiency.

The object of this research effort is to study traffic flow and control interaction, and develop an advanced control concept, strategy, and computer program. The research is to include development of an operational control program for calculating offset patterns for a network of signalized intersections that has the capability for independent and variable split adjustment. The program is to be tested and evaluated on an installed system with actual traffic and be applicable to both undersaturated and oversaturated conditions.

The research is proceeding in three phases spanning a two-year period: Phase I—an 8-month planning and initial evaluation phase; Phase II—an 8½-month control program coding and software integration phase; and Phase III—a 9-month implementation and evaluation phase.

The agency has completed development of control logic evaluation methodology, including specifications of the manner in which traffic performance parameters are to be measured using four highly instrumented "floating cars."

Computer programs for evaluation of the collected field data have also been written. Using the travel-time data collected from the "floating car" runs, the existing San Jose signal control has been evaluated, and, in conjunction with simulation of the signal network, the existing signal setting has been "fine tuned." That is, signal offsets, splits, and cycles are being optimized as a function of current time-of-day traffic demands. The "fine tuning" of the existing signal system insures that the research results do not attribute accomplishments to the computer that are rightfully due to re-engineering the fixed-time signal plans to reflect current operating conditions.

An interim report has been submitted and loan copies are available from the NCHRP Program Director.

Project 3-18(2) FY '71

Traffic Control in Oversaturated Street Networks

Research Agency: Polytechnic Institute of Brooklyn
Principal Invest.: Dr. Louis J. Pignataro
Effective Date: September 1, 1971
Completion Date: March 31, 1973
Funds: $100,000

Severe traffic congestion occurs on the street networks in central districts and other high-activity centers of many urban areas. When streets become "jammed," or oversaturated, capacity and operational efficiency are degraded, resulting in suboptimum utilization of existing facilities.

High levels of pedestrian and truck activity intensify the problem. Density of land use in many centers is trending upward; hence, the problem of over-saturated street networks may increase in severity.

Traffic operations and control techniques that function effectively when street network demands are below saturation deteriorate when severe saturation exists for any length of time. Research is needed to define the scope and magnitude of the problem, nationwide; to determine how the problem can best be combatted with existing control techniques; and to begin a systematic research process leading to improved operation and control of oversaturated networks.

The specific objectives are to:

1. Define the measures of network oversaturation and determine the existing scope and magnitude of the oversaturated street-network problem.
2. Define the root causes of the problem.
3. Evaluate the relative effectiveness of existing operations and control techniques used to combat the problem.
4. Prepare detailed operational guidelines for application of existing traffic operations and control techniques of illustrated effectiveness.
5. Describe alternative concepts of advanced traffic-control techniques for improving the efficiency of traffic operation in oversaturated networks.
6. Formulate a detailed plan and program for systematic development, testing, and application of improved traffic control in oversaturated networks.

A detailed literature survey has been conducted to review existing and ongoing research dealing with traffic measurements and their usefulness in characterizing oversaturation. The Highway Research Information Service has been utilized as a basic source of information, as have independent reviews of pertinent periodicals. An annotated bibliography has been prepared. As part of the sensitivity analysis, parameters have been examined for their sensitivity to changes in basic flow components.

The operation of a pair of intersections (one, a critical intersection; the other, an adjacent upstream intersection) has been analytically synthesized using available data on start-up time, headway distributions, queue dissipation, and acceleration. The spread of oversaturation from the critical intersection to the adjacent upstream intersection is being determined. Using the UTCS-1 model simulator recently developed for the Federal Highway Administration, the predictive ability of various parameters to indicate the rate of saturation has been evaluated.

To determine the scope and magnitude of the oversaturation problem, a questionnaire survey has been conducted. Questionnaires were sent to all State highway departments, to all cities of population greater than 50,000 in both the United States and Canada, and to all other cities having a full-time traffic engineer. The survey responses have been tabulated, summarized, and analyzed for general implications.

An interim report has been submitted and loan copies are available from the NCHRP Program Director.

Project 3-19 FY '72

Grade Effects on Traffic Flow Stability and Capacity

Research Agency: Midwest Research Institute
Principal Invest.: Andrew D. St. John
Effective Date: September 1, 1971
Completion Date: November 30, 1973
Funds: $200,000

The nonuniform performance capabilities of vehicles are a major detrimental factor in the flow of traffic on two-lane roads and on multilane highways. The performance differences are more significant on grades and increase the likelihood of traffic instabilities, accidents, and loss of capacity.

The objectives of this research are to:

1. Determine and verify methods for calculating the acceleration and speed-maintenance capabilities on grades of a wide range of motor-vehicle types, including trucks and combinations, buses, campers, housetrailers, low-performance passenger cars, and other atypical vehicles normally found on Interstate and primary highway systems.
2. Determine the factors that create instabilities in the traffic stream on grades. Particular attention is to be given to the role of low-performance and unusual-size vehicles in the creation of these instabilities.
3. Determine, through use of appropriate digital-computer traffic-simulation models and by correlated field measurements, the passenger-car equivalencies for the vehicle types enumerated in objective 1.
4. Determine the effects on safety and traffic flow with both restricted and unrestricted operations of 12- and 14-ft-wide loads on highways in varying terrain. The goal of this objective is to provide guidance for the regulation of these unusual load widths.
5. Estimate, by use of correlations between traffic flow characteristics and accident frequencies, the accident implications for the situations studied in objectives 2 and 4.

Field tests have been conducted on several combinations of passenger sedans with trailers and of pickup-bed campers with trailers to determine their acceleration and speed-maintenance capabilities. Drag strip facilities were used for the tests because they provide an accurately measured course, external timing equipment, and certified scales to weigh each vehicle and trailer.

Field tests have also been conducted on graded sections of public highways. Special recording instruments were attached to each vehicle so that accurate speed and distance profiles could be compiled as the vehicle made routine trips in mountainous terrain.

An interim report concerning traffic operations on a two-lane mountainous road has been submitted and loan copies are available from the NCHRP Program Director.

Project 3-20 FY '73

Traffic Signal Warrants

Research Agency: KLD Associates
Principal Invest.: Edward B. Lieberman

Effective Date: September 1, 1972
Completion Date: November 30, 1973
Funds: $120,000

The purpose of traffic signal warrants should be to determine when the improvement of intersection performance (operation and/or safety) should include the installation of a traffic control signal.

Existing traffic signal warrants as presented in the "Manual on Uniform Traffic Control Devices for Streets and Highways" may not consider all of the factors that should go into a determination of need for traffic signal control, or consider them only in general terms. It is often necessary to temper the numerical warrants with judgment to the degree that the warrants may appear discredited. This is not to say that engineering judgment should be precluded in the decision. Improved warrants should lead to better and more consistent applications.

The objective of this research is to evaluate the adequacy of existing warrants, or the need for revised or additional warrants, in meeting current needs for determining whether a traffic signal should be installed.

Progress through December 31, 1972, included design of field tests, survey of the literature, collection and analysis of data, and initiation of simulation studies to verify the cost effectiveness of the field test methodology.

AREA 4: GENERAL MATERIALS

Project 4-1 FY '63 and FY '64

Development of Appropriate Methods for Evaluating the Effectiveness of Stabilizing Agents

Research Agency: University of Illinois
Principal Invest.: Dr. E. J. Barenberg
Effective Date: June 1, 1963
Completion Date: October 31, 1966
Funds: $114,991

This study was directed toward the further improvement of existing methods or the development of new methods of tests which will lead to a way of measuring the effectiveness of various stabilizing agents. The methods are expected to provide definitive data to predict performance under in-service conditions and provide criteria for the design and construction of pavement components involving stabilized materials.

This research was conducted principally by means of laboratory experiments to investigate the effectiveness of viscous and nonviscous materials as stabilizing agents. Type I portland cement and a penetration-grade asphalt were chosen for the study because of their popularity as reflected in current usage, and limited tests of model pavements stabilized with both these materials were conducted in the research agency's test track for the purpose of correlating the results obtained in the laboratory with the behavior of the model pavements.

Research has been completed. The project report will not be published in the regular NCHRP Report series, but a summary of the contents is included under "Summaries of Unpublished Reports," *Summary of Progress Through June 30, 1968.*

Project 4-2 FY '63 and FY '64

A Study of Degrading Aggregates in Bases and Subbases with Production of Excessive Amounts of and/or Harmful Types of Fines

Research Agency: Purdue University
Principal Invest.: Dr. R. B. Johnson
Dr. N. B. Aughenbaugh
Dr. N. M. Smith
Dr. T. R. West
Effective Date: February 15, 1963
Completion Date: November 30, 1966
Funds: $63,990

This study was directed toward the development of tests or procedures for predicting the amount and effects of aggregate degradation and the development of techniques for upgrading such aggregates for economic use in highway pavement structures.

Numerous aggregate samples were obtained from highway agencies, together with available test data and information on performance experience. Standard laboratory tests, such as determination of specific gravity, freeze-thaw resistance, and Los Angeles abrasion loss, were conducted by the research agency. Many additional data, primarily of a petrographic nature, were also collected. An analysis was made of the standard laboratory data, the petrographic information, and the reported field performance to determine the group of tests most likely to predict the degradation of an aggregate when used in a roadway base or subbase course.

The research has been completed, and the project report has been published as:

NCHRP Report 98, "Tests for Evaluating Degradation of Base Course Aggregates."

Project 4-3(1) FY '63 and FY '66

Development of Methods to Identify Aggregate Particles Which Undergo Destructive Volume Changes When Frozen in Concrete

Research Agency: Virginia Polytechnic Institute
Principal Invest.: Dr. R. D. Walker

Effective Dates:	Mar. 1, 1963	July 1, 1965
Completion Dates:	Sept. 30, 1964	Mar. 31, 1967
Funds:	$20,000	$23,337

Research conducted under this study related to the development of a rapid method of test(s) to distinguish deleterious particles in aggregates and to predict their behavior under various degrees of exposure in concrete subjected to freezing and thawing. The work was similar to that conducted under Project 4-3(2) at Pennsylvania State University (the same objectives apply) but different in approach.

Certain aggregates investigated were common to both studies.

The initial research phase has been completed, and the project report for this phase has been published as:

NCHRP Report 12, "Identification of Aggregates Causing Poor Concrete Performance When Frozen."

The final research phase has been completed, and the project report has been published as:

NCHRP Report 65, "One-Cycle Slow-Freeze Test for Evaluating Aggregate Performance in Frozen Concrete."

Project 4-3(2) FY '63 and FY '66

Development of Methods to Identify Aggregate Particles Which Undergo Destructive Volume Changes When Frozen in Concrete

Research Agency:	The Pennsylvania State University	
Principal Invest.:	Dr. T. D. Larson	
Effective Dates:	Mar. 25, 1963	July 1, 1965
Completion Dates:	Jan. 31, 1965	Aug. 31, 1967
Funds:	$56,457	$49,756

This project involved the development of a rapid test(s) to distinguish deleterious particles in aggregates and thereby predict their behavior under various degrees of exposure in concrete subjected to freezing and thawing. The study was similar to that conducted under Project 4-3(1) at Virginia Polytechnic Institute (the same objectives apply) but different in approach. A number of aggregates investigated were common to both studies.

The initial research phase has been completed, and the project reports for this phase have been published as:

HRB Special Report 80, "A Critical Review of Literature Treating Methods of Identifying Aggregates Subject to Destructive Volume Change When Frozen in Concrete and a Proposed Program of Research," and

NCHRP Report 15, "Identification of Concrete Aggregates Exhibiting Frost Susceptibility."

The final research phase has been completed, and the project report has been published as:

NCHRP Report 66, "Identification of Frost-Susceptible Particles in Concrete Aggregates."

Project 4-4 FY '63

Synthetic Aggregates for Highway Uses

Research Agency:	Battelle Memorial Institute
Principal Invest.:	M. J. Snyder F. F. Fondriest
Effective Date:	March 1, 1963
Completion Date:	April 15, 1964
Funds:	$14,790

In an effort to determine potential sources of aggregates, this study was authorized to explore the feasibility of utilizing artificial aggregates in highway construction. The study involved a survey of various industries regarding their production of potential aggregates, particularly as by-products. Inquiries were made of such users as highway departments as to desirable characteristics for aggregates. Consideration was given to the production of synthetic aggregates by nuclear or other new techniques.

Research has been completed, and the project report has been published as:

NCHRP Report 8, "Synthetic Aggregates for Highway Construction."

Project 4-5 FY '63

A Study of the Mechanism Whereby the Strength of Bases and Subbases Is Affected by Frost and Moisture

Research Agency:	Michigan Technological University
Principal Invest.:	Dr. W. M. Haas
Effective Date:	February 15, 1963
Completion Date:	August 31, 1965
Funds:	$64,105

This project involved an extension of present knowledge and understanding of the phenomena of the action of frost and moisture in bases and subbases. Initially, laboratory models were developed which incorporated significant variables as an aid in analyzing the mechanism of frost action and its relation to strength. Hypotheses evolving from the laboratory were checked in the field.

Research has been completed. The project report will not be published in the regular NCHRP report series, but a summary of the contents of the report is included under "Summaries of Unpublished Reports," *Summary of Progress Through June 30, 1968.*

Project 4-6 FY '65

Protective Coatings for Highway Structural Steel

Research Agency:	Steel Structures Painting Council
Principal Invest.:	John D. Keane
Effective Date:	March 1, 1965
Completion Date:	November 30, 1966
Funds:	$25,000

Considerable information exists in the literature concerning the protection of structural steel from corrosion. This, however, is widely scattered, often contradictory, and has never been critically reviewed and reported on as to which of the numerous coating formulations, coating systems, and practices are best in conjunction with environmental differences. This research involved a state-of-the-art review, field exposure testing on which definitive rankings may be based, and the development of plans for research to acquire needed information where adequate coatings are not available.

Information necessary to review, summarize, and evaluate the current state of the art of protection of structural steel was secured from a search of some 2,000 pieces of technical

literature and by correspondence and discussions with numerous individuals, organizations, and societies both in the United States and abroad. A parallel experimental study was conducted to determine the effects of surface preparation on the performance of coatings.

Research has been completed and the final report has been published as:

NCHRP Report 74, "Protective Coatings for Highway Structural Steel."

In addition, the following documents have been published in extremely limited quantities:

NCHRP Report 74A, "Protective Coatings for Highway Structural Steel—Literature Survey."

NCHRP Report 74B, "Protective Coatings for Highway Structural Steel—Current Highway Practices."

Project 4-7 FY '68, '69

Fatigue Strength of High-Yield Reinforcing Bars

Research Agency:	Portland Cement Association	
Principal Invest.:	Dr. John M. Hanson	
Effective Date:	Oct. 1, 1967	Feb. 1, 1971
Completion Date:	Feb. 28, 1970	Sept. 30, 1972
Funds:	$100,000	$50,000

The AASHO Road Test indicated that the fatigue strength of reinforcing bars is one of the key elements determining the fatigue life of reinforced concrete bridge members. Advances in bridge technology, utilizing high-yield reinforcing bars, increase the possibilities of the fatigue strength of the reinforcement limiting the life of the structure. Reliable test data are not available to support realistic design criteria for the economical use of high-yield-strength reinforcing bars.

The principal objective of this study was to obtain fatigue strength test data on ASTM A432 steel bars (60-ksi yield strength) by the design and execution of a statistically valid experiment with major emphasis on the evaluation of the effect of stress range; minimum stress, including reversal of stress; bar diameter (a minimum range of No. 5 to No. 9 bars); type of specimen; and grade of steel.

Phase I experimental work consisted of repeated-load tests on 231 rectangular or T-shaped concrete beams reinforced with a single longitudinal bar. These specimens contained bars ranging in size from No. 5 to No. 11, and having nominal yield stresses from 40 to 75 ksi. NCHRP Research Results Digest 30 summarizes the results of Phase I.

Phase II had the objectives of (1) determining the effect of surface geometry (deformation pattern and details), and (2) incorporating the results of Phases I and II into a single final report.

The study has been completed and has achieved its objective of providing the evidence necessary to support a design criterion for the fatigue behavior of ASTM A 432 steel reinforcement bars (60,000-psi yield strength). The project report has been received and is in the review stage.

Project 4-8 FY '68

Research Needs Relating to Performance of Aggregates in Highway Construction

Research Agency:	Virginia Polytechnic Institute
Principal Invest.:	Dr. R. D. Walker
Effective Date:	January 1, 1968
Completion Date:	April 30, 1969
Funds:	$55,254

There is concern over the shortage of high-grade aggregates available at reasonable cost in many areas of the country. Efficient use of aggregates is handicapped by lack of quantitative information on the interaction between properties of the aggregate and its performance in a particular environment. The total problem involves (1) identification of the uses for which available aggregates are suitable with normal processing, (2) methods of upgrading available aggregates where necessary to make them acceptable for a particular use, and (3) adapting construction practices to permit use of available aggregates.

The objective of this research was to formulate a comprehensive series of statements of research problems and recommended studies (including estimates of time, cost, and priority) which have as their objective the development of procedures by the use of which a highway materials engineer may evaluate quantitatively the relevant properties of aggregates to be selected for a given class of use, in a given environment of service, for a given level of performance.

Research has been completed and the project report has been published as:

NCHRP Report 100, "Research Needs Relating to Performance of Aggregates in Highway Construction."

Project 4-8(2) FY '71

Density Standards for Field Compaction of Granular Bases and Subbases

Research Agency:	Clemson University
Principal Invest.:	J. P. Rostron
Effective Date:	April 1, 1971
Completion Date:	March 31, 1973
Funds:	$99,981

Information is needed on the degree of compaction that should be attained during the construction of highway granular base and subbase courses as a function of such factors as: nature of the material, environment, traffic, subgrade conditions, thickness of layer, location of layer within the system. Density standards that provide for these factors are needed. Test procedures used to develop data to set such standards must be suitable for various materials, however they may be used, and must account for these factors as may be appropriate. Often the so-called "degree of compaction" (such as 95% AASHO T 180) is not directly related to the materials' properties or to field performance. Improper setting of density standards results in (a) rejection of materials from which satisfactory bases and subbases can be constructed, and (b) construction of bases and subbases that contribute to pavement system failure by subsequent additional compaction.

The objectives of this project are:

1. To evaluate current and proposed procedures and criteria for the setting of density standards to control compaction during construction of granular base and subbase courses.
2. To develop new or revised procedures and criteria, whose employment would permit the setting of more appropriate density standards.
3. To illustrate, from available published and unpublished data, specific examples of inadequate standards, the consequences of such inadequacy, and the manner in which the new or revised procedures and criteria would have avoided such consequences.
4. To illustrate, with respect to specific cases where satisfactory pavement performance has been obtained, that the new or revised procedures and criteria would have yielded equally adequate density standards.
5. To draft, in a form suitable for adoption or adaptation by highway departments, proposed new or revised procedures and criteria for the setting of density standards to control compaction during the construction of granular bases and subbases. Development of acceptance plans to control compaction during construction and/or design procedures is not anticipated.

The research program conducted by the agency to meet these objectives included:

1. A literature survey.
2. An information survey of all State highway departments, to determine current practice regarding granular base and subbase compaction specifications.
3. Interviews with personnel of 30 State highway departments.
4. Laboratory tests involving numerous combinations of the following parameters: (a) six methods of compaction, (b) four aggregate types, (c) six gradations and, (d) two moisture conditions. Four replicates were tested for each combination of parameters.
5. Prototype tests in large-scale laboratory test pits (8 ft x 12 ft in plan view) with a 12-ton vibratory roller to obtain the "ultimate" density.

Research has been completed and the preliminary draft copy of the report is being reviewed by the project advisory panel.

Project 4-8(3) FY '72

Predicting Moisture-Induced Damage to Asphaltic Concrete

Research Agency:	University of Idaho
Principal Invest.:	Dr. Robert P. Lottman
Effective Date:	September 1, 1971
Completion Date:	February 28, 1974
Funds:	$200,000

The phenomenon of adhesion between asphalt cement and aggregate particles in an asphaltic concrete is very complex and not clearly understood at this time. The loss of bond (stripping) due to the presence of moisture between the asphalt and the aggregate is a problem in many areas of the country and is severe from the standpoint of highway pavement performance in some instances. Although the problem is influenced by many factors, such as asphalt characteristics, aggregate properties, mix design, construction procedures, environmental conditions, and traffic, the vast amount of field experience indicates that the presence of moisture in combination with the other factors is most critical with regard to the phenomenon of adhesion between the asphalt cement and the aggregate particles.

Ultimately, identification must be made of the aggregate properties and the asphalt cement characteristics that affect adhesion. This knowledge is basic to the development of techniques that are needed for optimizing the choice of materials or for specifying appropriate corrective measures where loss of bond is likely to be a problem. However, the accomplishment of these ultimate objectives requires fundamental studies that are time consuming and necessitate the development of test systems for correlating the findings with field performance.

The immediate objective is to meet the need for a laboratory testing system that will quantitatively predict the ability of asphaltic concrete to resist the detrimental effects of moisture under field conditions.

The specific objectives of this project are to:

1. Develop a practical laboratory test system for quantitatively predicting the ability of an asphaltic concrete to resist the detrimental effects of moisture under field conditions. The test system shall: (1) be based on previous and current research, field experience, and laboratory experiments, (2) simulate the conditions under which asphaltic concrete pavements must perform in the field, and (3) provide a practical means for accelerated testing of asphaltic concrete to predict the rate of damage due to the effects of moisture for any given set of influencing factors, such as asphalt characteristics, aggregate properties, mix design, construction procedures, environmental conditions, and traffic loading.
2. Conduct a pilot evaluation of the test system involving a laboratory experimental program utilizing information from in-service pavements and existing field experiments exhibiting both good and poor performance histories.
3. Prepare a detailed research plan for a field evaluation study to verify the correlation between predicted performance using the test system and actual field performance.

The primary research program is being conducted by the University of Idaho, with assistance by Battelle-Northwest and the University of Washington.

Experimentation with samples from asphaltic concrete pavements in Arizona, Idaho, and Virginia has provided a tentative laboratory technique for predicting the field response of asphaltic concretes to moisture. A pilot evaluation of the test system utilizing information from pavements showing good and bad performance histories is now in progress through the cooperation of several additional state highway departments.

Project 4-9 FY '69

Evaluation of Preformed Elastomeric Pavement Joint Sealing Systems and Practices

Research Agency:	Utah State Highway Department	
Principal Invest.:	Dale E. Peterson	
Effective Date:	Oct. 1, 1968	Oct. 1, 1972
Completion Date:	June 30, 1971	Dec. 31, 1977
Funds:	$93,494	$125,000

The problem of sealing transverse joints in portland cement concrete pavements to prevent intrusion of objectionable materials is of prime importance to many State highway departments. For several years, a number of States have specified extruded neoprene compression seals for the sealing of these joints. Recently, other types of elastomeric preformed seals have also been used for this purpose. Largely because of a lack of sufficient correlation between joint sealing requirements and field performance information, most existing specifications for preformed seals consist of requirements pertaining to the neoprene elastomer used in fabricating the seal and the size, shape, configuration, etc., of the fabricated product. The relation of these requirements to seal performance in service, or their significance as predicators of performance, has not been fully developed. In view of the increasing use of preformed seals, further laboratory and field studies are required to develop design, material, installation, and performance criteria.

Phase I of this project, through a review and analysis of existing information and an extensive laboratory testing program, has successfully provided urgently needed tentative guide specifications, inclusive of performance criteria, for preformed elastomeric joint seals for use in portland cement concrete pavement joints. This information was reported in NCHRP Research Results Digest 35, "Evaluation of Preformed Elastomeric Pavement Joint Sealing Systems and Practices" (Feb. 1972). The primary experimental program for Phase I was conducted by the Utah State Department of Highways, with analytical assistance from the University of Utah.

The tentative guide specifications provided by Phase I are well suited to interim service. A field research program is now needed to validate the soundness of, or provide appropriate modifications for, the tentative specifications that have been established. This program is being conducted as Phase II of the project.

The objectives of the Phase II work are to:

1. Plan and arrange for the conduct of a field study program using the tentative guide specifications for sealing joints in portland cement concrete pavements developed under Phase I.
2. On the basis of an evaluation of information from the study and other documented research and experience, verify or modify as appropriate the tentative guide specifications developed under Phase I.

The following tasks are being undertaken to accomplish the project objectives:

1. Design an experimental program for field study of the tentative guide specifications for sealing regular sawed transverse contraction joints in portland cement concrete pavements. Joint spacing and climatic conditions are to be the primary variables in the experimental program.
2. Arrange with several highway agencies having personnel experienced in installation of preformed elastomeric seals for the inclusion of portions of the experimental program in portland cement concrete pavement construction.
3. Provide planning, supplemental specifications, procedures, and surveillance for installation of the seals in the experimental sections.
4. Retain samples of the seals used in the experimental sections, arrange for removal of seal samples from the experimental sections, and subject all samples to a laboratory testing program. Samples will be removed at 6, 12, 24, and 48 months after installation, or more frequently if deemed necessary. Force-deflection tests will be the primary method for evaluating the field samples.
5. Collect and evaluate documented information from previous and current research and experience as appropriate to project objectives.
6. Prepare an interim report, essentially in final report format, containing preliminary findings after two years of exposure of the experimental sections.
7. Prepare a final report containing an evaluation of the tentative guide specifications after four years of exposure of the experimental sections. On the basis of the project findings and any other available documented information recommend modifications of the tentative guide specifications as appropriate and develop performance criteria for preformed elastomeric pavement joint seals.

Project 4-10 FY '70

Promising Replacements for Conventional Aggregates for Highway Use

Research Agency:	University of Illinois
Principal Invest.:	Dr. C. R. Marek
Effective Date:	October 15, 1969
Completion Date:	March 31, 1971
Funds:	$50,000

Although nationally there is an abundant supply of conventional aggregates suitable for highway construction, there are localized areas, and in some cases regions, in which they are not economically available or are becoming depleted. The problem is compounded because many of the existing sources are becoming unavailable through zoning restrictions, pollution control, and appreciating land values.

It is imperative that studies now be initiated to determine whether this technology can be used to alleviate the problem of diminishing aggregate supplies in the affected areas.

The purpose of this project was to study the utilization of modern technology as it might apply to the development of substitute materials and/or new procedures for upgrading existing unsuitable materials for use as aggregates in portland cement concrete, bituminous mixes, and base courses.

The research has been completed and the project report has been published as:

NCHRP Report 135, "Promising Replacements for Conventional Aggregates for Highway Use."

Project 4-10A FY '70

Waste Materials as Potential Replacements for Highway Aggregates

Research Agency:	Valley Forge Laboratories
Principal Invest.:	Richard H. Miller
Effective Date:	Sept. 1, 1972
Completion Date:	Nov. 30, 1973
Funds:	$49,942

Although an abundant supply of conventional aggregates suitable for highway construction exists nationally, there are localized areas, and in some cases regions, in which aggregates are not economically available or are becoming depleted. The problem is compounded by the loss of existing sources through zoning restrictions, pollution controls, and appreciating land values.

The use of waste material as aggregate offers one method of alleviating this problem in highway construction where suitable sources are available in significant quantities. Such utilization will serve the public interest by providing ecologically and economically acceptable means for disposal of wastes in addition to providing replacements for needed aggregates in urban areas where the shortage is often most severe. Research is needed now to determine the types, sources, and quantities of waste materials potentially useful as replacements for highway aggregates.

NCHRP Project 4-10, "Promising Replacements for Conventional Aggregates for Highway Use," identified the potential for using waste materials as aggregate in highway construction. The objectives for Project 4-10A, as developed from the prior effort, are to:

1. Provide an inventory of the types, sources, and quantities of waste materials potentially suitable for the production of synthetic aggregates or for otherwise replacing conventional aggregates in highway construction.
2. Provide an assessment of the prospects for practical use of specific waste materials for production of synthetic aggregates or otherwise replacing the need for conventional aggregates in highway construction, particularly where aggregate supplies are scarce.

The accomplishment of project objectives will involve the following tasks:

1. Identification of all types and locations of waste materials available or anticipated to be available in the future in significant quantities that are considered potentially suitable for use in highway construction as replacements for conventional aggregates.
2. Compilation of information essential to evaluating the technical and economic feasibility of using the most promising waste materials as replacements for aggregates in highway construction.
3. Based on the information compiled in Task 2, an assessment of the technical and economic feasibility of current and future use of the waste materials having the greatest potential for use as replacements for aggregates in highway construction, particularly where conventional aggregates are not economically available or are becoming depleted.
4. Determination of the status of use of waste materials in highway construction as replacements for aggregates.

AREA 5: ILLUMINATION AND VISIBILITY

Project 5-2(1) FY '63

Effects of Illumination on Operating Characteristics of Freeways—Traffic Flow, Driver Behavior, and Accidents

Research Agency:	Yale University, Bureau of Highway Traffic	
Principal Invest.:	Fred W. Hurd	
Effective Dates:	Feb. 15, 1963	Feb. 1, 1967
Completion Dates:	May 31, 1966	July 31, 1967
Funds:	$124,319	$21,530

Because of insufficient information on the requirements in freeway illumination, thorough research needs to be performed. A scientific basis for warrants and design criteria for use in installing continuous and localized lighting on freeways is needed, as is evaluation in terms of benefits and costs.

A 5-mile segment of the Connecticut Turnpike in the Bridgeport area was selected for the study site. The light intensity was changed to reflect illumination at both the 0.2 and 0.6 average horizontal footcandle levels. The same study area has been used for Projects 5-2(2) and 5-2(3).

Yale University has evaluated the day and night operating characteristics of traffic flow, driver behavior, and accidents. Traffic characteristic data from more than 400,000 picture frames were transferred to punched cards, and analyzed by an electronic computer. Information was obtained on lane use, variation of placement and velocity, headway distributions, vehicle clustering by type, and use of the on-ramp. Evaluations of day and night accident data and traffic volume data have been made.

The project report has been published as:

NCHRP Report 60, "Effects of Illumination on Operating Characteristics of Freeways."

Project 5-2(2) FY '63

Effects of Illumination on Operating Characteristics of Freeways—Driver Response, Visibility, and Visual Discomfort

Research Agency:	The Ohio State University
Principal Invest.:	Dr. Thomas H. Rockwell Dr. H. Richard Blackwell
Effective Date:	February 15, 1963
Completion Date:	August 31, 1965
Funds:	$81,187

The objectives of this research supplemented Project 5-2(1), the accent in this contract being on the characteristics of driver response, visibility, and visual discomfort.

In conducting its research, Ohio State made interdisciplinary personnel and resources available. The instrumented vehicle utilized in Project 3-3 was also used in this project, as were various types of lighting and optical instruments developed by The Ohio State University. This project was coordinated with Project 5-2(1) for the phases of the work that were conducted on the Connecticut Turnpike site.

The driver response and roadway luminance data were transformed from the oscillograph record from the survey vehicle to numerical records for the studies conducted on the Connecticut Turnpike. Analytical procedures were prepared to provide a cross-correlation of driver control activity with roadway geometry, traffic density, subject characteristics, and illumination levels. The analysis tested the correlation of driver variables with the severity of disability glare, and studies were conducted to see if any change in the visual environment was effected by the light intensity change.

The results presented in the project report have been combined with the results of Project 5-2(1) and have been published as:

NCHRP Report 60, "Effects of Illumination on Operating Characteristics of Freeways."

Project 5-2(3) FY '63

Effects of Illumination on Operating Characteristics of Freeways—Driver Discomfort

Research Agency:	The Institute for Research at State College, Pennsylvania
Principal Invest.:	Dr. Paul M. Hurst
Effective Date:	February 20, 1963
Completion Date:	February 28, 1966
Funds:	$37,460

As with Project 5-2(2), this research complemented that of Project 5-2(1). This study was concerned with only one aspect, that of driver comfort as related to anxiety as measured under various lighting conditions. The Institute for Research, a private research agency located at State College, Pennsylvania, obtained research data from motorists driving through the test area of the Connecticut Turnpike. Driver-questionnaire information was used to determine apprehension based on a numerical score and also to locate those events related to illumination which appeared to be most vexing to drivers.

The analysis included nonparametric tests of the effects of illumination, weather, moon brightness (as a function of elevation and phase), traffic volume, driver experience, driver familiarity, and day vs. night upon DDS scores and NTD scores.

The results presented in the project report have been combined with the results of Project 5-2(1) and have been published as:

NCHRP Report 60, "Effects of Illumination on Operating Characteristics of Freeways."

Project 5-3 FY '64

Visual Information Needed by the Driver at Night

Research Agency:	The Ohio State University
Principal Invest.:	Dr. Thomas H. Rockwell Dr. Ronald L. Ernst
Effective Date:	September 1, 1964
Completion Date:	March 31, 1967
Funds:	$100,940

This research was designed to determine minimum information necessary to maintain control stability and identify the information which is normally used. Visual degradation studies were conducted to determine limits of performance stability based on driver performance criteria previously established. Mapping of the visual field through selective degradation was conducted to identify classes of information used by nighttime drivers. Research was conducted to determine times and distances to satisfy information needs for optimal control. Visual cues were scaled by photometric calibration of viewed object contrasts and edge markings. An eye marking unit was employed to assess relative cue importance in maintaining performance. An attempt was made to formulate the effect of freeway informational features on driving performance based on perceptual and highway design factors.

The project report has been published as:

NCHRP Report 99, "Visual Information Needed by the Driver at Night."

Project 5-4 FY '64

Economic Study of Roadway Lighting

Research Agency:	The Franklin Institute
Principal Invest.:	Arno Cassel
Effective Date:	July 20, 1964
Completion Date:	August 31, 1965
Funds:	$19,412

The purpose of this project was to determine capital cost ranges and operating costs for prevailing light sources in relation to type of luminaire distribution system and light intensity on the pavement.

The researchers collected data for economic comparisons, including costs for hardware, installation, useful operating life, power, maintenance, depreciation, taxes, insurance, and financing for various lighting systems. Sample type and quantity of equipment were analyzed to provide standard illumination levels on typical two-lane, four-lane, and six-lane divided highways. A literature search was made of available lighting cost studies, specifications, design criteria for highway lighting installations, maintenance, and replacement factors. Methods for evaluating capital improvement proposals were reviewed, and the annual cost method appeared to be most suitable for evaluating costs of different roadway lighting configurations. Questionnaires were received from public utility companies, municipalities, and State highway departments to acquire cost information.

The project report has been published as:

NCHRP Report 20, "Economic Study of Roadway Lighting."

Project 5-5 FY '65

Nighttime Use of Highway Pavement Delineation Materials

Research Agency:	Southwest Research Institute	
Principal Invest.:	John M. Dale	
Effective Dates:	Mar. 1, 1965	July 15, 1967
Completion Dates:	Dec. 31, 1966	Sept. 15, 1969
Funds:	$50,000	$100,000

Many pavement marking materials in common use lose their effectiveness to a marked degree during periods of darkness in adverse weather. A driver's need for guidance is most critical during these periods and ease of driving and highway safety will be enhanced when effectiveness of pavement delineation under adverse weather conditions approaches the effectiveness provided under normal conditions. In this study, ways of improving delineation of roadways under wet and dry conditions by either improving techniques utilizing existing materials or developing new materials and techniques were investigated.

This program was initiated by a field study of the performance characteristics of conventional marking materials. Following this, the researchers conducted studies of the physical nature of reflective materials with particular emphasis on their performance characteristics under various types of water films. Attention was directed to the development of a systematic approach to marking pavements wherein one qualifies the surface to be marked, determines the water film thicknesses to be encountered, and then selects one of several marking systems that will perform under the imposed conditions.

The project report on the laboratory phase of the research has been published as:

NCHRP Report 45, "Development of Improved Pavement Marking Materials—Laboratory Phase."

The purpose of the continuation phase was to further develop, optimize, and field test the new marking system that emerged from the initial research effort.

A two-man, self-propelled machine similar to a normal paint machine has been developed and constructed. This equipment pumps the viscous epoxy material and the fluid catalyst to the application gun. At the gun the two materials are accurately mixed and immediately applied to the roadway through a specially designed nozzle. Major field testing of the experimental marker throughout the U.S. was completed. Experimental markers were placed on highways, for long-term observation, in California, Oregon, Washington, Wyoming, Illinois, Michigan, Pennsylvania, Connecticut, North Carolina, Florida, Texas, and Missouri.

The project report on the field phase of the research has been published as:

NCHRP Report 85, "Development of Formed-in-Place Wet Reflective Markers."

In addition to the final report, a motion picture film was produced describing the results of the research. Loan copies of the film are available from the NCHRP Program Director.

Project 5-5A FY '71

Development of Optimum Specifications for Glass Beads in Pavement Markings

Research Agency:	The Pennsylvania State University
Principal Invest.:	Dr. Luke M. Shuler
Effective Date:	May 1, 1971
Completion Date:	April 30, 1973
Funds:	$100,000

This study is a continuation of recommended research based on the findings of Project 5-5 as reported in NCHRP Report 45. Effective utilization of glass beads used for reflectorization of pavement marking materials is dependent on a number of variables that are not fully understood or defined. As a result, various bead gradations and compositions, thicknesses and composition of the binder, bead surface treatments, rates of application, and so forth, are used today. A better understanding of the principles surrounding performance of glass beads in traffic paint markings is necessary if delineation techniques are to be improved and maximum benefits are to be derived from use of glass beads.

Specific objectives are to:

1. Review and analyze world-wide research and practices involving the use and manufacture of traffic marking beads.
2. Identify those variables that markedly influence the effective utilization of glass beads in pavement markings. Evaluate these variables by laboratory and field tests as required in order to rate them in terms of their influence on the effectiveness and serviceability of delineation under actual traffic conditions. Field tests are to include measurements of wet-nighttime reflectivity.
3. Determine the capability and economics of producing glass beads of specified gradation, composition, shape, flow properties, color, etc.
4. Develop practical specifications and criteria for the selection and use of beads for reflectorizing traffic paint markings.
5. Evaluate for one or more states the probable benefits that would accrue should the proposed specifications be adopted in place of current specifications.

The literature search and survey of current practice portion of the project have been completed. The latter included visits to state highway departments and glass bead manufacturing plants. A quantitative study of the behavior of retroreflecting glass spheres in horizontal markings by calculations from general mathematical optical theory has been completed. Properties of the glass beads that were included in the calculations are refractive index, depth of embedment in binder, light-scattering properties of the

bead-binder interface, diameter, shape, clarity of color, and mutual shadowing of spheres. The results of the optical calculations are being used to develop optimum glass bead specifications by providing comparison between the calculations and field experience.

The first season test lines have been installed and evaluations are under way. These tests were relatively general and exploratory, and involved mainly standard commercial products and common application rates. The test lines were installed on portland cement concrete and bituminous concrete, paint binder thickness was 10, 15, and 20 mils, and the glass bead samples included flotation-type beads and conventional beads having refractive indices of 1.6 and 1.9.

Progress through December 31, 1972, included submittal of an interim report and a questionnaire survey of glass beads users. Questionnaires were sent to all state highway departments and the responses have been tabulated, summarized, and analyzed for general implications.

Loan copies of the interim report are available from the NCHRP Program Director.

Project 5-5B FY '72

Pavement Marking Systems for Improved Wet-Night Visibility Where Snowplowing is Prevalent

Research Agency: Texas A & M Research Foundation
Principal Invest.: Dr. William M. Moore
Effective Date: September 1, 1971
Completion Date: August 31, 1974
Funds: $200,000

Conventional reflectorized pavement marking systems in common use lose their effectiveness markedly during periods of darkness in rainy weather. Raised reflectorized markers are quite effective under such circumstances and are in use where exposure to snowplows is not a factor. However, such markers may be quickly dislodged or destroyed in a large part of the U. S. where snowplowing is common during the winter months. Past and current research to achieve wet-night pavement delineation compatible with snowplowing operations includes: Low-profile, large-bead marking systems; combined longitudinal grooving and striping; rubber-tipped snowplow blades compatible with raised marking systems; so-called "snowplowable" raised markers; thickly applied corrugated thermoplastic stripes; and various U.S. and foreign wet-weather pavement delineation devices and concepts. To a large extent, none of these developments and concepts has been fully accepted or utilized because of restricted applicability, limitations in performance and cost, or limited degree of development and practicality. Thus, there remains a continuing need for additional research to explore further the development of alternative, innovative, and practical pavement marking systems that are economically feasible, effective under wet-weather conditions, and, at the same time, compatible with snowplowing operations.

Accordingly, the objectives of this research are:

1. Develop one or more innovative concepts for pavement marking systems that are practical, economical, and effective under nighttime wet-pavement conditions and compatible with snowplowing.

2. Conduct a laboratory and controlled field evaluation of the system(s) developed in objective 1 and demonstrate its (their) practical and economic feasibility.

The researchers have completed making a detailed state-of-the-art review of literature, current practices, and innovative concepts. Preliminary evaluation of the feasibility of the more promising innovation concepts is complete. A few of the innovative concepts being studied are: pavement pretreatment for conventional paint striping, low-cost formed-in-place markers, magnetic markers, snap-over markers, complainant markers, protruding reflectors, electrically powered emissive markers, and a radioactive emissive marker. With the completion of the feasibility studies of these and other innovative concepts, laboratory prototypes have been constructed and highway field tests have been initiated at test sites in Pennsylvania and Virginia.

Progress through December 31, 1972, included submittal of an interim report that summarizes accomplishments in this study to date. Loan copies are available from the NCHRP Program Director.

Project 5-6 FY '68

Highway Fog

Research Agency: Cornell Aeronautical Laboratory
Principal Invest.: W. C. Kocmond
K. Perchonok
Effective Date: October 2, 1967
Completion Date: April 30, 1969
Funds: $99,955

A state-of-the-art summary was completed. The summary shows that highway fog has had the following effects: (1) a slight reduction in accident frequency, (2) an increase in the likelihood that an accident will result in a fatality, and (3) an increase in the likelihood that accidents will involve either a single vehicle or more than three vehicles.

Traffic measurements made during this program indicate that: (1) speeds were slightly lower in fog, (2) the probability of overdriving one's visual range was greatly increased, and (3) lateral location and vehicle interactions were not affected by fog. It was concluded that drivers exercise more caution in fog, but that the increase in overdriving probably explains the increased severity of accidents.

Field tests have demonstrated that visibility in dense fog can be improved by seeding with practical amounts of carefully sized hygroscopic material. Additional studies are needed to refine seeding procedures and to determine the scope of application for highway fog abatement. Other concepts (e.g., vegetation barriers to influence the movement of shallow fog, monolayers to inhibit evaporation from water reservoirs, use of helicopters to mix drier air with fog) have limited application and may be tailored to spe-

cific types of highway fog. These concepts were discussed in the text.

Previously suggested vehicle guidance procedures were studied. It was determined that at least two types of roadway lighting systems can be used to effectively provide illumination for night driving in fog. The lighting techniques include: (1) specially designed lights mounted near the road surface, producing an area of illumination directed about 110° to the direction of traffic flow and (2) overhead street lamps having a narrow beam spread with the beam of illumination perpendicular to the driver's line of sight.

A vehicle guidance system involving the use of polarized headlamps was evaluated in field experiments and judged impractical as an aid to drivers in fog. Measurements of the effect of vehicle lighting on visibility showed that rear lighting systems can be improved to allow better detection of vehicles in fog.

The project report has been published as:
NCHRP Report 95, "Highway Fog."

Project 5-6A FY '70

Highway Fog

Research Agency:	Sperry Rand Corporation
Principal Invest.:	James O. Dyal Richard T. Brown
Effective Date:	September 1, 1970
Completion Date:	November 30, 1972
Funds:	$95,195

This research is a continuation of NCHRP research in the general area of highway fog. The major objectives of the research are to:

1. Analyze the highway fog problem and determine the day and night fog levels (standards of visibility) that produce significant detrimental effects on driver performance and traffic operations.
2. Explore the feasibility of active and passive guidance systems for freeways and expressways that will inform and warn the motorist of prevailing roadway fog and traffic conditions ahead, and guide and control traffic more safely and conveniently through the fog area.

The research was addressed principally to the first objective and developed a measurable fog visibility index and related this index to potential actions that can be taken to eliminate or minimize the detrimental effects of fog. Cooperative arrangements made with the New Jersey Turnpike Authority allowed the investigators to conduct verification tests and obtain measurements of traffic operations during foggy roadway conditions.

The accomplishments of the study are partly reflected in the agency's interim report covering the work completed during 1970 and 1971. The report presents details of the instruments developed to measure fog visibility and describes the results of the studies to determine the day and night fog levels that affect driver performance and traffic operations. Loan copies of the interim report are available from the NCHRP Program Director.

A draft final report has been submitted and is in the review and revision stage.

Project 5-7 FY '69

Roadway Delineation Systems

Research Agency:	The Pennsylvania State University
Principal Invest.:	Dr. J. I. Taylor
Effective Date:	October 1, 1968
Completion Date:	June 30, 1971
Funds:	$469,526

Present delineation techniques include the use of paint markings, inset lights, reflective delineators, raised markers, surface treatments, curbs, rumble strips, and colored pavements. Only limited information is available concerning the effectiveness of these devices. Conditions that warrant the installation of the particular type of delineation treatment have not been defined.

Vehicles running off the road constitute a substantial portion of the accidents on the nation's highways. Improved pavement and roadway delineation treatments may aid drivers in controlling their vehicles, thus improving the safety aspects of the highway and easing the driving task, especially during adverse weather conditions and at night.

Accordingly, the objectives of this research were: (1) to review past and current research pertaining to roadway delineation; (2) to prepare a state-of-the-art summary of the review; (3) to determine the driver's delineation requirements during various conditions, such as traffic, weather, highway geometry, and illumination; (4) to establish rational technique(s) for determining the effectiveness and any detrimental side effects of delineation treatments and, using the technique(s) established, evaluate existing and proposed delineation systems; (5) to test the more promising delineation systems; (6) to develop practical criteria for the selection of delineation treatments, including factors of cost effectiveness and maintenance problems; and (7) to compare the physical characteristics and performance of colored pavements with those of conventional asphalt and portland cement pavements.

A comprehensive state-of-the-art summary covering the application of various delineation treatments to highway situations, delineation material properties, the human factors literature pertinent to delineation, and cost effectiveness considerations was compiled. Emphasis was placed on current practices—particularly departures from the standard manuals—and recent research findings. Foreign practices and research results were also included.

Specific driver performance requirements at eight "classical" geometrical situations were defined. An information-decision-action (IDA) task analysis procedure was utilized to translate performance requirements to information requirements.

The experimental program consisted of two major types of studies. Laboratory studies, conducted primarily by experimental psychologists, were carried out to develop and

evaluate concepts basic to all delineation requirements, such as positive vs. negative delineation, clutter of the visual environment, overdelineation, target value, and the various aspects of color and shape coding. Field experiments were conducted under naturalistic conditions to evaluate the effectiveness of specific treatment at specific situations. Studies included the use of post delineators and/or raised pavement markers at horizontal curves, the use of colored pavements, variations in center-line marking patterns, and variations in color and spacing of post delineators at stop approaches.

Recommendations for application of the various treatments at each of the "classical" situations were made based on these studies, discussions with other researchers and practicing engineers, and careful review of the literature.

The research has been completed and the final report has been published as:

NCHRP Report 130, "Roadway Delineation Systems."

Project 5-8 FY '70

Warrants for Highway Lighting

Research Agency:	Texas A & M University Research Foundation
Principal Invest.:	Neilon J. Rowan Ned Walton
Effective Date:	March 16, 1970
Completion Date:	June 15, 1972
Funds:	$199,627

A need exists to establish warrants for fixed roadway lighting on the various classes of roadways in both urban and rural areas; whether the lighting should be continuous or just at specific locations; and guidelines for the design of lighting. Much information on these matters is contained in the literature, but some additional research will be necessary where insufficient data exist. Benefits from fixed-source roadway illumination, including driver performance, comfort, convenience and accident prevention, need to be evaluated.

Warrants for fixed lighting on specific roadway classes and at local highway situations should include consideration of benefits and costs of lighting (initial and operating) to satisfy the visual requirements of the driver. A method or methods of evaluating costs and benefits of roadway lighting to maximize returns on the investment should be developed for the designer in order to determine the specific design.

The specific objectives of this project were to:

1. Review and analyze world-wide research and practice in roadway lighting. Prepare a state-of-the-art summary of the review.
2. Develop requirements for a suitable visual environment to be obtained by fixed roadway lighting for safe and efficient traffic operations. Provide guidelines for the design of fixed roadway lighting to obtain this environment.
3. Evaluate the possible benefits derived when a suitable visual environment is provided by fixed roadway lighting.
4. Determine warrants (the minimum conditions) for where fixed roadway lighting systems should be installed for continuous lighting and at specific locations including, but not limited to, interchanges and intersections.
5. Analyze the role of cost-effectiveness and other evaluation techniques in (a) establishing the need for fixed roadway lighting, (b) setting priorities for fixed lighting projects, and (c) evaluating alternative designs of lighting.
6. Recommend a method of setting priorities for the installation of fixed lighting.
7. Provide typical example(s) of where lighting is warranted and demonstrate the practical application of objectives 1 through 6.

A detailed state-of-the-art study indicated the complex relationships that exist within the over-all design process for roadway lighting. A total design process was developed for roadway lighting based on a conceptual framework of improving the efficiency of night visual communications on traffic facilities through the provision of informational needs.

The driver's informational needs were established by the diagnostic team approach and classified on the basis of geometric, operational, and environmental conditions. These classifications were developed to be the manner in which a facility is evaluated for lighting needs and minimum warranting conditions.

A method of determining the design level of lighting intensity has been suggested that indicates that benefits or effectiveness be measured in terms of supplying informational needs.

The project final report has been accepted for publication. In the interim, loan copies are available from the NCHRP Program Director.

AREA 6: SNOW AND ICE CONTROL

Project 6-1 FY '63

Development of Economical and Effective Chemical Deicing Agents to Minimize Injury to Highway Structures and Vehicles

Research Agency:	IIT Research Institute
Principal Invest.:	D. B. Boies
Effective Date:	February 15, 1963
Completion Date:	September 30, 1964
Funds:	$40,000

Research was directed to the development of chemical agents that are not only economical and effective when used as deicing agents but also have minimal harmful effects on metals and concrete. Consideration was given to the relatedness of laboratory tests to field conditions.

The project report has been published as:

NCHRP Report 19, "Economical and Effective Deicing Agents for Use on Highway Structures."

Project 6-2 FY '63

Nonchemical Methods for Preventing or Removing Snow and Ice Accumulations on Highway Structures

Research Agency: Roy Jorgensen and Associates
Principal Invest.: R. E. Jorgensen
R. D. Johnson
Effective Date: February 15, 1963
Completion Date: February 29, 1964
Funds: $25,000

This study was primarily one of searching the literature and appraising the current status of knowledge of the subject. In addition to a literature survey, contacts were made with highway departments and other agencies that have been confronted with the problem. Designs for structure heating systems as used in the U.S. and other countries have been evaluated, as have other nonchemical methods. The researchers have included in their studies the effectiveness of nonchemical methods and economic losses due to structure deterioration.

The project report has been published as:

NCHRP Report 4, "Non-Chemical Methods of Snow and Ice Control on Highway Structures."

Project 6-3 FY '63

Development and Evaluation of Protective Coatings to Prevent Deterioration of Concrete Structures by Deicing Agents

Research Agency: Battelle Memorial Institute
Principal Invest.: M. J. Snyder
Effective Date: March 1, 1963
Completion Date: February 28, 1965
Funds: $58,557

Investigations on this project were oriented toward developing new and evaluating existing materials to be applied to concrete surfaces to inhibit concrete deteriorations from deicing agents. Consideration was given to fresh as well as hardened concrete.

The project report has been published as:

NCHRP Report 16, "Protective Coatings to Prevent Deterioration of Concrete by Deicing Chemicals."

Project 6-4 FY '63

Evaluation and Development of Methods for Reducing Corrosion of Reinforcing Steel

Research Agency: Battelle Memorial Institute
Principal Invest.: A. B. Tripler, Jr.
Effective Date: March 1, 1963
Completion Date: April 30, 1965
Funds: $39,330

Research investigations for this project related to an appraisal of existing methods for inhibiting corrosion of reinforcing steel in concrete. Consideration was given to such methods as (1) coatings on reinforcing bars, (2) inhibitors in concrete mixtures, (3) inhibitors in deicing chemicals, and (4) cathodic protection.

The project report has been published as:

NCHRP Report 23, "Methods for Reducing Corrosion of Reinforcing Steel."

Project 6-5 FY '63

Study of Physical Factors Influencing Resistance of Concrete to Deicing Agents

Research Agency: University of Illinois
Principal Invest.: Prof. C. E. Kesler
Effective Date: March 1, 1963
Completion Date: August 31, 1965
Funds: $72,500

This research concerned the relationships between the physical characteristics of concrete and the susceptibility of concrete to damage from freezing and thawing in the presence of free moisture and deicing agents. Studies were made of the effects of varying concrete production methods on potentially durable concrete. Variations in the surface porosity, strength, and air-void system produced by differing finishing techniques were evaluated for typical air-entrained concretes. Large- and small-scale specimens were cast and effects of period and time of finishing, environmental conditions, and additions of water during finishing were evaluated using surface scaling tests, surface tensile strength tests, and microscopical determination of surface air-void parameters.

This project has been completed, and the report has been published as:

NCHRP Report 27, "Physical Factors Influencing Resistance of Concrete to Deicing Agents."

Project 6-6 FY '63

To Evaluate Existing Methods and/or Develop Improved Methods for the Measurement of Certain Properties of Concrete

Research Agency: The Ohio State University
Principal Invest.: Prof. R. W. Bletzacker
Effective Date: March 1, 1963
Completion Date: February 28, 1966
Funds: $69,393

In order to insure that finished concrete will conform to those specifications selected to produce adequate resistance to deicing agents, this study was initiated to evaluate and/or develop methods for securing pertinent quality control information at the earliest desirable or feasible age in order that any necessary corrective measures can be applied to the work in progress. Specifically, the study concerned the factors of (1) air content and uniformity of distribution, (2) cement content and uniformity of distribution, (3) water content and uniformity of distribution, and (4) thickness of cover over reinforcement.

Research has been completed. The project report will not be published in the regular NCHRP Report series, but a summary of the contents was included in the "Summaries of Unpublished Reports," *Summary of Progress to June 30, 1967.*

Project 6-7 FY '63

Estimation of Disintegration in Concrete Structures

Research Agency: Geotechnics
Principal Invest.: Floyd O. Slate
Effective Date: March 1, 1963
Completion Date: August 31, 1964
Funds: $8,547

This study involved the development of instruments and method(s) for field use to detect and determine the extent of disintegration of structural concrete. The method(s) should be able to delineate area and depth within an accuracy of approximately 10 percent.

The contract was terminated with no project report. Research was resumed under Project 6-7A.

Project 6-7A FY '63

Estimation of Disintegration in Concrete Structures

Research Agency: IIT Research Institute
Principal Invest.: Dr. W. J. McGonnagle
Effective Date: February 1, 1965
Completion Date: July 31, 1966
Funds: $44,614

This research study involved the development of instruments and method(s) for field use to detect and determine the extent of disintegration of structural concrete. The method(s) should be able to delineate area and depth within an accuracy of approximately 10 percent.

Research has been completed. The project report will not be published in the regular NCHRP Report series, but a summary of the contents was included in the "Summaries of Unpublished Reports," *Summary of Progress to June 30, 1967.*

Project 6-8 FY '63

Evaluation of Methods of Replacement of Deteriorated Concrete in Structures

Research Agency: Bertram D. Tallamy Associates
Principal Invest.: Dr. B. D. Tallamy
Effective Date: February 15, 1963
Completion Date: February 29, 1964
Funds: $25,000

This study was directed toward a search of available literature and a canvass of agencies that have been known to employ methods of repair of structural concrete. The researchers attempted an evaluation of the economics and adequacy of the various methods to accomplish the job. Recommendations were made of areas requiring further study.

The project report has been published as:

NCHRP Report 1, "Evaluation of Methods of Replacement of Deteriorated Concrete in Structures."

Project 6-9 FY '64

Potential Accelerating Effects of Chemical Deicing Damage by Traffic and Other Environmental-Induced Stresses in Concrete Bridge Decks

Research Agency: University of Illinois
Principal Invest.: Prof. Clyde E. Kesler
Effective Date: January 1, 1965
Completion Date: June 15, 1968
Funds: $200,000

Some present bridge designs allow a degree of flexibility, which, under traffic and other environmental forces, may cause cracking and opening of existing cracks. This of itself may be structurally unimportant, but in the presence of deicing chemicals may contribute to corrosion of the reinforcing and spalling of the concrete by providing access channels for the corrosive agents. Stresses induced by traffic may augment those of frost action sufficiently to cause scaling in cases where a satisfactory performance would otherwise be expected. The objectives of this research were to establish by laboratory studies the relationships between performance and displacement in bridge-deck slabs. Air-entrained reinforced concrete deck slabs with restraints similar to those experienced by slabs on structural steel and reinforced concrete beam-type bridges were investigated, and tests were conducted on replicas of actual bridge-deck slabs. Loading and environmental conditions in these tests simulated those encountered in the field.

The final report has been published as:

NCHRP Report 101, "Effect of Stress on Freeze-Thaw Durability of Concrete Bridge Decks."

Project 6-10 FY '68 and FY '69

Develop Improved Snow Removal and Ice Control Techniques at Interchanges

Research Agency:	Bertram D. Tallamy Associates
Principal Invest.:	L. G. Byrd
Effective Date:	September 1, 1967
Completion Date:	September 30, 1970
Funds:	$95,000

The variety of geometrical shapes of interchange ramps, with associated structures, and their urban or rural locations invariably creates problems with respect to optimum snow removal and ice control techniques in the interchange areas. Furthermore, alternate freezing and thawing of plowed or unplowed snow across superelevated ramps contributes to problems in snow and ice control. Drifting may further aggravate this problem. Improved snow removal and ice control techniques in interchange areas are vital to the safety of highway traffic.

The purpose of this study was to identify and evaluate the specific problems associated with snow removal and ice control operations at interchanges and to recommend methods for alleviating the problems. The investigation has been completed and both physical and operational factors that influence winter maintenance operations at interchanges have been listed in the project report. Design considerations and operational procedures aimed at alleviating the problem have been described in a manual submitted as part of the final report.

The project report has been published as:

NCHRP Report 127, "Snow Removal and Ice Control Techniques at Interchanges."

Project 6-11 FY '71

Economic Evaluation of the Effects of Ice and Frost on Bridge Decks

Research Agency:	Midwest Research Institute	
Principal Invest.:	Robert R. Blackburn	
Effective Date:	Sept. 1, 1970	Sept. 12, 1972
Completion Date:	Nov. 30, 1971	Mar. 11, 1974
Funds:	$50,000	$50,000

Ice or frost on bridge decks while the approach pavements remain ice- or frost-free has been accepted as a safety hazard in many states. Although little hard evidence has been presented to indicate the extent of the problem, maintenance practice and research on various preventive or remedial techniques often assumes it to be significant. There is a need to quantify the problem as a basis for rational decisions concerning the economics of design and maintenance practices. The total cost of potential accidents, assuming no special design or maintenance practice, needs to be balanced against added design or increased maintenance costs incurred in preventing or remedying ice or frost on bridge decks. There is a need to develop a methodology, including cost-benefit or cost-effectiveness procedures, complete with a realistic set of parameter values, that can be used by a highway administrator to determine the added design or extra maintenance cost justified to prevent or remedy ice or frost on any bridge deck.

Phase I of the project consisted of a literature search, a survey of selected state highway departments, the formulation of a comprehensive cost-benefit methodology, a preliminary model parametric analysis, the collection of cost data on preventive and remedial techniques in current use, the development of a subsidiary net cost model, the formulation and evaluation of a simplified bridge classification model, and the computation of illustrative examples of the cost-benefit methodology. The cost-benefit methodology that was developed is comprehensive in scope and is sufficiently flexible to represent a variety of situations and countermeasure systems. A report of the work has been written.

The application of the methodology developed in Phase I to sample cases identified data that are lacking and need to be collected. Furthermore, the models that were produced must be recognized as not being in a convenient form for ready implementation. Phase II of the project is designed to overcome the present deficiencies. The continued research will evaluate and implement the methodology developed so that it can be used readily by a highway administrator to determine the added design or extra maintenance cost justified to prevent or remedy ice or frost on bridge decks.

Two subsidiary goals pursuant to the principal objectives also have been established:

1. Test the cost-benefit models to ensure their complete usefulness to the highway engineer, and either collect lacking data significant to the evaluation of the models or establish well-defined guidelines for obtaining the data.
2. Develop a more complete bridge characterization model, to be used with Task 1, which will enable the highway engineer to identify those bridge characteristics that contribute most to icy-bridge accidents.

AREA 7: TRAFFIC PLANNING

Project 7-1 FY '64 and FY '65

The Influence of Land Use on Urban Travel Patterns

Research Agency:	Louis E. Keefer	
Principal Invest.:	Louis E. Keefer David K. Witheford	
Effective Dates:	Feb. 1, 1964	Apr. 1, 1966
Completion Dates:	Jan. 31, 1966	Sept. 30, 1967
Funds:	$62,674	$66,894

This project sought to determine the criteria or values concerning travel patterns created by major traffic generators. Such information is useful in forecasting the effect of various land uses on street networks and in providing a better basis for facility design, as well as for the control of various land uses. The nature or relationship between travel patterns and influencing factors (i.e., travel time, traffic generator characteristics such as location, size, type and

intensity of land use, modes of travel, and other pertinent variables) were evaluated.

A report on the initial research has been published as:

NCHRP Report 24, "Urban Travel Patterns for Airports, Shopping Centers, and Industrial Plants."

Origin and destination data for 12 commercial airports, 28 shopping centers, and 51 industrial plants from various cities in the United States were used in the analysis.

A report on the continuing phase of the research has been published as:

NCHRP Report 62, "Urban Travel Patterns for Hospitals, Universities, Office Buildings, and Capitols."

This report presents trip characteristics for four specific uses of land. The travel information on hospitals has been derived from the study of data for 77 hospitals located in 16 different metropolitan areas. The findings for college and university travel were developed from 38 institutions located in 16 metropolitan areas. Travel patterns for six state capitol complexes are presented. The trip characteristics for 20 office buildings located in 9 cities comprise the fourth type of land use studied and reported in the continuation research phase.

Project 7-2 FY '64 and FY '65

Traffic Attraction of Rural Outdoor Recreational Areas

Research Agency:	IIT Research Institute	
Principal Invest.:	Andrew Ungar	
Effective Dates:	Feb. 1, 1964	May 1, 1965
Completion Dates:	Mar. 15, 1965	May 31, 1966
Funds:	$24,652	$24,844

This research was concerned with determining the traffic attraction and generation of rural outdoor recreational areas, such as those created in many places by the creation of artificial lakes. Knowledge of the traffic patterns generated by such recreational areas would enable rational planning of highway access and parking facilities.

The final report evaluates the attractiveness characteristics and location of 18 Indiana state parks and compares the results to a similar study of reservoir recreational areas in Kansas. A predictive model suitable for application to the planning of new recreational areas is described utilizing trip distribution, a socio-economic activity index of the contributing area, and an estimate of the attractiveness based on the facilities to be provided.

The project report has been published as:

NCHRP Report 44 "Traffic Attraction of Rural Outdoor Recreational Areas."

Project 7-3 FY '64 and FY '65

Weighing Vehicles in Motion

Research Agency:	The Franklin Institute
Principal Invest.:	R. Clyde Herrick
Effective Date:	February 1, 1964
Completion Date:	August 31, 1967
Funds:	$73,391

The purpose of this research was to develop new or improved methodology for weighing vehicles in motion with review and study of existing or new equipment. The ultimate aim was to obtain load magnitudes automatically in a way similar to obtaining traffic volumes by traffic counters.

Franklin Institute's approach to this problem served to complement the studies performed by others rather than to duplicate existing research. The data processing system in block form only was developed on the project. It was planned that no full-scale or field testing would be performed under this contract. Study was primarily given to methods that will allow static weights of the axle to be calculated from a limited number of dynamic load observations.

The methods for estimating the static axle weight from sampled force studied include averaging, dynamic models, the interlacing polynomials, and regression analysis. A preliminary system for the detection and the analysis of weighing vehicles in motion was synthesized.

The project report has been published as:

NCHRP Report 71, "Analytical Study of Weighing Methods for Highway Vehicles in Motion."

Project 7-4 FY '64, FY '65, and FY '67

Factors and Trends in Trip Lengths

Research Agency:	Alan M. Voorhees & Associates	
Principal Invest.:	Alan M. Voorhees	
	Salvatore Bellomo	
Effective Dates:	Feb. 1, 1964	Oct. 23, 1967
Completion Dates:	Oct. 31, 1966	Jan. 10, 1969
Funds:	$89,250	$61,730

This research involved the establishment of the characteristics of trends in trip lengths. Knowledge of such trends is needed to determine future urban travel demands. It was expected that characteristics of trip lengths will be influenced by factors such as trip purpose, level of service, size and spatial characteristics of urban areas, socioeconomic characteristics, and trip-generating activity location.

The results of the first two years of this research have been published as:

NCHRP Report 48, "Factors and Trends in Trip Length."

This report provides empirical and theoretical analyses from data collected from several transportation studies. Trip length guidelines have been developed to provide transportation planners with tests of reasonableness for travel forecasts.

The project was continued to enable the study of trip length in subareas within metropolitan areas. The objectives of the second phase were to establish various relationships to assist planners in minimizing trip length on a subarea basis, and to provide guidelines for checking metropolitan trip length forecasts.

Data were collected for analysis from the two separate origin-and-destination studies conducted in each of the

following cities: Detroit, Mich. (1953 and 1965); Sioux City, Iowa (1955 and 1965); Reading, Pa. (1958 and 1964).

The final report provides results of hypotheses formulated and tested to state the relationship over time between trip length and influencing factors. Simulation studies are reported of home-based work-trip analyses for certain hypothetical urban forms and transportation systems.

The results of the continuation phase of the project have been published as:

NCHRP Report 89, "Factors, Trends, and Guidelines Related to Trip Length."

Project 7-5 FY '64 and FY '65

Predicted Traffic Usage of a Major Highway Facility Versus Actual Usage

Research Agency:	Yale University, Bureau of Highway Traffic
Principal Invest.:	M. J. Huber H. B. Boutwell
Effective Date:	February 1, 1964
Completion Date:	November 30, 1966
Funds:	$99,675

This project involved the development of better methods for forecasting and assignment of traffic. Various methods in current use were investigated. Methods were developed to determine the effects a new facility has on the traffic pattern of existing facilities. A major emphasis of the research was to determine the accuracy of the predicted use as compared to the actual use of highway facility.

The project report describes various electronic computer traffic assignment methods with test results compared to actual survey data obtained along the Connecticut River. Pittsburgh Area Transportation Study data and network assignments were obtained to study several forecasts made 15 to 20 years ago.

A computer program was assembled to assign traffic to a network using four different capacity restraint methods. An analysis of statistical inferences from different network loadings was conducted.

The project report has been published as:

NCHRP Report 58, "Comparative Analysis of Traffic Assignment Techniques with Actual Highway Use."

Project 7-6 FY '66

Multiple Use of Lands Within Highway Rights-of-Way

Research Agency:	Barton-Aschman Associates
Principal Invest.:	Harvey R. Joyner
Effective Date:	February 1, 1966
Completion Date:	February 28, 1967
Funds:	$24,220

Controlled-access highways in urban and rural areas include land which was necessarily acquired to provide space for the present and future safe design and operation of the facility but which is not now used. This project assembled information that illustrates what has been and what might be accomplished with these plots of land in the interest of both the highway user and the adjacent community.

The researchers reviewed the literature and prepared an annotated bibliography on the subject. A questionnaire was sent to the highway departments and several cities in the U.S. as well as abroad to survey existing uses being made of highway rights-of-way. Personal visits to various sites were made to acquire more information on the effects of various uses. Policies and legal requirements were reviewed and recommendations made for the use of land within the highway rights-of-way.

The project report has been published as:

NCHRP Report 53, "Multiple Use of Lands Within Highway Rights-of-Way."

Project 7-7 FY '66

Motorists' Needs and Services on Interstate Highways

Research Agency:	Airborne Instruments Laboratory
Principal Invest.:	Martin A. Warskow
Effective Date:	January 1, 1966
Completion Date:	December 31, 1967
Funds:	$99,267

This project was concerned with the needs and desires of motorists traveling on the Interstate Highway System, how these needs and desires are being satisfied, and what additional service provisions should be made. Legal and financial implications for providing various services were studied.

The researchers analyzed three basic classes of services: emergency services, which include out-of-fuel, mechanical failures, accidents, and medical needs; normal necessities, which include need for fuel, food, lodging, and directional information; and supplemental services, which include information on choice of lodging, fuel, and food facilities as to quality, location, brand, etc.

A national questionnaire was mailed to a sample of registered motorists to determine motorists' desires. Emergency service data were collected from various sources. A series of road trips was conducted in seven states in various parts of the country to experience a variety of the geographic aspects of this study. In each state, the researchers visited the local auto club, the state highway officials, and the state police to obtain various types of data.

The project report has been published as:

NCHRP Report 64, "Motorists' Needs and Services on Interstate Highways."

Project 7-8 FY '71

User Cost and Related Consequences of Alternative Levels of Highway Service

Research Agency:	Stanford Research Institute
Principal Invest.:	David A. Curry
Effective Date:	September 1, 1970
Completion Date:	April 15, 1972
Funds:	$99,070

Techniques for conducting comprehensive economic analyses of planned highway projects can be slow and cumbersome. In view of the evolving nature of the highway planning process, a need exists for an economic analysis supplement to the *Highway Capacity Manual* utilizing the manual's definitions of highway types, levels of highway service, and other key concepts. The *Highway Capacity Manual* describes six levels of service for each of five types of highway facilities and provides detailed procedures for determining levels of service under various conditions. At present, however, these levels of service have not been quantified with respect to user costs and related consequences.

The objectives of this project were to evaluate data related to user costs on various highway facilities under different levels of service, volumes, and other conditions, and to develop a methodology that will relate these variables to user costs. Through the means of sensitivity analyses, highway design and situation variables were identified that have major impact on output variables that can be of use to highway decision-makers.

Motor vehicle running cost data were compiled and updated for use in calculating relative road user costs at different levels of highway service and as affected by details of geometric design and traffic performance. By use of Appendix A of the *Highway Capacity Manual,* relationships were derived for peak-hour volume per lane in conjunction with AADT per lane pair. Queuing was analyzed based on the shock-wave method for uninterrupted flow and the deterministic method for interrupted flow. A methodology for estimating vehicle emissions was developed based on a "typical" vehicle configuration.

The research has been completed and the project report has been published as:

NCHRP Report 133, "Procedures for Estimating Highway User Costs, Air Pollution, and Noise Effects."

Project 7-9 FY '73

Development of Models for Predicting Weekend Recreational Traffic

Research Agency:	Midwest Research Institute
Principal Invest.:	Edward L. Perkins
Effective Date:	September 1, 1972
Completion Date:	November 30, 1973
Funds:	$74,983

Traffic congestion occurs frequently on weekends at the fringes of urban areas as well as at recreation sites. For a number of highways serving recreational travel, it has been found that the peak hours of the year are concentrated on weekends. This weekend dilemma is of increasing concern to highway officials particularly, because it is expected to increase with increasing personal income and work-free time. Urban transportation studies, charged with forecasting future travel patterns, have excluded weekend travel.

The objective of this research is to develop techniques for the prediction of weekend recreational traffic capable of responding to changes in recreation demand, recreation supply, and transportation supply. The techniques are to be capable of predicting weekend recreational traffic factors for major recreational routes serving urban areas. The models are to consider the interrelationship of all significant, identifiable variables and their effects on traffic. If such models require computer application, they must be shown to be operational and suitable for inclusion in the transportation planning process.

The prediction of travel patterns has to consider factors generating travel demands and related aspects of highway transportation. Demand components that need to be considered are: (1) appropriate recreation opportunities and characteristics of facilities, (2) adequate means of reaching recreation areas, and (3) characteristics of the traveler.

Progress through December 31, 1972, included review and analysis of data on the characteristics of weekend recreational traffic, collection of additional data on the generation of weekend recreational trips, and initiation of the expansion of an existing recreation resource inventory.

AREA 8: URBAN TRANSPORTATION

Project 8-1 FY '64

Social and Economic Factors Affecting Travel

Research Agency:	Vogt, Ivers and Associates
Principal Invest.:	Robert S. Vogt
Effective Date:	February 1, 1964
Completion Date:	September 23, 1966
Funds:	$94,558

The purpose of this research was to develop means of estimating intercity travel using known traffic volumes and available economic and social data between selected cities and testing it by application to other pairs of cities between which travel is also known. A review was made of the adequacy of current processes of estimating urban travel using social and economic factors and the applicability of these techniques in estimating intercity travel. This study also researched whether useful and reliable work can be done by using urban transportation study techniques and applying them to other travel areas.

Knowledge gained by this research is useful to transportation planners and design engineers. Extensive use of electronic computers and existing computer programs to extract and classify summarized pertinent origin-destination data from existing studies has been accomplished.

A nationwide network has been produced for trip distribution purposes. More than 3,000 centroids representing each county or county equivalent with basic population, employment, income, bank deposit, and other social-economic information have been assigned. The centroids are connected by links representing the highway system. External O-D data were acquired and processed for 22 cities in Tennessee, Wisconsin, and Missouri. From these data, regression analyses were run to test various equation forms and the correlation between variables, combination of variables, and transformation of variables for total trips and for trips by purpose. The trips predicted from the

regression equations have been compared to actual survey trips.

The project report has been published as:

NCHRP Report 70, "Social and Economic Factors Affecting Travel."

Project 8-2 FY '64 and FY '65

Factors Influencing Modal Trip Assignment

Research Agency: IIT Research Institute
Principal Invest.: Dr. F. C. Bock
Effective Date: February 1, 1964
Completion Date: August 31, 1966
Funds: $298,033

The intent of this research was to improve methods of assigning urban area traffic to the various modes of travel. It involved the identifying of factors underlying choice of travel mode, the determination of the relationships of these factors, and also the development of a method of analysis and forecasting. Methods were tested and found to be practicable for use under real-life conditions. Such methods would be applicable in making better trip assignments in urban transportation systems.

The project report contains a survey of existing modal split models, and analysis of five metroplitan areas having rail rapid transit, a study of factors influencing choice in travel mode, and prediction models for modal choice based on discriminant functions with a comparison of reported trips and computed paths.

A survey of travel choice of IIT Research Institute personnel was conducted. The reported trip time was compared with computed times using the updated 1965 CATS network. The Chicago 1960 census data were analyzed to improve predictive techniques for mode choice. A composite Chicago travel network was developed, with an analysis of variance of reported and computed transit travel time.

The project report has been published as:

NCHRP Report 57, "Factors Influencing Modal Trip Assignment."

Project 8-3 FY '64

Individual Preferences for Various Means of Transportation

Research Agency: University of Pennsylvania
Principal Invest.: Dr. Russell L. Ackoff
Effective Date: February 1, 1964
Completion Date: March 31, 1965
Funds: $63,282

This project was designed to probe individuals' transportation preferences as contrasted to the more objective studies that Project 8-2 is concerned with. It was expected that the research would develop additional knowledge as to why and under what conditions persons will use or shift from one form of transportation to another. Better information and estimating bases are needed in order to obtain broad community agreement on plans for transit and highway improvement.

The final report will not be published, but is available from the NCHRP on loan. A detailed summary was included under "Summaries of Unpublished Reports," *Summary of Progerss to June 30, 1967.*

Project 8-4 FY '65

Criteria for Evaluating Alternative Transportation Plans

Research Agency: Northwestern University
Principal Invest.: Dr. Edwin N. Thomas
Dr. Joseph L. Schofer
Effective Date: February 1, 1965
Completion Date: August 1, 1967
Funds: $89,900

Present benefit-cost and other evaluative techniques do not take into account a number of costs, benefits, and broad policy matters which do not easily lend themselves to numercial computation. This project was intended to identify and evaluate the broad array of factors which should be considered in making an intelligent choice among alternative transportation plans. A system for using these factors should be devised.

To identify and evaluate the broad array of factors which reflect the user's and community's scale of values, the researchers took a systems-analysis approach. A home interview was conducted as a pilot effort to establish user and community values in specific cities. The perceptions and attitudes of the driver were derived, as well as the citizen's views about the transportation system in general. Models were developed to be able to match potential transportation system consequences with specific planning goals. Problems associated with predicting system consequences were studied.

The multi-volume report consists of a section in three parts entitled "Strategies for the Evaluation of Alternative Transportation Plans," and a section entitled "Evaluation of Engineering Projects Using Perceptions of and Preferences for Project Characteristics."

In response to comments of the advisory panel, some additional material was found to be desirable to be added to the final report. Certain modifications were deemed necessary to relate the findings of the research more closely to the immediate needs of transportation planners.

A continuation contract was executed under NCHRP Project 8-4A for the purpose of modifying the final report for publication.

Project 8-4A FY '65

Criteria for Evaluating Alternative Transportation Plans

Research Agency: University of Illinois
Principal Invest.: Dr. Joseph L. Schofer

Effective Date: October 14, 1968
Completion Date: January 10, 1969
Funds: $5,000

See Project 8-4 for general scope and objective of the research.

To improve the flow of ideas throughout the document, the final report of Project 8-4 was modified. In addition, more extensive descriptions of strategies for treating streams of cost and effectiveness indicators were prepared and integrated into the text. Also, several illustrative examples of the application of cost-effectiveness analysis to transportation-plan evaluation were prepared to demonstrate the use of the methodology, as well as to support some of the broader concepts described in the final report.

The project report has been published as:

NCHRP Report 96, "Strategies for the Evaluation of Alternative Transportation Plans."

Project 8-5 FY '65 and FY '68

Transportation Aspects of Land-Use Controls

Research Agency:	Victor Gruen Associates	
Principal Invest.:	Harold Marks	
Effective Dates:	April 1, 1965	Aug. 7, 1967
Completion Dates:	May 31, 1966	Jan. 15, 1970
Funds:	$25,967	$99,571

Proper land-use controls, properly administered, protect and enhance the public investment in transportation. Zoning, subdivision regulations, and all other land-use controls are intended to shape the pattern of the urban development. The objective of this research was to provide a better understanding of the effectiveness of existing land-use controls on the continuing utility of transportation systems.

The initial research primarily consisted of a literature search and a canvass of selected highway departments and other agencies concerned with tarnsportation planning in areas of rapid growth and intensive development. The effects of zoning and general plans were studied, as were highway geometry and access control, in regard to protecting the investment of the highway systems.

A first technical report has been published as:

NCHRP Report 31, "A Review of Transportation Aspects of Land-Use Control."

This project was continued to establish principles or guidelines for developing land-use controls and other techniques that will be stable and effective in the protection of highway utility. The research effort was conceptual in nature and presented a variety of ideas and proposals by which the highway investment can be protected. Some of the guidelines were developed in considerable detail. These can be incorporated into the procedures and practices of land-use and highway administrators. Other principles were developed as a base from which more detailed analyses can be undertaken.

The project report discusses basic interrelationships between transportation facilities and land use and how such relationships can cause transportation facility breakdowns. The effects of changing land-use controls on the utility of highways are discussed, with special attention being given to large traffic generators located near freeway interchanges.

The continuation research has been completed and the project report has been published as:

NCHRP Report 121, "Protection of Highway Utility."

Project 8-6 FY '66

Individual Preferences for Alternative Dwelling Types and Environments

Research Agency: University of North Carolina
Principal Invest.: F. Stuart Chapin, Jr.
Effective Date: February 14, 1966
Completion Date: March 13, 1968
Funds: $99,897

In predicting the future demand for transportation, it is imperative that future densities of residential areas be projected. In order that this may be done with confidence, a better understanding must be acquired for the preferences of various housing types and environments.

To measure and report on a representative cross section of the population, the researchers interviewed a sample of 1,476 households in various metropolitan areas. Logical relationships were developed between desired home type, price range, travel access mix, and living qualities. An attempt was made at estimating the number of people expected to move in a specified time period and where they will probably locate.

A national survey in 43 Standard Metropolitan Statistical Areas was conducted in October and November 1966. The information provides a detailed, factual profile on the mobility and residential choice behavior of households in metropolitan areas.

The project report deals with a summary of findings on housing choice of the households interviewed; an analysis of the residential mobility process; an analysis of the housing-choice process; and, drawing on these analyses, a discussion of the elements needed for a model of moving behavior which will have the capability of dealing with both the mobility and choice processes as components of residential changes.

The project report has been published as:

NCHRP Report 81, "Moving Behavior and Residential Choice—A National Survey."

Project 8-7 FY '69

Evaluation of Data Requirements and Collection Techniques for Transportation Planning

Research Agency: Creighton, Hamburg
Principal Invest.: Roger L. Creighton
Effective Date: September 13, 1968
Completion Date: August 28, 1970
Funds: $190,000

Urban transportation planning studies require travel, transportation facility, land-use, and various socioeconomic

data. Techniques for obtaining these data are slow and costly. The accuracy, utility, and adequacy of the data and the methods employed for their collection and assembly need to be evaluated in the light of the evolving transportation planning process.

The purpose of the research project was to see what data were needed, first, for the basic transportation planning process such as was required to be undertaken for metropolitan areas by the Highway Act of 1962, and, second, for new kinds of transportation planning that are developing. A very limited number of transportation studies were selected for careful and detailed data analysis to establish recommendations on guidelines for data requirements and collection techniques. The project defined data requirements for both basic and continuing urban transportation studies with regard to travel, transportation facility, land-use, and socioeconomic data. Sensitivity analysis was performed to examine variations of the transportation data for assessing the impact that data errors have on the output of the transportation planning process.

The research included a comprehensive study of the transportation planning process in five cities to determine data collected, how they were used for planning and research, and their times and costs. Sensitivity tests of these data were conducted. Studies of data needs for new types of transportation-planning processes and alternate means of collecting data were also undertaken. Research was conducted on data needs of related planning processes, such as TOPICS Planning and Transit Planning.

The project report has been published as:

NCHRP Report 120, "Data Requirements for Metropolitan Transportation Planning."

Project 8-7A FY '71

Data Requirements and Transportation Planning Procedures in Small Urban Areas

Research Agency:
Principal Invest.:
Effective Date:
Completion Date: Contract Pending
Funds: $100,000

Urban transportation planning studies in urban areas of less than 250,000 population have evolved as miniature versions of the transportation planning process in large urban areas. These studies are time consuming and costly and have inordinate data requirements. The complexity and expense of these procedures is of increasing concern to highway officials because of the need to establish ongoing, continuing transportation planning processes in small urban areas.

The objective of this research is to develop a simplified transportation planning process for a small urban area of less than 250,000 population that is sufficiently flexible so that travel forecasts can be based on a small-sample home-interview survey or on simulation. The investigation will consider both planning process requirements and data requirements to take full advantage of recent advances in the understanding of travel behavior, dwelling unit analysis, and new census procedures with increased data availability.

Project 8-8(1) FY '69

The Impact of Highways upon Environmental Values (Study Design)

Research Agency: Massachusetts Institute of Technology
Principal Invest.: Dr. Marvin L. Manheim
Effective Date: September 16, 1968
Completion Date: March 14, 1969
Funds: $29,654

The increased emphasis on social and esthetic values has focused attention on the need for improving integration of the highway with the community.

The scope of this project was to develop an independent study design to be used as the research plan for the second-phase work. The study design has been completed and the report has been received, but will not be published.

Refer to Project 8-8(3) for description of the over-all project objectives and details of the second phase of this study.

Project 8-8(2) FY '69

The Impact of Highways upon Environmental Values (Study Design)

Research Agency: Daniel, Mann, Johnson & Mendenhall
Principal Invest.: S. R. Sludikoff
Effective Date: September 9, 1968
Completion Date: March 7, 1969
Funds: $28,950

The increased emphasis on social and esthetic values has focused attention on the need for improving integration of the highway with the community.

The scope of this project was to develop an independent study design to be used as the research plan for the second-phase work. The study design has been completed and the report has been received, but will not be published.

Refer to Project 8-8(3) for description of the over-all project objectives and details of the second phase of this study.

Project 8-8(3) FY '69

The Impact of Highways upon Environmental Values

Research Agency: Massachusetts Institute of Technology
Principal Invest.: Dr. Marvin L. Manheim
Effective Date: September 15, 1969
Completion Date: December 31, 1973
Funds: $470,000

The increasing emphasis on social and environmental values has focused attention on the need for improving integration of the highway with the community. To achieve

desirable levels of integration, research is needed to develop a practicable method for evaluating the effects of highways on communities, and to test, evaluate, and refine the method through application to specific cases covering a range of situations. Methodological guidelines are needed for use in highway planning, location, and design in reaching enlightened decisions.

The objective of this research is to develop a practicable method for evaluation of the immediate and long-term effects of urban highways on social and environmental considerations. Although the scope ultimately should cover all types of highways, this study is limited to consideration of highways in urban areas; i.e., expressways, freeways, parkways, and major streets and highways (except local roads and streets).

Under Project 8-8(1) MIT prepared a study design, which served as the working plan for Phase I of this study.

An urgent need exists for a pragmatic approach that will insure that community values are properly considered in highway location and design—in spite of the present lack of knowledge about how to measure and predict impacts of highways on the community. The method from this research is designed to maximize the probability that significant community values will in fact be considered by the location team, even if the state of the art does not allow all these values to be measured quantitatively or predicted precisely. Therefore, the research program emphasizes the development of a method in the context of the location process.

The agency concluded the first phase of work on September 30, 1971, with the submission of a draft report, "Community Values in Highway Location and Design: A Procedural Guide." That report is available in uncorrected draft copy for short-term loan. The report will not be published in its present form; additional work under way is expected to yield new knowledge that may require substantial revisions.

The second phase of work includes (1) working with selected state highway departments to implement the proposed method and adapt it to specific situations; (2) extending the method for use in metropolitan area, statewide multimodal, and systems-level planning; (3) extending, testing, and refining the techniques set forth in the Procedural Guide; and (4) revising the Procedural Guide to reflect the additional knowledge.

Through December 31, 1972, the agency had selected test sites in Georgia and Michigan for implementing Procedural Guide methods in cooperation with the state highway departments, concluded initial evaluation of the Procedural Guide's effectiveness, and initiated preliminary revisions of the guide's techniques.

Project 8-9 FY '72

Comparative Economic Analysis of Alternative Multimodal Passenger Transportation Systems

Research Agency: Creighton, Hamburg
Principal Invest.: F. F. Frye
Effective Date: September 1, 1971
Completion Date: January 31, 1973
Funds: $93,738

Economic evaluation of proposed new highway facilities traditionally has been on a cost-benefit basis, as is common with other public works projects. On the other hand, evaluation of proposed new transit facilities, as an action of a private company or a public utility, has too often been on a cashbox-revenue return basis. From the point of view of public investment, it is necessary to view these expenditures within a comparable evaluation framework so that the measures of benefits an dcosts are interchangeable. Such a framework for the economic evaluation of multimodal passenger transportation systems is needed for use in urban transportation studies.

The objective of this research is to develop improvements and expansion for existing processes that evaluate alternative multimodal transportation system plans. These improvements will be obtained by increasing the number of relevant criteria used in the evaluation framework and ensuring that the measuring techniques developed represent accurately the impacts of alternative transportation plans. These techniques were included within the framework of the economics of alternative multimodal metropolitan transportation systems.

Progress through December 31, 1972 included preparation of an interim report that was distributed among the state highway departments and is available for loan. A report from the economic consultant to Creighton, Hamburg, Inc., entitled "Economic Criteria for Evaluating Alternative Multimodal Transportation Systems," also is available for loan. The final report is being reviewed for acceptance.

Project 8-10 FY '72

Planning and Design Guidelines for Efficient Bus Utilization of Highway Facilities

Research Agency: Wilbur Smith and Associates
Principal Invest.: Herbert S. Levinson
Effective Date: September 1, 1971
Completion Date: February 28, 1973
Funds: $149,907

Highways are capable of moving large numbers of persons on buses, but in high-volume corridors transportation service deteriorates due to peak traffic congestion. In order to move more people at an acceptable level of service, special facilities and control measures can be employed. The desired goal is rapid, convenient, reliable bus transit. Thus, a highway transportation system can be designed to offer a high level of service for peak commuter loads.

Preferential bus facilities for improving bus commuting include preferential (including exclusive) bus lanes and ramps; traffic controls for smooth, uncongested flow; loading points and shelters; and park-ride lots. Although transportation planners and traffic engineers are interested in advanced bus utilization applications, their ability to implement these concepts is hindered by the lack of planning

experience and design guidelines for these various elements.

The goal of this project is to develop a single reference source of information on bus utilization applications that increase the person-carrying capacity of existing highway facilities. This reference source will document existing and proposed preferential bus facilities for expediting movement of buses on highways; contain guidelines for planning and designing preferential bus facilities; and recommend needed research.

An interim report, "Bus Utilization of Highway Facilities—State of the Art," has been prepared with a view toward publication in the regular NCHRP series. Concurrently, work has continued toward the major objective of planning and design guidelines.

AREA 9: BITUMINOUS MATERIALS

Project 9-1 FY '64 and FY '65

Asphalt Durability and Its Relation to Pavement Performance

Research Agency:	American Oil Company	
Principal Invest.:	Dr. A. W. Sisko L. C. Brunstrum	
Effective Dates:	Feb. 1, 1964	Nov. 1, 1965
Completion Dates:	July 31, 1965	Apr. 30, 1967
Funds:	$50,000	$50,000

Research is needed to determine those fundamental properties of an asphalt which contribute to the durability of pavements and to develop suitable methods of tests for determining such properties. These tests are needed to provide improved bases for asphalt specifications to assure products which, when properly used, will result in durable asphalt pavements. The general properties with which this over-all problem was concerned involve rheological, chemical, and physio-chemical properties of the asphalt alone and as influenced by its interfacial relationship with aggregates. These properties and their values in the original asphalt and the retention of these values over a period of time in service are of importance.

Research has been completed, and the project report has been published as:

NCHRP Report 67, "Relation of Asphalt Rheological Properties to Pavement Durability."

Project 9-2 FY '65

Asphalt Durability and Its Relation to Pavement Performance—Adhesion

Research Agency:	Montana College of Mineral Science and Technology
Principal Invest.:	D. W. McGlashan
Effective Date:	January 1, 1965
Completion Date:	October 31, 1967
Funds:	$107,670

This research was concerned with asphaltic concrete pavement performance, particularly with regard to the influence of asphalt-aggregate adhesion. The research approach was based on the principle that interfacial activity occurring at the boundary between an asphalt cement and an aggregate is influenced by the characteristics of the particular asphalt and aggregate and that this activity, measured in electrical quantities, provides a comparative assessment of the adhesion between the asphalt and the aggregate.

A data acquisition system was developed for making electrokinetic measurements of interfacial activity when asphalt cements were forced through porous plugs under controlled temperature and pressure conditions. The porous plugs contained aggregates that were being tested for adhesion. Data were collected and analyzed using 15 asphalt cements and a number of different aggregate types to demonstrate the ability of the procedure for assessing the adhesion of an asphalt-aggregate mixture.

Research has been completed. The project report will not be published in the NCHRP report series; however, a summary is included in the *NCHRP Summary of Progress Through 1972.*

Project 9-3 FY '65

Evaluation of Pavement Joint and Crack Sealing Materials and Practices

Research Agency:	Rensselaer Polytechnic Institute
Principal Invest.:	Dr. John P. Cook
Effective Date:	June 1, 1965
Completion Date:	June 30, 1966
Funds:	$24,996

Under environmental, structural, and traffic requirements, highly variable and inadequate performance may result from the materials and construction practices regarding the sealing of joints in new pavements and the maintenance of joints and cracks in old pavements. All aspects of the sources of the deficiencies need to be identified so that corrective measures may be established either in terms of improved materials or improved construction practices. The objectives of this research were to (1) prepare a state-of-knowledge report on joint and crack sealing materials, joint design, specifications, test methods, and construction practice; (2) make a critical analysis of the information and define needs to improve performance; and (3) recommend a feasible research program. Bituminous and nonbituminous materials were included, and due consideration was given to such factors as economics and practicalities of usage.

Research has been completed, and the project report has been published as:

NCHRP Report 38, "Evaluation of Pavement Joint and Crack Sealing Materials and Practices."

Project 9-4 FY '72

Minimizing Premature Cracking of Asphaltic Concrete Pavements

Research Agency: Materials Research & Development
Principal Invest.: F. N. Finn
Keshavan Nair
Effective Date: November 1, 1971
Completion Date: January 31, 1973
Funds: $99,560

The premature cracking of asphaltic concrete pavements is a continuing problem and often results in large expenditures of money to maintain a necessary level of pavement serviceability. It is acknowledged that considerable research effort is being directed toward the development of more rational procedures for pavement design, utilizing the measured values of the significant basic properties of materials used in road construction, which will be applicable to all locations, environments, and traffic loadings. It should also be recognized that implementation of currently available research results provides prospects for some improvement in the performance of new asphaltic concrete pavements.

Cracking of the surface course is generally considered to be the most significant manifestation of asphaltic concrete pavement distress. Many factors, such as asphalt properties, mix design, construction procedures, aggregate properties, subgrade support, environmental conditions, and traffic loadings, influence the ability of the pavement to resist cracking. Premature cracking (that cracking occurring at an early life or after less accumulated traffic than anticipated during design) is particularly troublesome. Methods are needed for modifying current requirements and procedures that will result in the minimizing of this type of cracking.

The over-all objective of this project is the determination of suitable materials specifications, paving mix design criteria, and construction requirements that will result in the ability to design and construct asphaltic concrete pavements to carry design traffic with a minimum of premature cracking. This over-all objective is intended to be accomplished in two or more phases. Continuation of the research will be subject to the findings and satisfactory documentation of the preceding phase.

The specific objectives of Phase I are:

1. Identify, evaluate, and synthesize into a form usable by highway departments the avaliable information from recent and current research and field experience pertaining to the minimizing of premature cracking in asphaltic concrete pavements.
2. Using the information developed under objective 1, recommend tentative criteria for material specifications, mix design, and construction requirements for asphaltic concrete to minimize premature cracking in asphaltic concrete pavements.
3. Prepare a detailed research plan intended to verify or modify the recommendations developed under objective 2 using the following approaches:
   (a) Case history studies of in-service pavements and existing field experiments, and
   (b) Evaluation of new construction projects implementing the recommendations.
4. Test the case history study approach for verification of the recommendations to the extent possible within project time and funds. It is anticipated that the researchers will need to establish liaison with a highway agency or agencies to accomplish this objective.

During the initial stages of the study, all identified literature on (a) laboratory studies of paving materials, and (b) field experience on the occurrence of cracking, was reviewed to provide a basis for formulating recommendations to minimize premature cracking in asphaltic concrete pavements. A synthesis report has been submitted containing tentative recommendations for minimizing cracking, and a plan is being prepared for verifying or modifying these tentative recommendations. It is recognized that conventional approaches to the design of field experimental programs involving a relatively large number of variables are costly and time consuming. Consequently, alternate approaches for verification or modification of the tentative recommendations that depend to a large extent on the accumulation of engineering experience with supplemental observations on existing and newly constructed pavements are being considered.

AREA 10: SPECIFICATIONS, PROCEDURES, AND PRACTICES

Project 10-1 FY '64

Development of Guidelines for Practical and Realistic Construction Specifications

Research Agency: Miller-Warden Associates
Principal Invest.: W. B. Warden
Effective Date: November 15, 1963
Completion Date: November 14, 1964
Funds: $25,000

It is recognized that many existing specifications do not properly consider variations in work and materials which are inevitable and characteristic of the best construction possible today. In a development of guidelines for adequate specifications, this project included such areas as surface smoothness for subgrades, bases, and pavements, thickness measurements for bases and pavements, gradation and other requirements for aggregates and aggregate mixtures, and a summary of selected current specifications pertinent to the areas of study. Consideration was given to the validity of specifications with respect to need in the accomplishment of purpose, economic impact inherent in specifications, natural variations inherent in work and material, and variations inherent in methods of measurement and control test procedures.

The final report for this project has been published as:

NCHRP Report 17, "Development of Guidelines for Practical and Realistic Construction Specifications."

Project 10-2 FY '64

Evaluation of Construction Control Procedures

Research Agency:	Miller-Warden Associates
Principal Invest.:	S. B. Hudson
Effective Date:	November 4, 1963
Completion Date:	February 1, 1966
Funds:	$59,750

This research was initiated to obtain needed basic information for the formulation of standards for evaluation and acceptance of work, materials, and highway construction. Its objectives included a study to determine variations inherent to measurement methods, testing techniques, and sampling methods and procedures. The scope of this study was confined to the examination and investigation of gradation of aggregates. It included a review of measurement and test procedures to determine those not including precision statements and a study involving statistical techniques for evaluating gradation test procedures, sampling methods, and variations inherent in aggregate gradations.

Initial phase research has been completed, and the project report has been published as:

NCHRP Report 34, "Evaluation of Construction Control Procedures—Interim Report."

Project 10-2A FY '65

Evaluation of Construction Control Procedures

Research Agency:	Materials Research and Development
Principal Invest.:	S. B. Hudson
Effective Date:	July 15, 1966
Completion Date:	November 14, 1967
Funds:	$70,945

The continuation phase of Project 10-2 was conducted by Material Research & Development, Inc., Miller-Warden Associates Division. The research specifically considered (1) the variations in gradation of aggregates, including fine aggregates, drawn from the bins of operating hot-mix plants, with sampling error, short- and long-term variations, and the effect of cold-feed variations to be included; (2) a statistically designed experiment to determine the effect of variation in gradation of coarse aggregate, within the range found to be inherent under existing controls, on the strength and workability of laboratory prepared concrete; (3) the effect of increment size with respect to maximum particle size and accuracy of the results of sampling to provide additional information as to the shape and minimum capacity of tools to be used for sampling coarse aggregates; and (4) further study of the basic pattern of variation of gradation.

Research has been completed, and the project report has been published as:

NCHRP Report 69, "Evaluation of Construction Control Procedures—Aggregate Gradation Variations and Effects."

Project 10-3 FY '64 and FY '65

Effects of Different Methods of Stockpiling and Handling Aggregates

Research Agency:	Miller-Warden Associates	
Principal Invest.:	S. B. Hudson	
Effective Dates:	Oct. 22, 1963	Oct. 15, 1964
Completion Dates:	Apr. 30, 1964	Oct. 16, 1965
Funds:	$25,000	$30,000

The difficulties associated with producing aggregates and providing them at the job site within desirable specification limits have been recognized for many years. To provide further knowledge for a possible solution to these difficulties, the over-all objectives of this research were to (1) find the effects of stockpiling and handling on the properties of an aggregate, including segregation and degradation, and (2) establish suggested procedures for better practices in stockpiling and handling.

Initial research was directed principally to the aspects of stockpiling, and the results have been published as:

NCHRP Report 5, "Effects of Different Methods of Stockpiling Aggregates."

Continuation of the initial research was authorized to expand the scope to include, in addition to further stockpiling investigations, the effects on aggregate properties of several routine methods for handling, spreading, and compacting bases. This work has been completed, and the project report has been published as:

NCHRP Report 46, "Effects of Different Methods of Stockpiling and Handling Aggregates."

Project 10-4 FY '64 and FY '65

Rapid Test Methods for Field Control of Construction

Research Agency:	Clemson University	
Principal Invest.:	Dr. A. E. Schwartz	
Effective Dates:	Feb. 1, 1964	May 1, 1965
Completion Dates:	Feb. 28, 1965	Feb. 28, 1967
Funds:	$30,000	$69,320

It has been recognized that there is a need for improved methods of sampling and testing to keep pace with accelerated production rates and increased volumes of materials being used in highway construction. In an effort to fulfill this need, this research project proposed to seek out areas in which rapid test needs are most critical and to explore and summarize existing knowledge in these areas with the ultimate aim of accelerating the development of new methods of meeting these needs.

Work in the initial phase of this project consisted of a survey of the state of the art in the development, need, and use of rapid test methods for field control of construction. Areas of greatest need were determined; the present knowledge and state of development of various methods for meeting these needs were investigated; and those methods with greatest promise for satisfying the needs in the areas of bituminous paving mixtures, base course construction, and soil compaction were selected

for detailed study and development. An additional study was made of quality control and acceptance sampling plans in respect to the number of tests required to provide adequate statistical information for acceptance or rejection of highway materials within given limits of risk and confidence.

During the continuation phase, emphasis was placed on further development and evaluation of improved test procedures in the areas of asphalt content of bituminous paving mixtures, density of aggregate base courses and bituminous layers, gradation of aggregates, and soil compaction.

Research has been completed, and the project report has been published as:

NCHRP Report 103, "Rapid Test Methods for Field Control of Highway Construction."

Project 10-5 FY '64 and FY '65

Density and Moisture Content Measurements by Nuclear Methods

Research Agency:	Research Triangle Institute	
Principal Invest.:	Dr. R. P. Gardner	
Effective Dates:	Jan. 15, 1964	Apr. 1, 1965
Completion Dates:	Jan. 31, 1965	Oct. 7, 1966
Funds:	$28,801	$59,835

For the past several years investigators have studied the application of nuclear devices for determining moisture content and density of subgrade, subbases, and base components. Some of the researchers have indicated such devices are applicable for field control, while others are still evaluating the technique. If these nuclear devices are capable of accurate and reliable determinations, there is a possibility that considerable economy may result in construction and control procedures. The objectives of the initial research were (1) to review the literature and other available data to determine what has been done by others in the evaluation and correlation of nuclear equipment, (2) to evaluate and analyze assembled data considering such factors as accuracy and precision, and (3) to make recommendations for the development of needed equipment.

Research on the initial phase has been completed and the project report for this phase has been published as:

NCHRP Report 14, "Density and Moisture Content Measurements by Nuclear Methods—Interim Report."

The objective of the continuation phase was to investigate in depth the promising findings from the initial research. Theoretical investigations were supplemented by field experiments to establish a technique for calibrating nuclear gauges to provide improved accuracy in the measurement of soil moisture content and density. In the pursuit of these objectives, calibration standards were developed which are applicable to nuclear gauges currently in use.

Research on the continuation phase has been completed, and the project report for this phase has been published as:

NCHRP Report 43, "Density and Moisture Content Measurements by Nuclear Methods."

Project 10-5A FY '68

Optimization of Nuclear Density and Moisture Content Measurement Methods

Research Agency:	North Carolina State University
Principal Invest.:	Dr. R. P. Gardner
Effective Date:	February 1, 1968
Completion Date:	January 31, 1970
Funds:	$49,986

In recent years there have been numerous investigations of nuclear methods for determining the moisture content and density of subgrade, subbase, and base components of highway pavements. Nuclear devices have been evaluated and found to be potentially more accurate and faster than conventional measurement methods. During the conduct of Project 10-5 the primary problems associated with these devices were identified as sensitivity elemental composition, nonuniform response to the sample due to the nonhomogeneous nature of soil and aggregate materials, surface roughness of the measurement area, and gauge calibration. Several nuclear gauge calibration methods were developed utilizing calibration model, energy discrimination, and dual-gauge principles.

The essential objective of this study was to optimize nuclear gauge calibration methods and thus improve operational performance of the gauges for control of moisture and density during construction of highway subgrade, subbase, and base components. Research has been completed and the objectives have been met. Procedures have been developed for optimization of nuclear backscatter-type density gauge calibration, a quality factor approach has been developed for evaluating the over-all performance of density gauges, and a tentative model is available for improved calibration of nuclear moisture gauges. The research has also provided a basis for design of even better nuclear backscatter-type density gauges.

Research has been completed, and the project report has been published as:

NCHRP Report 125, "Optimization of Density and Moisture Content Measurements by Nuclear Methods."

Project 10-6 FY '64 and FY '65

Measurement of Pavement Thicknesses by Rapid and Nondestructive Methods

Research Agency:	IIT Research Institute
Principal Invest.:	K. E. Feith
	Dr. S. D. Howkins
Effective Date:	February 1, 1964
Completion Date:	October 31, 1966
Funds:	$108,821

Present methods of measuring the thicknesses of highway pavements are time consuming and generally do not provide data early enough for the contractor to alter operations so as to comply. It is recognized that a nondestructive technique would be advantageous, both cost- and time-wise, in comparison to present methods. In initiating this research, four objectives were outlined. They

included: (1) a study of all past and present methods of measuring thicknesses of highway pavements to determine if any existing method may be suitable; (2) a feasibility study of proposed methods now under development; (3) proposals for other feasible methods; and (4) recommendations for promising methods for development of instrumentation.

Research has been completed, and the project report has been published as:

NCHRP Report 52, "Measurement of Pavement Thickness by Rapid and Nondestructive Methods."

Project 10-7 FY '64

Potential Uses of Sonic and Ultrasonic Devices in Highway Construction

Research Agency:	The Ohio State University
Principal Invest.:	Dr. F. Moavenzadeh
	Dr. R. C. McMaster
Effective Date:	February 1, 1964
Completion Date:	March 31, 1965
Funds:	$24,310

The use of sonic and ultrasonic devices is well known in some fields. Present practical application of sonic and ultrasonic frequencies and the results of recent experiments indicate a wide range of potential uses of such devices in highway construction. It is felt that possible uses may include pile driving, mixing and compaction of materials, sampling of materials, drilling, cutting, and many other applications. In an effort to evaluate potential uses, this research study was initiated with the objectives of studying available information on present uses of high-frequency vibrations and making a feasibility study of possible applications to highway construction.

This research has been completed, and the project report has been published as:

NCHRP Report 25, "Potential Uses of Sonic and Ultrasonic Devices in Highway Construction."

Project 10-8 FY '70

Evaluating Procedures for Determining Concrete Pavement Thickness and Reinforcement Position

Research Agency:	Pennsylvania Dept. of Transportation
Principal Invest.:	W. G. Weber
	R. L. Gray
Effective Date:	March 2, 1970
Completion Date:	May 31, 1973
Funds:	$199,835

The measurement of portland cement concrete pavement thickness and strength and the determination of the position of reinforcing steel are necessary to establish conformance with design and construction specification requirements. The conventional method for making these determinations —by cutting cores from the hardened concrete and performing the related operations of handling, and testing— is time consuming and costly as well as destructive to the finished pavement. Furthermore, the determinations thus made, although of value for record purposes, are of little use during the construction process.

It is recognized that the ultimate solution to this problem may involve greater dependence on a quality control system during paving operations rather than the several elements of currently used conventional testing programs. The immediate need, however, is for rapid, practical, and nondestructive test methods for making conventional measurements. Pavement thickness should be determined nondestructively on the plastic concrete or as soon as possible after hardening. The determination of reinforcing steel position in a pavement, while the concrete is in the plastic state, enables corrective adjustments. Nondestructive determination of strength of in-place concrete at the earliest possible time after placement is most desirable.

The determination of strength, although part of the overall problem, is not to be included in the research to be conducted under this project.

The objective of this research is limited to the field evaluation of available systems of inspection testing for determining pavement thickness and reinforcing steel position at the construction site, either before or soon after the concrete has hardened, to permit the elimination of, or substantial reduction in, the coring of pavements.

It is envisioned that, to accomplish this objective, the research agency will:

1. Conduct a state-of-the-art study and preliminary evaluation to the extent necessary to select the devices and procedures for determining concrete pavement thickness and reinforcing steel placement that have been developed to the point that field evaluation is now feasible.
2. Recommend candidate procedures for field evaluation and propose a detailed field evaluation program.
3. Submit an interim report covering items 1 and 2.
4. Conduct the approved field evaluation program.
5. Analyze field data and compare with current practices with regard to such considerations as practicality, accuracy, ease of operation, and nondestructiveness.

Research on items 1 and 2 has been completed, and the interim report has been received and reviewed by the project advisory panel. Considerable concern was expressed with regard to prospects for successful accomplishment of all project objectives by completion of the study as proposed in the interim report. Due to this concern, the panel recommended modification of the research plan, an extension of project time, and an increase in project funds to fully implement the revised research plan. Item 4 was revised to provide for a pilot field evaluation in 1971 followed by a more extensive field evaluation in 1972 if warranted by the results of the pilot study.

Both the pilot field evaluation program in Pennsylvania and the extended program in other states, including Louisiana, Maryland, Minnesota, Ohio, and Utah, have been completed. A resistivity gauge, the Ohio State ultrasonic gauge, and to a lesser extent the eddy current proximity gauge, were used in thickness determinations.

The regular coring procedures for pavement thickness were also applied. A second interim report, submitted at the conclusion of the pilot field study, provided the basic plan for the extended field study.

Project 10-9 FY '70

Criteria for Need of Seal Coats for Bituminous Pavements

Research Agency: University of Minnesota
Principal Invest.: E. L. Skok
Effective Date: November 1, 1969
Completion Date: January 31, 1973
Funds: $50,000

In order to most economically maintain bituminous-surfaced pavements in serviceable conditions, applications of seal coats may be periodically required. The determination of the need for seal coats, the type required, and the proper time to apply are important. Premature sealing results in a needlessly early expenditure of funds, while tardy action may result in excessive deterioration or unsafe conditions and greater total maintenance expenditures. Currently available methods of rating pavements for the need of sealing are not totally adequate. They are time consuming, require the use of costly equipment and highly skilled personnel, rely on the judgment of experienced personnel, or are not reproducible. Methods and criteria for determining when seal-coat applications should be made are needed.

The purpose of this project was to develop criteria for the need of seal coating bituminous surfaces. These criteria were to be based on relatively simple methods, such as visual evaluation of pavement surfaces or the use of measuring devices or equipment. In establishing the methods of evaluating surfaces and criteria for sealing, various types or classes of bituminous surfaces should be distinguished. Also, the types of seals should be classified. It was suggested that emphasis be directed to so-called low-type bituminous surfaces, and that the seal coats include only those types with a thickness of ¾ inch or less; this would include thin plant-mix seals. (Attention is directed to HRB Circular No. 73 for classification systems.) The criteria for determining the need for a seal coat may differ for various types of bituminous pavements and for the use of different types of seals. The criteria should also indicate where other remedial measures should be used.

It was proposed that the following approaches be used:

1. Obtain and evaluate information on criteria and methods in use by agencies at the present time.
2. Develop tentative criteria for the need of seal coats.
3. After development of tentative criteria and the necessary rating methods, field test the procedure by application of the criteria by a number of individuals, and evaluate the consistency of their determinations.
4. Outline an experimental program for use by other agencies to evaluate the criteria and methodology.
5. Modify the criteria on the basis of the field tests and present the criteria and associated methodology in a form suitable for inclusion in maintenance manuals.

Research as initially proposed has been completed and tentative criteria for the need of seal coats based on a visual rating system of bituminous surfaces have been developed. After review of the preliminary draft report, the contract amount was increased to the AASHO initial allotment of $50,000 and the completion date was extended to provide for the preparation of training aids that would be useful in the implementation of the visual rating system. A draft of the training aids program, including a slide series, has been prepared and pilot tested in several states. The training aids are being modified, and the final report is being prepared.

AREA 11: LAW

Project 11-1 FY '65

Rules of Compensability and Valuation in Highway Land Acquisition

Research Agency: University of Wisconsin
Principal Invest.: Dr. Richard U. Ratcliff
Effective Date: January 1, 1965
Completion Date: April 30, 1967
Funds: $84,840

Difficult problems of compensability and valuation of land acquisition for highway rights-of-way continue to plague courts, highway administrators, and appraisers. This project analyzed current legal rules and appraisal practices and suggests methods to eliminate inconsistencies, ambiguities, and inequities based on constitutional mandates, sound judicial analysis, and appraisal theory and practice.

The research was to express the parameters of indemnity representing the ideal based upon logical and acceptable criteria, identify deviations from the ideal basic principles found in statutes, operating rules, and court decisions, analyze the motivation for these deviations, and suggest a workable compromise between the ideal and the practicalities in the application of the power of eminent domain.

The research included a sampling of reported highway condemnation cases involving evidentiary problems for 25 States covering a 16-year period. Cases of particular interest were cited to support the discussions about the specific rules of admissibility of various types of evidence.

The report contains information relative to the present law of evidence in eminent domain proceedings. Divergencies which appear in the law from State to State are identified and analyzed. The cause and extent of diversity are determined and the connection between evidentiary law and the legal rules, and standards of compensability and valuation, is examined. The reasons the courts give as a basis for their decisions to admit or exclude various types of evidence are set forth and described.

The final report has been published as:

NCHRP Report 104, "Rules of Compensability and Valuation Evidence for Highway Land Acquisition."

Project 11-1(1) FY '68

Eliminating Enhancement or Diminution Effects on Right-of-Way Valuation

Research Agency: Real Estate Research Corporation
Principal Invest.: Stanley F. Miller
Morris A. Lieberman
Effective Date: September 2, 1968
Completion Date: February 28, 1969
Funds: $5,000

Most frequently, the date of taking is the same as the date of valuation. However, especially in urban areas, valuation of property on such date frequently creates inequities, to either the property owner or the State because of an enhancement or diminution in value of the surrounding or subject properties resulting from the public improvement or the announcement thereof. The diminution occurs when knowledge of the highway improvement depreciates the value of property to be taken prior to the date of taking. The enhancement occurs when such knowledge appreciates the value of the property.

The objectives of the research were to assemble and analyze whatever statutory and case law now exists on this subject. Valuation problems involved were also studied.

The research included a study of the general principles and techniques (both valuation and legal) that cause enhancement or diminution in the value of surrounding properties or those being taken by eminent domain as a result of the date of valuation or announcement thereof. Statutory laws of each of the 50 States were examined.

The final report covers a general discussion of valuation principles, including identification of factors which cause enhancement or diminution of value. The impact of date of valuation is discussed, and case studies of the effect of time are presented. There is also a general discussion of the legal aspects and practices.

The final report has been published as:

NCHRP Report 114, "Effects of Proposed Highway Improvements on Property Values."

Project 11-1(2) FY '68

Recognition of Benefits to Remainder Property in Highway Valuation

Research Agency: Joseph M. Montano & Assoc.
Principal Invest.: Joseph M. Montano
Effective Date: October 1, 1968
Completion Date: March 31, 1969
Funds: $5,000

The subject of benefits is often discussed and casually considered, largely because it is a mandatory finding in many States, but rarely pursued with enthusiasm. Because of the need for more equitable treatment of the public interest, the practitioner, both legal and appraisal, needs to be more fully informed of the potential involved.

Actually there is a rather large and surprisingly liberal body of case law allowing a variety of benefits to offset or mitigate the amount of compensation that must be paid. These were collected, analyzed, and grouped, with emphasis on the most recent cases to ascertain trends. The desired end product was a trial memorandum that can be used by the practicing trial lawyer and appraised on a day-to-day basis. The research explored different approaches, both legal and appraisal, that would lead to greater recognition of benefits to offset or mitigate the amount of compensation which must be paid.

The final report gives a short and concise, but comprehensive, statement of what appellate courts have said about the trial aspects of benefits. It further contains an inventory of these appellate decisions, as well as a list of annotations, treatises, and legal periodicals. Moreover, the report gives some suggestions and ideas about what should be done and how to prove that benefits have resulted by virtue of the construction of public improvements.

The project report has been published as:

NCHRP Report 88, "Recognition of Benefits to Remainder Property in Highway Valuation Cases."

Project 11-1(3) FY '68

Taxation Aspects of Right-of-Way Acquisition

Research Agency: University of Tulsa
Principal Invest.: Dr. E. Dale Searcy
Effective Date: September 16, 1968
Completion Date: April 30, 1969
Funds: $2,500

Public land acquisition may have significant effects on landowners' tax status and liability, depending on alternative methods of valuation and payment of compensation. Such tax aspects should be considered, inasmuch as a full appreciation of the alternative methods of tax treatment of land acquisition can facilitate negotiations.

The objective of this research was to identify, analyze, and explain, with appropriate examples, the many elements of the taxation aspects of right-of-way acquisition. It included the Federal income and capital gains tax elements, but also treated these elements from a state income and ad valorem tax point of view for purposes of illustration.

The research distinguished, for taxation purposes, between all of the different compensation elements involved (i.e., relocation payments, partial takes, etc.). It included these and other elements involved in the various interests or awards (negotiations vs. condemnation, etc.) and types of properties (residential, business, agricultural, investment properties, etc.).

A final report was not submitted; therefore the contract was terminated.

Project 11-1(4) FY '68

Compensation in the Nature of Additives to Market Value

Research Agency: Univ. of Oklahoma Research Inst.
Principal Invest.: J. Dwain Schmidt
Effective Date: December 1, 1968
Completion Date: May 31, 1969
Funds: $2,500

In recent years, the courts, Congress, and the State legislatures have been and are being pressed to allow reimbursement or damages to property owners in addition to payment of compensation under the traditional market value concept. These include payment of interest; property owner's litigation costs, including appraisal and attorney fees; moving or relocation expenses; percentage premiums above market value; hardship premiums; business discontinuation allowances; rent supplements; etc.

The objective of this study was to analyze statutes and cases on a Federal and State-by-State basis to ascertain the present state of the law of these issues and to measure the trend, if any.

The research examined some outstanding cases concerning additives to market value in highway condemnation cases and delved into recent legislation materially affecting the law of eminent domain as it relates to just compensation.

The final report will not be published in the NCHRP report series; however, a summary is included in the *NCHRP Summary of Progress Through 1972*. Loan copies of the uncorrected agency draft are available on request to the NCHRP Program Director.

Project 11-1(5) FY '68

Rules of Discovery and Disclosure in Highway Condemnation Proceedings

Research Agency:	Long, Mikkelborg, Wells & Fryer
Principal Invest.:	Jeremiah Long
Effective Date:	September 15, 1968
Completion Date:	April 14, 1969
Funds:	$2,500

A significantly large body of statute and case law is developing concerning the applicability of State and Federal rules of discovery to eminent domain actions and the rights of the parties to compel disclosure of the opposition's valuation and other testimony. Depending on the way such disclosure is permitted, advance possession of the other party's valuation evidence, which is largely opinion, and the reasons therefor, may materially affect cross examination. The highway legal practitioner should be aware of the state of the law in this field.

Divergent conclusions and opinions relating to value are not based on the existence of differing facts, but on individual interpretation of those facts in the expert's valuation of the property before and after acquisition. No amount of independent pre-trial effort on the part of opposing counsel or his client will reveal the conclusions and opinions of the opposing experts. Add to the uncertainties of preparation for cross-examination and rebuttal the primary importance of expert testimony in condemnation actions and the wide divergence in the contents of such opinion, and it is not surprising that the field of eminent domain has produced the most activity and the greatest diversity of legal opinion in the area of pre-trial discovery of the opinions and conclusions of value experts retained for negotiation and in anticipation of litigation.

The final project report discusses the existing Federal and State cases on the subject, the statutes, and rules adopted in various jurisdictions to resolve the uncertainties attending discovery of expert opinion.

The project report has been published as:

NCHRP Report 87, "Rules of Discovery and Disclosure in Highway Condemnation Proceedings."

Project 11-1(6) FY '68

Valuation and Condemnation Problems of Selected Special Purpose Properties

Research Agency:	Edward E. Level
Principal Invest.:	Edward E. Level
Effective Date:	September 2, 1968
Completion Date:	November 28, 1969
Funds:	$7,500

Properties put to special uses are frequently required, in whole or in part, for highway right-of-way purposes. The rules of compensation and methods of valuation of such properties are inconsistent in their practical application, often with incongruous and varying results from State to State.

Research is needed to clarify the special-purpose-property field illustrated by the taking of cemeteries, parks, schools, and churches, or portions thereof. The research was to assemble and analyze the case law applicable to this class of property and the present state of appraisal practice in the field involving these special-use properties; and was to provide a clear exposition of the correct theory and practice, in terms of a series of alternatives applicable to such properties.

Schools, churches, cemeteries, parks, utilities, and similar properties, due to the lack of sales data, cannot readily be valued by the usual appraisal methods or legally allowable proof. The project report considers what special appraisal techniques and legal rules are applied in valuing such properties.

Cases and appraisal methods are discussed as to just compensation, elements of the special-purpose properties, appraisal evidence and evidence allowed, and the competency of witnesses in trials concerning special-purpose properties. Specific discussions of appraisal techniques and legal rules applicable to cemeteries, churches, parks, schools, and other special properties are discussed.

The project report has been published as:

NCHRP Report 92, "Valuation and Condemnation of Special Purpose Properties."

Project 11-1(7) FY '68

Valuation and Compensability of Noise, Pollution, and Other Environmental Factors

Research Agency:	Univ. of Oklahoma Research Inst.
Principal Invest.:	J. Dwain Schmidt
Effective Date:	October 1, 1968
Completion Date:	March 31, 1969
Funds:	$2,500

Highway departments today are confronted with some complicated takings, particularly in urban areas, wherein

allegations are made claiming damages which arise from highway-oriented noise, air and water pollution, and other similar environmental factors.

The decided cases in this limited area were singled out and examined, with careful analysis given to the valuation and legal compensability problems.

The power to take private property for a public purpose by eminent domain is a basic right of government. However, in the United States, private property shall not be so taken without the payment of just compensation. The question researched in this project was whether highway-produced noise, air, and water pollution—and other similar environmental factors—are the type of injuries for which compensation must be paid.

The final report will not be published in the NCHRP report series; however, a summary is included in the *NCHRP Summary of Progress Through 1972*. Loan copies of the uncorrected agency draft are available on request to the NCHRP Program Director.

Project 11-1(8) FY '68

Remainder Damages Caused by Drainage, Runoff, Blasting, and Slides

Research Agency: Harrison Lewis
Principal Invest.: Harrison Lewis
Effective Date: October 15, 1968
Completion Date: January 15, 1970
Funds: $7,500

During highway construction, or shortly thereafter, there are special types of damages relating to drainage, runoff, blasting, slides, etc., which sometimes result. Generally speaking, all damages which are the natural and probable result of involuntary takings are to be included and assessed in the condemnation proceedings, but the law and the appraisal practice relating to such special situations, litigated and negotiated, is far from clear and is not understood by many appraisers.

The purpose of the research was to identify and clarify these elements. The research included an assembly and analysis of case law from a majority of jurisdictions applicable to each of these special situations; an assembly and analysis of the best and prevailing appraisal principles applicable thereto; and a statement of the logical alternative methods of dealing with the valuation and damage problems involved, including the pros and cons of each such legal alternative.

The project report has been published as:

NCHRP Report 134, "Damages Due to Drainage, Runoff, Blasting, and Slides."

Project 11-1(9) FY '68

Valuation and Condemnation Problems Involving Trade Fixtures

Research Agency: Edward L. Snitzer
Principal Invest.: Edward L. Snitzer
Effective Date: March 15, 1969
Completion Date: December 1, 1969
Funds: $5,000

In the acquisition of commercial properties, questions and disputes often arise between condemnor and condemnee as to the obligation of the comdemning authority to take and pay for "trade fixtures." The condemning authority frequently takes the position that as same are movable, and hence not affixed to the freehold, they are personal property and thus they may be removed by the condemnee. In this area, the courts have also recognized a different rule than exists between landlord and tenant and mortgagor and mortgagee in regard to such fixtures.

The objective of the research was to review all appellate cases in the trade fixture area and to cite and compare these with selected typical landlord-tenant and mortgagor-mortgagee cases to illustrate the different rules of law applicable. Appropriate jury instructions, based on the decided cases, were developed as to the acquisition and valuation criteria that have been judicially prescribed. Comments were made on the valuation techniques involved, particularly as to how they may differ, if they do, from conventional methods of fixture valuation. Existing legal and appraisal literature was reviewed and cited, particularly law review articles, *ALR* annotations, and *The Appraisal Journal.*

The project report has been published as:

NCHRP Report 94, "Valuation and Condemnation Problems Involving Trade Fixtures."

Project 11-1(10) FY '68

Compensability and Valuation Aspects of Residential Displacement in Highway Programs

Research Agency: Ross, Hardies, O'Keefe, Babcock, McDugald & Parsons
Principal Invest.: Fred P. Bosselman
Effective Date: March 15, 1969
Completion Date: September 15, 1969
Funds: $5,000

Serious practical problems arise when highway construction unavoidably necessitates substantial displacement of residential units, both in urban and rural areas. Relocation of displaced residents is, in varying degrees, becoming a responsibility of public agencies. However, up to the present time alternative means and procedures for performing this responsibility have been limited, and it is evident that new and greater efforts in this activity must be made. Significant legal and valuation problems must be solved if legislators and administrators are to have guidelines for development of new methods of improving relocation assistance and for decisions between alternatives in specific situations.

The research report contains discussions of the constitutional requirements and limitations and how the basic standards for the payment of compensation to persons whose property is taken for public use are derived from such sources. The need for new compensation techniques

is discussed and analyzed. Traditionally, "consequential damages" resulting from the taking of a man's property have been considered part of the burden of citizenship. The rapid increase of residential takings has caused great pressure on government to compensate more of these consequential damages. The various monetary and nonmonetary effects are outlined to indicate the wide range of losses that may result when residences are taken.

The project report has been published as:

NCHRP Report 107, "New Approaches to Compensation for Residential Takings."

Project 11-1(11) FY '68

Valuation Elements of Joint Development Projects, Including Air Rights

Research Agency:	Real Estate Research Corp.
Principal Invest.:	John M. Bohling
Effective Date:	February 24, 1969
Completion Date:	August 25, 1969
Funds:	$5,000

Interest is increasing with respect to joint development projects involving highways and other kinds of public and private facilities. There is actually little information available, however, about the application of known appraisal concepts to such joint development projects. Additionally, a whole new valuation dimension has come into focus, involving the valuation of vertical planes of value (air rights). All of these aspects need to be explored.

The study briefly reviewed the legal factors covering the valuation of air rights and of joint development projects. An exploration was made of known appraisal concepts and valuation principles and their application to the valuation of multiple-use projects. The findings of this study will provide guidance for appraisal practitioners and public officials concerned with the valuation of joint development projects.

The study found that the current appraisal technique, as presented by the Keuhnle and White formulas, appears to present the best potential for the valuation of multiple-use projects, particularly as they apply to rights-of-way. These formulas present the value of the property interest to be disposed of (the air rights or tunnel easement) in order to approximate the difference between the value of the fee property before and after the specific property interest is conveyed. These formulas take into consideration other costs or benefits, such as (a) economic value loss because of reduction in functional utility due to construction, (b) added costs of constructing improvements in a different fashion than if erected on surface fee, (c) additional interest expense which would be incurred, (d) savings in excavation costs, (e) tenant relocation, (f) demolition.

The final report will not be published in the NCHRP report series; however, a summary is included in the *NCHRP Summary of Progress Through 1972*. Loan copies of the uncorrected agency draft are available on request to the NCHRP Program Director.

Project 11-2 FY '65

Theory and Practice in Inverse Condemnation

Research Agency:	Regional and Urban Planning Implementation
Principal Invest.:	Mrs. Barbara Hering
Effective Date:	February 1, 1965
Completion Date:	June 30, 1966
Funds:	$15,000

Legal procedures for determining the question of liability of damage occurring during or after highway construction are neither clearly understood nor agreed upon. This project was intended to review case law covering inverse condemnation, review techniques to litigate inverse condemnation claims and defenses, analyze administrative techniques used in handling such claims, and compare judicial treatment and alternative statutory proposals applicable to state highway department problems.

An intensive review of legal cases has been conducted for five States having a substantial volume of such cases. Questionnaires supplemented by personal contact studied legal and administrative practice.

The project report has been published as:

NCHRP Report 72, "Theory and Practice in Inverse Condemnation for Five Representative States."

Project 11-3 FY '67

Valuation and Legal Implications of Scenic, Conservation, and Roadside Easements

Research Agency:	Donald T. Sutte, Jr., and Assoc.
Principal Invest.:	Donald T. Sutte, Jr. Prof. Roger A. Cunningham
Effective Date:	November 1, 1966
Completion Date:	December 15, 1967
Funds:	$25,000

Because of the difficult problems that are emerging from the implementation of the Highway Beautification Act of 1965 and the scenic road programs, this project relates to the identification and application of legal and valuation principles for the acquisition of scenic, conservation, and roadside easements; outdoor advertising and junkyard activities; scenic enhancement interests; and the like.

All the available information was assembled pertaining to past experience in the use of scenic roadside easements and similar property interests in programs for scenic enhancement. An annotated bibliography of the relevant legal and appraisal literature has been prepared, and State and Federal highway agencies that have been active in acquisition of scenic easements were interviewed. The material was analyzed with regard to the statutory bases, the character of the easement, and the administrative and acquisition practices developed.

The researchers studied the steps for acquiring scenic easements, the advantages and disadvantages of scenic easements, and similar less-than-fee property interests. Model legislation was developed to deal with the legal problems identified.

The project report has been published as:

NCHRP Report 56, "Scenic Easements—Legal, Administrative, and Valuation Problems and Procedures."

Project 11-3(1) FY '68

Public Control of Roadside Advertising Signs for Highway Beautification

Research Agency:	Donald T. Sutte, Jr., and Assoc.
Principal Invest.:	Donald T. Sutte, Jr. Prof. Roger A. Cunningham
Effective Date:	October 1, 1968
Completion Date:	December 31, 1969
Funds:	$20,000

The Highway Beautification Act of 1965 made several major changes in Federal policy regarding control of roadside advertising, which changes have affected State and local programs on such matters and require valuation and legal studies.

Based on the assumption that compensation must be paid for the elimination of those signs erected before October 1965 that must be removed, the legal research included a review of all the decided cases discussing all the various elements of compensation and, in particular, the taking from the owner of the sign, display, or device of all right, title, leasehold, and interest in such sign, display, or device and the taking from the owner of the real property on which the sign, display, or device is located, the right to erect and thereafter maintain such signs, displays, and devices thereon.

The valuation research included a general discussion of all applicable valuation principles and concepts considering the special-purpose nature of outdoor advertising signs; gave consideration to the explanation of the alternative methods of estimating compensation for all elements; gave separate treatment to the methods of measuring business losses; and recognized and separately treated the different types of outdoor advertising signs. Actual illustrations and case studies were utilized.

The project report has been published as:

NCHRP Report 119, "Control of Highway Advertising Signs—Some Legal Problems."

Project 11-3(2) FY '68

Public Control of Junkyards for Highway Beautification

Research Agency:	Real Estate Research Corp.
Principal Invest.:	Stanley F. Miller Morris A. Lieberman
Effective Date:	September 2, 1968
Completion Date:	February 28, 1970
Funds:	$13,300

The Highway Beautification Act of 1965 made several major changes in Federal policy regarding control of junkyards, which changes have affected State and local programs on such matters and require valuation and legal studies.

Based on the assumption that compensation must be paid for the relocation, removal, or disposal of junkyards specified in the Highway Beautification Act of 1965, the legal research included an investigation of decided cases in five representative States. Furthermore, the statutory laws of the 50 States were examined as they pertained to the problem and the research objective.

The research included a general examination of valuation principles and concepts applicable to the valuation of junkyards. Careful and objective consideration was given to alternative methods of estimating compensation for all elements. The studies recognized and separately treated the different types of junkyard establishments.

The project report covers the basic principles of market value and compensation. Valuation practices and procedures are discussed and factors that cause enhancement or diminution of value are identified. Case studies are included in the report to show examples of the effect of time on value, and to show examples of remainder and specific parcels.

The project report has been published as:

NCHRP Report 112, "Junkyard Valuation—Salvage Industry Appraisal Principles Applicable to Highway Beautification."

Project 11-4 FY '68

Elimination of Wide Divergence in Right-of-Way Valuation

Research Agency:	Amer. Inst. of Real Estate Appraisers
Principal Invest.:	Frances Hokanson
Effective Date:	July 1, 1969
Completion Date:	February 28, 1971
Funds:	$24,959

Wide variations in valuation have been reported in many States. These have most frequently occurred in instances (a) where two or more appraisers are so divergent that their testimony has little merit and (b) where appraisal of severance damage is shown by subsequent experience to be wholly unrealistic. Continued occurrence of such instances results in unnecessarily high awards, and raises questions regarding validity of current valuation methods.

This research reviews, analyzes, and evaluates actual cases in which divergences existed. The reasons or bases for such divergences are identified. The research includes analyses of how divergencies relate to type of taking, type of use, level of government that acquires, and other factors. It also covers the extent to which appraisal divergencies reflect inadequacies in the appraisal process and techniques such as (a) misunderstanding of the facts of a particular appraisal, (b) lack of training and experience of appraisers, (c) conflicting legal and engineering premises, (d) problems of severance damages. Alternative solutions are suggested to eliminate or diminish such divergences. The alternative solutions explored include possible changes in the law, presentation and admissibility of valuation evidence, changes of appraisal concept, or methods of administration.

The project report has been published as:

NCHRP Report 126, "Divergencies in Right-of-Way Valuation."

Project 11-5 FY '71

Valuation of Air Space

Research Agency: Daniel, Mann, Johnson, & Mendenhall
Principal Invest.: Daniel J. McNichol
Effective Date: October 1, 1970
Completion Date: May 31, 1972
Funds: $49,800

Use of air space over or under highways gives great promise as a major means of fitting highway transportation into the urban environment. However, difficulties in placing a proper valuation on rights in air space are hampering such developments in some areas. It is imperative that better methods for making such valuations be devised so that proper and orderly development can proceed without delay.

The objective of this study was to provide guidelines, procedures, and documentation for the right-of-way agent and lawyer in valuation, legal, and administrative problems as applied to air space acquisition and planning. The primary emphasis was on developing applicable valuation theory and criteria.

The research includes an inventory and review of before-and-after case study material where air space has been bought, sold, or leased. An analysis has been made in terms of factors common to all cases and of special factors relevant to various uses of air space and various types of highway structures.

The research also evaluates the adequacy of existing legislation and analyzes and reports on legal ramifications that influence the valuation process, taking into consideration legal constraints peculiar to air space valuation. A basic theory for the evaluation of air rights has been developed.

The variables and factors that influence air space acquisition and the valuation processes have been identified and analyzed. Matrices have been developed to provide a comprehensive collection of relevant valuation factors, including economic feasibility analysis. The primary aim was to provide a clear and precise presentation of all factors considered in the valuation process and a basis for selecting the most desirable use.

The project report is in the NCHRP editorial and publication process.

AREA 12: BRIDGES

Project 12-1 FY '65

Deformation of Steel Beams Related to Permitted Highway Bridge Overloads

Research Agency: University of Missouri
Principal Invest.: Dr. Adrian Pauw
Dr. J. W. Baldwin, Jr.
Effective Date: February 1, 1965
Completion Date: June 30, 1967
Funds: $50,000

The bridge research in the AASHO Road Test demonstrated that permanent deformations can occur in steel beams due to a combination of load, fabrication, and environmental stresses which totally exceed the yield point of the steel. The current AASHO specifications permit overloads on the typical highway bridges in service, and the possible occurrence of similar permanent deformations in these could foreseeably affect the useful life of the structure. This study was confined to simple-span composite and simple-span noncomposite steel-stringer highway bridges and is directed to a determination of the causes and magnitudes of fabrication and environmental stresses, of the possible existence of permanent deformations in existing bridges due to current specifications, and of the effect from cycles of overloading.

This research was initiated to study the magnitude and effect of permanent deformations in simple-span composite and noncomposite steel-stringer highway bridges. It was proposed to include in the work a study of the causes and magnitudes of stress which, in addition to normal load stresses, lead to yielding of the steel stringer at load stresses with calculated magnitudes lower than the yield point of the material. Such factors as residual stress distribution due to rolling and welding, effects of thermal gradients, and the effects of creep and shrinkage of the slab on the stress in the steel were proposed for consideration. The planned level of subsequent effort related to (1) an analysis, for the overloads now permitted by AASHO specifications, of typical steel-stringer highway bridges of the specified type and modern design to determine the residual stress levels necessary to result in permanent deformations and (2) an extension of this analysis to determine the redistribution of residual stresses due to overloads causing permanent deformation and to determine the effect of repeated cycles of overloading.

The final report has been included in the report for Project 12-6 and is in the NCHRP editorial and publication process.

Project 12-2 FY '66

Distribution of Wheel Loads on Highway Bridges

Research Agency: Iowa State University
Principal Invest.: Dr. W. W. Sanders, Jr.
Effective Date: June 1, 1966
Completion Date: December 31, 1968
Funds: $79,512

The current AASHO specifications for the distribution of wheel loads to highway bridge floor systems are inadequate. This study correlated and evaluated the large amount of research conducted on this problem to date and made suitable recommendations for changes in the specifications covering wheel-load distribution factors for the various types of floor systems used in bridges. The major emphasis was on short- and medium-span bridges without skew. Included were floor slabs supported by steel, reinforced concrete, and prestressed concrete, as well as floor systems produced by adjacent box beams.

The final report has been published as:

NCHRP Report 83, "Distribution of Wheel Loads on Highway Bridges."

Project 12-3 FY '66

Development of Waterproof Roadway Joints for Bridges

Research Agency: Southwest Research Institute
Principal Invest.: Dr. E. W. Kiesling
J. E. Minor
Effective Date: December 15, 1965
Completion Date: March 14, 1969
Funds: $149,895

Difficult maintenance problems have resulted from bridge deck expansion joints as they are presently designed and constructed. These problems include corrosion and disintegration of structural elements due to the passage of water through the joints and curtailment of longitudinal movement due to the accumulation of foreign material in the joint. The problem is compounded by the range of longitudinal motion required for the proper functioning of the joint and the magnitude of skews of many joints. The research was directed toward the development of designs for economically feasible waterproof bridge expansion joints that adequately provide for thermal expansion and contraction and remain serviceable when installed normal or skewed to the line of traffic. Recommendations were made for the design, installation, and maintenance of the joints.

The research has been completed. The essential findings from the study have been reported in NCHRP Research Results Digest 14 (Oct. 1969). Because it contains proprietary information, the final report is available only to the sponsors of the Program.

Project 12-4 FY '66

Thermal Characteristics of Highway Bridges

Research Agency: Southwest Research Institute
Principal Invest.: Dr. Thein Wah
Effective Date: December 15, 1965
Completion Date: March 31, 1968
Funds: $102,400

Actual field studies on thermal behavior of bridges have shown that thermal forces can be of an appreciable magnitude and merit consideration. Inasmuch as present methods of design normally allow only for uniform thermal expansion of bridges, quantitative information is needed concerning all consequential ways in which temperature affects deformation and stresses in the structure. This study sought to determine the magnitude and significance of thermal gradients in girder-supported highway bridges and to develop an analytical method for predicting the resulting thermal stresses. Field tests were conducted to attempt to validate the analytical method.

The final report on this project will not be published in the NCHRP series. A summary is included in the *NCHRP Summary of Progress Through December 31, 1969.*

Project 12-5 FY '67

Protection of Steel in Prestressed Concrete Bridges

Research Agency: University of Denver
Principal Invest.: Dr. W. C. Hagel
Effective Date: September 15, 1966
Completion Date: November 15, 1968
Funds: $173,255

This project sought to determine environmental conditions under which special protection is required and to develop effective protective systems under both pre- and post-tensioning configurations. Specifically, the objectives were (1) to conduct a thorough survey of available domestic and foreign data on corrosion and prevention of corrosion of prestressing steel in bridges, buildings, pavements, and other structures; (2) to review present practice to evaluate the effectiveness of prevention of corrosion and mechanical damage during manufacturing, shipping, and placing; (3) to identify the mechanisms of corrosion which attack prestressing tendons under various conditions, possibly including, but not limited to, the influence of concrete and grout composition, the presence of free water, electrolysis, and the presence or absence of cracking; (4) to devise an appropriate accelerated corrosion test or tests simulating the various service conditions surrounding prestressing tendons; (5) to evaluate various possible protective systems for prestressing tendons, including, but not limited to, metallic, plastic, or inhibitive coatings, grout substitutes or admixtures, cathodic protection, etc.; (6) to perform field and laboratory experiments to determine the effectiveness of present grouting methods for post-tensioned work and to suggest improvements in methods and/or materials; and (7) to evaluate the effectiveness of concrete cover over tendons.

The final report has been published as:

NCHRP Report 90, "Protection of Steel in Prestressed Concrete Bridges."

Project 12-6 FY '67

Prediction of Permanent Camber of Bridges

Research Agency: University of Missouri
Principal Invest.: Dr. James W. Baldwin, Jr.
Dr. Adrian Pauw
Effective Date: February 1, 1967
Completion Date: January 31, 1969
Funds: $85,000

The present construction practices used in providing camber in rolled beams result in an unpredictable loss of camber during the early life of the bridge. This loss of camber occurs under loads lower than those causing strains

equal to the yield point of the material. There is a need for a determination of the causes of the loss of camber when the camber was produced by heat, strain, restraint, or a combination thereof. Toward fulfilling this need, the primary objective of this research was to recommend a means of predicting the permanent camber in rolled beams resulting from specific fabrication methods and to include (1) a thorough survey of available data on residual stresses in rolled beams; (2) a survey of existing methods of cambering beams and a classification of methods into different categories, if possible, with cambering by both mechanical and thermal means being studied; (3) the determination of the magnitude and distribution of residual stresses in beams as rolled and delivered to the fabricator without camber, with the beams studied being of sizes representative of typical highway bridges; (4) the determination of the effect of the cambering methods investigated on residual stresses; (5) the determination of permanent deformations in rolled beams without added camber when subjected to repeated loads at various levels with loads lower than those causing computed yield point stresses (this does not presume to be fatigue loading, but the number of cycles applied should be equal to six months service life of a bridge); (6) the determination of permanent deformations in rolled beams cambered by the methods investigated when subjected to repeated loads at various levels of loading lower than those causing computed yield point stresses, the number of cycles applied being equal to six months service life of a bridge; and (7) the formulation of a mathematical model (after the determination of objectives 5 and 6) for predicting the permanent camber.

The final report includes the findings of Project 12-1 and is being revised for publication.

Project 12-7 FY '67

Effects of Weldments on Fatigue Strength of Steel Beams

Research Agency:	Lehigh University	
Principal Invest.:	Dr. John W. Fisher	
Effective Dates:	Oct. 1, 1966	July 1, 1970
Completion Dates:	Jan. 31, 1970	Dec. 31, 1972
Funds:	$199,023	$200,000

The fatigue fractures observed in the coverplated steel beam bridges included in the AASHO Road Test, as well as those obtained in other similar structures, emphasize the important effect of welding and welded details on the life expectancy of highway beam or girder bridges. Also of great significance in these bridges are the loading history, the type of materials used, the design details, and the quality of fabrication. Among the more important design details are such factors as coverplates, stiffeners, attachments, and splices. To date, only approximate general mathematical design relationships have been possible on the basis of the limited existing experimental data. However, with the conduct of additional research, and an analysis and evaluation of the many interrelated fatigue parameters, suitable basic relationships can be developed to properly design welded bridges for a desired life expectancy.

The principal objective of Phase I of this research was to develop design relationships that define the basic behavior of welded coverplated beams under constant-amplitude fatigue loading. The results of the Phase I work have been reported in:

NCHRP Report 102, "Effect of Weldments on the Fatigue Strength of Steel Beams."

The Phase II work has the objective of extending the basic knowledge obtained under Phase I into important design considerations, including stiffeners and/or lateral and transverse connections. Phase II is to include a continuing review of existing data and mathematical relationships defining the fatigue behavior of various details under constant-amplitude loading. It also is to include a statistically designed and controlled experiment that is intended to provide new information for the development of suitable mathematical relationships that can predict the fatigue behavior of welded beams with stiffeners and/or lateral and transverse connections. Variables to be studied include applied stresses, design details, type of steel, and other significant factors.

Research has been completed, and the final report on Phase II is in the NCHRP editorial and publication process.

Project 12-8 FY '66

Bridge Rail Service Requirements as a Basis for Design Criteria

Research Agency:	Texas A & M University Research Foundation	
Principal Invest.:	Dr. Robert M. Olson	
Effective Dates:	Mar. 1, 1968	Jan. 2, 1970
Completion Dates:	Feb. 28, 1969	June 30, 1971
Funds:	$30,000	$70,000

Highway bridge railing systems have evolved through need and experience and with design information not fully substantiated by research. In recent years many full-scale crash tests on railings have been conducted providing much useful information, but still there is need for a better definition of service requirements. Of prime importance is a need for developing a fundamental concept of the purpose that railings are expected to serve under various site conditions, with due consideration being given to a balance between safety, appearance, and economy. Design criteria, when established, can then be correlated with existing research data for development of specifications for the design of various railing configurations and materials.

The Phase I research effort to develop tentative service requirements has been completed, and the results have been published as:

NCHRP Report 86, "Tentative Service Requirements for Bridge Rail Systems."

The Phase II effort has as its objective the quantification of the service requirements to produce design criteria for bridge rail systems. This objective is to be pursued by further establishing the validity of a simple mathematical model developed under Phase I; by conducting parameter studies using the mathematical model to evaluate simu-

lated vehicle-barrier collisions; by developing tables, curves, or nomographs for use by design engineers; and by refining the limits of tolerable deceleration on the basis of more recent information.

The agency has devoted study to the trends of automobile weights and dimensions; the evaluation of accident causation factors that may have a significant influence on the frequency of bridge rail-vehicle collisions; the analysis of structural response and failure mechanisms of concrete parapets; the relationship between barrier strength and rigidity versus vehicle damage and accelerations transmitted to the passengers; the effects of barrier design on the dynamic response of a vehicle; the required barrier height for certain selected vehicles; and analysis of crash-tested bridge rail designs by a mathematical model for purposes of further validating the model and theoretically estimating the efficiency of the design.

The Phase II research has been completed, and the final report is in the NCHRP editorial and publication process.

Project 12-9 FY '67

Elastomeric Bearing Research

Research Agency:	Battelle Memorial Institute
Principal Invest.:	J. C. Minor
Effective Date:	September 1, 1967
Completion Date:	January 31, 1970
Funds:	$84,800

The development of new elastomers and elastomeric bearing systems is proceeding at a rapid rate. The ability of these bearings and bearing systems to absorb the various loads and movements occurring in bridges in a more efficient manner and at a significantly lower cost than mechanical bearing systems justifies an effort to improve current designs. Toward this objective, this project contemplated research on elastomeric bearings and bearing systems using materials as defined in the AASHO specifications for elastomeric bearing pads.

The major objectives of the project were to evaluate (1) effect of geometry on compressive strain, compressive set, shear modulus, and rotational modulus for hardness between 50 and 70 durometer and sizes from 50 to 200 sq in., and the effect of lamination on these values; (2) relative performance of glued laminated pads compared to fully vulcanized units, including an effective test of the adhesion between layers; (3) relative performance of molded pads versus pads sawed from larger sheets with an evaluation of the sawing process and determination of an acceptable cut surface; and (4) evaluation of the aging and low-temperature (to —40 F) characteristics of the various pads.

The research has been completed, and the final report has been published as:

NCHRP Report 109, "Elastomeric Bearing Research."

Project 12-10 FY '70

Analysis and Design of Bridge Bents

Research Agency:	Portland Cement Association
Principal Invest.:	Dr. James E. Carpenter
Effective Date:	January 1, 1970
Completion Date:	December 31, 1973
Funds:	$297,900

The present strong emphasis on safe and aesthetic design of reinforced concrete highway bridges has resulted in substructure configurations that depart widely from the traditional footing-column-cap frame design. Aesthetic considerations often dictate the concealment of massive concrete caps and elimination of numerous vertical columns; however, design procedures in current use are not applicable to these new configurations. There is a general feeling that current procedures result in overdesigned structures containing much more steel than is necessary. Therefore, an urgent need exists for the development of appropriate design procedures.

Although the ultimate need is to establish valid design procedures that are applicable to many configurations of bridge bents, this project is limited to investigation of bent caps concealed in straight, continuous, reinforced concrete bridges.

It is anticipated that design procedures will be developed by (1) constructing and testing adequately-scaled reinforced concrete models of representative bents and (2) developing a mathematical model to correlate with the experimental results. The design procedures may be corroborated by data taken from full-size bridges instrumented during construction, but not necessarily as a part of this project.

Research is to be based on prototypes representative of popular box-girder designs. The accomplishment of the research is to include: (1) reviewing the technical literature; (2) determining a design procedure for single- and multiple-column bents; (3) determining the cap design width by defining the extent of superstructure participating in supporting the cap loads; (4) proof testing a model designed by the recommended procedure; and (5) specifying changes required in the AASHO specifications to permit use of the recommended design procedures.

To achieve the objectives of this research, a plan was developed that includes testing of one-fifth scale models of two reinforced concrete box girder bridges. These tests provide information on distribution of loads in the vicinity of the integrated bent cap. Five additional tests on model bent specimens will provide further information on the location of critical sections and the effective width of the bent cap. The specimens are intended to represent a transverse strip of bridge superstructure that is parallel to and includes the bent cap and columns. The reinforcement of the bent cap is being varied in these models, as well as column flare and the thickening of the deck slab. Analytical studies of load distribution in the entire bridges and of stress distribution in the bent cap accompany the experimental work. Finally, a one-fifth scale model of a bridge designed using recommendations developed from this research program will be constructed and tested.

Through December 31, 1970, the agency completed testing on the single-column support bridge model. Construction of the two-column support bridge model was completed, instrumentation was placed, and load testing began. Work continued on refining the computer program for

finite element analysis of box girder bridges. In addition, substantial work was accomplished on a computer program for load distribution.

Through December 31, 1971, the agency completed testing and analyses to determine the critical load placement for maximum stresses in the pier cap; determined that the pier cap is stronger in ultimate load capacity than the box girder spans; designed the remaining single-column bent box girder bridge models to be load tested; and constructed and initiated testing of the first bent model.

Through December 31, 1972, the agency completed testing and analysis of the four two-fifth scale single-column bent models. The load distribution and bent analyses also were completed during 1972. Work is continuing on the testing of a one-fifth scale double-column bent model of uniform deck thickness. Future efforts will be devoted to the development of a design procedure and the proof testing of a model of a bridge designed by that procedure.

Project 12-11 FY '71

Waterproof Membranes for Protection of Concrete Bridge Decks

Research Agency:	Materials Research & Development
Principal Invest.:	C. J. Van Til
	B. J. Carr
Effective Date:	August 1, 1970
Completion Date:	January 31, 1973
Funds:	$206,034

Many bridge decks suffer damage as a result of penetration of water and deicer solutions through the deck surface. One possibility for providing the protection necessary to alleviate this damage is to place an impermeable membrane over the entire deck surface. To be effective, such a membrane must maintain bond with the deck surface and must have sufficient extensibility to bridge active cracks without rupture through the range of temperature and loads to which the deck is subject. It is likely that, in order to realize an acceptable degree of permanence, the membrane either will be protected by wearing surface, such as asphaltic concrete, or will provide adequate wearing qualities within itself.

The objective of this research is to develop, or discover, one or more effective waterproofing membrane systems for use on concrete bridge decks. The study is planned for two phases; however, only Phase I is to be addressed at this time. It is anticipated that Phase II, field evaluation of selected membranes, will receive separate and additional funding following completion of Phase I.

Phase I of the research consisted of conducting a detailed literature search; defining the service requirements for effective membrane systems; conducting sufficient field inspections to evaluate selected systems, including application techniques; conducting controlled laboratory studies to identify and define those properties that affect performance of membrane systems, and devising qualifying tests relative to field performance; developing a procedure for determining cost-benefit ratios associated with the use of membrane systems, and demonstrating the procedure by example cases; and devising an experimental program for evaluating the performance in the field of selected membrane systems under service conditions.

The field inspection covered 15 different membranes at about 50 locations in 9 states. Analysis of the electrical resistance measurements taken as part of the field inspection revealed a wide range of effectiveness for the membranes examined. Most of the membranes appear to be ineffective in preventing the intrusion of water into the concrete deck. Resistance readings also indicated that certain membranes do not remain effective under applications of wheel loads. Observations of random cracking in the asphaltic concrete wearing surface over certain membranes indicated a problem in the system design. The analysis of bond values for the membranes examined showed a wide range of bond strength to exist.

About 70 systems were subjected to laboratory tests initially. Characterization and performance data (from both laboratory and field) eventually produced about a dozen survivor systems that appear to be promising candidates for further field evaluation. All of the survivors require a protective surfacing of asphaltic concrete to serve adequately, and all but two appear to require the application of an intermediate protective layer to avoid damage by construction operations subsequent to installation. An experimental program for further evaluation of the survivor systems has been designed. The report covering Phase I of the project has been received and is undergoing review. A decision on undertaking the further evaluation as Phase II of the project is pending.

Project 12-12 FY '71

Welded Steel Bridge Members Under Variable-Cycle Fatigue Loadings

Research Agency:	United States Steel Corporation
Principal Invest.:	C. G. Schilling
Effective Date:	October 1, 1970
Completion Date:	September 30, 1974
Funds:	$300,000

Highway bridges are subjected to a great variety of forces that range from constant dead load, through slowly changing forces due to creep of materials and temperature

differentials, to an almost infinite variety of live loads caused by moving vehicles. Currently, most bridges are designed to carry a static load produced by a design truck, with certain empirical allowances being made for dynamic effects. On the basis of these loads and an assumed frequency of occurrences, the design considers the static and fatigue properties of the material used. Not much is known about the actual service life of the bridge and the actual service loads.

The first major problem in predicting the life of highway bridges is to determine, from a heterogeneous spectrum of frequencies and amplitudes, the loading conditions to which the structure is subjected during its lifetime. A program of field tests is currently under way to develop this information.

This project is directed to the next major problem: to determine the behavior of welded highway bridge steels (for instance, A36, A441, and A514) under variable-cycle fatigue loads and to develop a hypothesis for the prediction of life expectancy from any spectrum of loading.

The primary objective of this project is to develop information on the properties of welded steel bridge members under variable-cycle fatigue loadings and to develop a hypothesis for the prediction of life expectancy from any spectrum of loading.

The agency plans to achieve the project objectives by: a study of pertinent past work, with particular emphasis on field measurements of stresses in bridges under traffic; a theoretical study to predict from existing hypotheses the fatigue behavior of small specimens and beams that will be tested later; variable-amplitude fatigue tests of small specimens simulating certain beam details for the purpose of verifying the variable-amplitude load spectra selected and crack propagation threshold assumptions; variable-amplitude fatigue tests of relatively large beams of various steels, with typical bridge details similar to those tested in NCHRP Project 12-7; and complete evaluation of the experimental results and development of methods of utilizing the results for design and specification purposes.

Through December 31, 1970, the agency concentrated on the collection and evaluation of field stress measurements of bridges under traffic available from the Federal Highway Administration and various state highway departments. In addition, a large effort went into planning a statistically valid experimental design for the pilot test program of small specimens and also the large beam specimens. Planning for the test setups, instrumentation, and methods for observation and recording was essentially completed.

Through December 31, 1971, the agency completed the review of field stresses in highway bridges, selected Rayleigh distributions for variable-amplitude stress spectra to be used in the experimentation, fabricated almost all the test specimens, initiated testing small specimens for crack-growth studies and beam coverplate simulation studies, initiated testing large welded beam specimens, and conducted analyses of the limited test data.

Through December 31, 1972, the agency concentrated primarily on testing beam and crack growth specimens. In October 1972 an interim report was submitted by the agency and reviewed by the project advisory panel. Section I of the report describes the material properties and fabrication methods for the beams and specimens. Section II describes the test setup procedures for the plate-specimen and the beam tests. Section III summarizes available field measurements of stresses in short-span bridges under traffic and describes the stress spectra that were developed from these measurements for use in the testing program. Section IV describes the fatigue-crack-growth behavior of 514 steel under the variable-amplitude random-sequence stress spectra developed in Section III. This report will not be published, but loan copies are available on request to the NCHRP Program Director.

Testing will continue for another year and a half.

Project 12-13 FY '73

Cathodic Protection for Reinforced Concrete Bridge Decks

Research Agency:	USS Engrs and Consultants
Principal Invest.:	J. B. Vrable
Effective Date:	October 1, 1972
Completion Date:	June 30, 1974
Funds:	$174,699

Many reinforced concrete bridge decks experience damage because of corrosion of the reinforcing steel. One potential method for controlling this corrosion is the application of cathodic protection. Effective cathodic protection must provide proper current distribution and achieve protective polarization of the reinforcing steel. Therefore, there is a need to develop design criteria and optimum designs for cathodic protection systems that can arrest or control corrosion of reinforcing steel in concrete bridge decks, particularly in existing structures.

The objective of this research is to develop a technically and economically feasible cathodic protection system(s) for reinforced concrete bridge decks. The objective is to be approached by two phases of research, only Phase I of which is to be addressed at this time. A decision on proceeding with Phase II will be made on the basis of the results from Phase I.

Phase I will consist of:

1. Determining the state of the art of cathodic protection for reinforced concrete bridge decks and identifying those systems, materials, and procedures that offer promise of controlling corrosion.
2. Devising and conducting laboratory research that will include analog and physical model testing to accomplish the following:
   (a) Establishment of the design and operations criteria and procedures for cathodic protection applied to typical reinforced concrete bridge decks.
   (b) Establishment of one or more systems to cathodically protect existing and future reinforced concrete bridge decks.

(c) Development of a procedure and determination of the costs and anticipated lives for the cathodic protection systems proposed.

3. Instrumenting and collecting test data on at least a 10-ft by 10-ft in plan, full depth, typically reinforced concrete bridge deck specimen to demonstrate the effectiveness of the cathodic protection system(s).

4. Proposing a method for evaluating the performance of selected cathodic protection systems on a bridge deck under service conditions.

Phase II, when undertaken, is expected to consist of a field evaluation of selected cathodic protection systems. In accordance with the outcome of Phase I research, tentative plans are to design and install a cathodic protection system(s) on a bridge(s) provided by a state highway department(s) and evaluate the effectiveness of the system(s).

Project 12-14 FY '73

Subcritical Crack Growth in Steel Bridge Members

Research Agency:	United States Steel Corporation
Principal Invest.:	Dr. John M. Barsom
Effective Date:	October 1, 1972
Completion Date:	June 30, 1974
Funds:	$99,923

Highway bridges are subjected to a great variety of forces, ranging from constant dead load, through slowly changing forces due to material creep and temperature differentials, to an almost infinite variety of live loads caused by moving vehicles.

The life of a welded steel bridge member may be determined by the size of the largest actively growing crack in the member that was not detected or was considered acceptable by inspection at the time of fabrication; the geometry of the welded details and effects on the rate of stable fatigue crack growth (current work on both NCHRP Project 12-7 and Project 12-12 deals with fatigue and crack growth of welded details in a benign environment); the increase of fatigue crack growth rate due to an aggressive environment; and the crack size that can initiate a rapid crack extension when the combined residual and applied stresses, crack size, and fracture toughness provide a critical condition. Some steel bridges have failed prematurely over the last 35 years because one or more of these factors were not considered properly in design.

Fracture toughness is presently being researched for a limited number of bridge steels by the U.S. Steel Corporation under AISI sponsorship and by Lehigh University under U.S. Department of Transportation sponsorship. Fatigue crack growth of welded details is being studied by the U.S. Steel Corporation and Lehigh University under NCHRP Projects 12-7 and 12-12. However, little has been published on the effects of aggressive environment on the rate of fatigue crack growth for bridge steels. In addition, no requirements have been established for fracture toughness levels for bridge steels, nor has the application of fracture mechanics and fracture toughness been applied to welded bridge details.

Accordingly, the long-range objective of this research is to develop information that will lead to prevention of unstable crack growth in welded steel bridge members. This objective includes the definition of material requirements and design specifications to avoid brittle fracture. The long-range objective is to be achieved through several phases of research.

Work in this project, Phase I of the long-range program, is limited to the determination of crack growth rates for stress intensity factor ranges (e.g., ΔK-10 to 100 ksi per sq in.) by means of cyclic loads simulating bridge conditions with stress fluctuation and under two environmental conditions. The steels to be studied include A36, A588 grades A and B, and A514 grades E and F. The environments are to be (1) 3% sodium chloride solution and (2) distilled water—both at room temperature. The test specimens are to be made from base metal of 1-in. plate material and are to be 1 in. thick.

The longitudinal and transverse tensile properties at room temperature are to be established for each grade of steel. Moreover, energy absorption, lateral expansion, and percent shear are to be determined in the temperature range between $-100°$F and room temperature by using standard impact Charpy V-notch specimens, the specimens being obtained from within the plate at a depth not less than ¼ of the thickness.

Through December 31, 1972, the agency conducted a review of available information and initiated testing of fracture toughness and chemical and mechanical properties.

Project 12-15 FY '73

Detection and Repair of Fatigue Cracking in Highway Bridges

Research Agency:	Lehigh University
Principal Invest.:	Dr. John W. Fisher
Effective Date:	October 1, 1972
Completion Date:	December 31, 1974
Funds:	$100,000

Relatively large reductions in fatigue strength of many welded details occur when fatigue cracks initiate and grow from the small micro-size defects that exist at the weld periphery. This behavior has been well demonstrated by studies on coverplated beams and other comparable details and has been reported in NCHRP Report 102, "Effect of Weldments on the Fatigue Strength of Steel Beams." Recently, fatigue cracking has been observed in the field where complete fracture of a tension flange was generated from fatigue crack growth at the toe of a transversely welded coverplate. In this instance, the bridge was only 13 years old. Subsequent inspection of 15 other coverplate ends revealed that the two beams adjacent to the cracked member were also cracked through about one-half the flange thickness. Smaller fatigue cracks were detected at several other coverplate ends.

To identify fatigue failures, a review of available methods for the detection of fatigue cracks is needed. Typical details that are most susceptible to fatigue cracking must also be identified. Methods are needed to improve the fatigue strength of severe notch-producing details of existing structures subjected to high volumes of heavy truck traffic.

The objectives of this research project are to: (1) compile a state-of-the-art review of existing methods of nondestructive inspection and evaluate their reliability and adaptability in the detection of fatigue cracks in welded highway bridges; (2) compile a state-of-the-art review of typical existing and currently designed welded bridge details and evaluate those most susceptible to fatigue crack growth. An interim report on the accomplishments under Objectives 1 and 2 is to be submitted at the end of the first contract year; (3) review and evaluate methods for improving the fatigue life and arresting the progress of fatigue damage that occurs at the weld toes of severe notch-producing details where the probability of failure is greatest. The methods are to be confirmed by tests of "as welded" and of fatigue-damaged coverplate beam specimens of A36 steel. These tests are to be comparable to and correlated with those conducted in NCHRP Project 12-7 and reported in NCHRP Report 102. The experimental variables are to include crack size at the time of repair or improvement, methods of improvement, stress range, and minimum stress; and (4) recommend methods for improving the fatigue life of, and arresting the progress of fatigue damage to, welded highway bridges.

Through December 31, 1972, the agency has been carrying out state-of-the-art reviews in pursuit of objectives (1) and (2). Preparations for the experimental work have also been started.

AREA 13: EQUIPMENT

Project 13-1 FY '65

Equipment Rental Rates

Research Agency: Ernst & Ernst
Principal Invest.: T. S. Dudick
Effective Date: February 1, 1965
Completion Date: January 31, 1966
Funds: $22,800

This research dealt with the development of uniform methods and procedures for establishing construction equipment rental rates. It included the establishment of the purposes for which rental rates are used; the feasibility of determining equipment rental rates by type, use, and region; a formula for equitable rental rates; and recommended procedures for obtaining and evaluating all information required for the various factors in the formula.

This research has been completed, and the project report has been published as:

NCHRP Report 26, "Development of Uniform Procedures for Establishing Construction Equipment Rental Rates."

AREA 14: MAINTENANCE OF WAY AND STRUCTURES

Project 14-1 FY '65

Upgrading of Unit Maintenance Cost Index and Development of Interstate Maintenance Requirements

Research Agency: Bertram D. Tallamy Associates
Principal Invest.: Dr. Bertram D. Tallamy
Effective Date: March 1, 1965
Completion Date: March 31, 1967
Funds: $205,128

This research involved an intensive study into typical maintenance operations on 28 Interstate test sections in several states for the purpose of satisfying the urgent need for a definitive system of determining maintenance requirements on a quantitative basis with due consideration being given to the requirements in terms of type, magnitude, and frequency. This system is applicable to Interstate highways within individual states and to comparable activities on the state highways. Attempts have been made to develop means for relating utilization of men, equipment, and material to production and maintenance operations and, further, to optimize efficiency in maintenance operations. The standards which were developed have been tested on a sample of maintenance operations on Interstate highways, and a unit maintenance cost index suitable for periodic updating was developed.

Research has been completed, and the project report has been published as:

NCHRP Report 42, "Interstate Highway Maintenance Requirements and Unit Maintenance Expenditure Index."

Project 14-2 FY '71

Techniques for Reducing Roadway Occupancy During Routine Maintenance Activities

Research Agency: Byrd, Tallamy, MacDonald, and Lewis
Principal Invest.: L. G. Byrd
Effective Date: October 1, 1970
Completion Date: March 31, 1973
Funds: $200,000

Highway maintenance activities often require occupancy of traffic lanes, structures, and shoulders of the roadway by men and equipment. This situation causes conflict between these activities and the traveling public, thus endangering both workmen and motorists and restricting the flow of traffic. The resulting development of hazardous situations and interference with the orderly flow of traffic is most pronounced where high-speed and/or high-density traffic conditions exist. There are several possible approaches to minimizing the problem and to providing a high level of safety, economy, and convenience for the highway user during required maintenance activities. At this time, utilization of techniques designed to reduce

occupancy of the roadway by maintenance activities appears to offer potential for alleviation of the problem with least duplication of research efforts.

The objectives of this project are to identify and evaluate superior existing techniques and promising new techniques that will significantly reduce the time of occupancy of the highway travel way and shoulders by maintenance forces for at least the following specific routine maintenance activities:

(a) Bridge deck repairing.
(b) Travel way patching.
(c) Crack and joint sealing.
(d) Mudjacking and subsealing.

Techniques for accomplishment of maintenance activities are intended to encompass the entire operation, including the necessary manpower, equipment, and materials. However, the development of new materials or equipment is not considered to be within the scope of this study.

It is intended that the research will include the following:

1. By actual field observations, measurements, and other methods, collect information on existing techniques and promising new techniques for accomplishment of each of the specific maintenance activities and evaluate their potential for reducing the conflict between maintenance operations and traffic in terms of such considerations as roadway occupancy time, relative hazard, public inconvenience, productivity, and economics.
2. Identify the techniques for accomplishment of maintenance activities that appear to be applicable to the problem but need further testing and field evaluation and the specific maintenance activities for which new or modified techniques should be developed and field tested.

Initial research effort has concentrated on collection and analysis of maintenance techniques for the listed routine maintenance activities. Each such activity has been subdivided into several individual tasks; some 18 tasks have been identified as the principle elements of the activities being studied. Thirty-four techniques for the accomplishment of the various tasks have been described in detail in Special Progress Report No. 2. A procedure has been developed for the evaluation (in terms of such considerations as roadway occupancy time, productivity, and economics) of different combinations of techniques for the accomplishment of a specific maintenance activity. The procedure can also be used to identify the task within an activity that most significantly influences roadway occupancy time, and thus should be a candidate for emphasis on development of new or modified techniques to reduce it.

Time-lapse photography is being used for data collection and analysis. Movie cameras using color film and a timing mechanism causing one frame to be exposed each 2-sec interval record the complete operation of a maintenance activity. The film is then analyzed through a special projector showing individual frames or operating at various speeds. Data have been collected in 12 states for all of the activities being studied. These data are being analyzed to determine productivity levels for each technique being used for accomplishment of the maintenance activities. Arrangements have been made for evaluation of modified techniques for several maintenance activities. Time-lapse photography of the original and modified techniques will provide a before-and-after record of procedures for reducing roadway occupancy time.

Project 14-3 FY '73

Improved Pavement-Shoulder Joint Design

Research Agency: Georgia Institute of Technology
Principal Invest.: Dr. R. D. Barksdale
Effective Date: September 15, 1972
Completion Date: September 14, 1974
Funds: $99,754

Many miles of highways have been constructed and are being designed and constructed with portland cement concrete roadway pavements and bituminous-surfaced shoulders. The resulting longitudinal joint between the pavement and the shoulder contributes to costly maintenance and inconvenience to motorists. Keeping this joint sealed to prevent the intrusion of water and other objectionable material is very difficult, but of prime importance to pavement performance. If the joint is not completely sealed, surface water will eventually get beneath the pavement and paved shoulder and contribute to pumping, faulting of transverse pavement joints, and shoulder settlement. Additionally, the presence of water in the subgrade and base course can cause swelling of some soils and frost damage in cold climates that, when combined with the physical forces of expansion and contraction and compaction under heavy wheel loads, results in deterioration of both pavement and shoulder surfaces.

Although the construction and maintenance of completely watertight pavement-shoulder joints for the life of the pavement is generally conceded to be impossible, it is believed that an effort should be made to minimize the passage of surface water through the joint. Because some water is therefore likely to enter through the joint at some time during the pavement life, provisions also should be made for subsurface drainage and/or treating the pavement layers to minimize the effects of the water. Consequently, there is need to develop reasonably adequate sealing systems for the joint, and to identify suitable design and construction techniques, including subsurface drainage, that will minimize the effects of the presence of some water.

The objectives of this project are to:

1. Determine the most suitable currently available procedures (including methods and materials for sealing the joint, subsurface drainage, and other methods for minimizing the effects of water) for alleviating the problems associated with the joint between a portland cement concrete pavement and a bituminous surfaced shoulder, taking into account the variations in such factors as climate, subgrade, roadway pavement design, shoulder design, and traffic.
2. Develop and experimentally evaluate improved systems for minimizing the passage of water through the pavement-shoulder joint.

3. Prepare a plan for a field study program that could be undertaken by highway agencies to evaluate promising procedures for sealing the pavement-shoulder joint.

The research is being conducted jointly with the University of Michigan.

AREA 15: GENERAL DESIGN

Project 15-1 FY '66

Guardrail Design

Research Agency: Cornell Aeronautical Laboratory
Principal Invest.: Raymond R. McHenry
Effective Date: December 15, 1965
Completion Date: June 14, 1966
Funds: $19,723

Many factors are involved when the highway design engineer is faced with the decision of when to install a guardrail. The decision should be based on rational warrants for their use, and the system should be effective and compatible with these warrants. A number of agencies have conducted tests on various systems. The resulting data on design and warrants need to be evaluated in order to provide the engineer with a choice of effective systems. Phase I of the project was directed toward the search and evaluation of existing data on design and warrants, a critical analysis of past and current research, and defining additional needed research.

Research has been completed, and the project report has been published as:

NCHRP Report 36, "Highway Guardrails—A Review of Current Practice."

Project 15-1(2) FY '66 and FY '70

Guardrail Performance and Design

Research Agency:	Southwest Research Institute	
Principal Invest.:	J. D. Michie	
Effective Dates:	July 1, 1967	May 1, 1970
Completion Dates:	Aug. 31, 1970	Oct. 31, 1971
Funds:	$280,000	$100,000

Highway design engineers need a choice of effective guardrail systems. The considerable research already conducted on the more commonly used types (W-beam, standard cable, box beam) needed to be compared and analyzed critically for determination of further investigations necessary to refine structural details and to obtain more effective performance. A need for full-scale testing was apparent to fill in the gaps in previously concluded investigations. Accordingly, the objectives of the Phase I research were: (1) to critically analyze existing data on guardrail performance and identify additional needed research; (2) to conduct additional full-scale performance tests; and (3) to evaluate performance of various guardrail systems considering vehicle response and damage as a measure of accident severity and rail repair.

The Phase I findings have been published as NCHRP Report 54, "Location, Selection, and Maintenance of Highway Guardrails and Median Barriers," and NCHRP Report 115, "Guardrail Performance and Design." A 10-min sound film that summarizes the Phase I research is available on loan.

The Phase II work consisted of four major tasks. The first task was to prepare a revision to NCHRP Report 54 that incorporates pertinent findings from the Phase I research and the findings from research conducted by others. Task 2 of the Phase II work was the preparation of a document to delineate warrants, service requirements, design criteria, and design procedures for all traffic barrier systems. For this purpose traffic barrier systems were defined as including guardrail, median barrier, bridge rail, and energy attenuation devices. Task 3 included the formulation of new concepts for improved end treatments for longitudinal traffic barriers, with some work devoted to improved transitions. Task 4 included the full-scale crash test evaluation of those promising concepts produced under Task 3.

The results of Phase II Tasks 1 and 2 have been published as NCHRP Report 118, "Location, Selection and Maintenance of Highway Traffic Barriers." The results of Phase II Tasks 3 and 4 have been published as NCHRP Report 129, "Guardrail Crash Test Evaluation—New Concepts and End Designs."

Additional work is under contract and, for administrative reasons, has been designated Project 22-2, "Traffic Barrier Performance and Design." Details will be found under that heading.

Project 15-2 FY '66

Design to Control Erosion in Roadside Drainage Channels

Research Agency: University of Minnesota
Principal Invest.: Dr. Alvin G. Anderson
Effective Date: July 1, 1966
Completion Date: June 30, 1973
Funds: $95,000

The highway drainage engineer is required to provide designs to control erosion in roadside drainage channels over a wide range of conditions. Acceptable procedures have been developed for the design of channels for conditions where easily established grass cover will suffice and for conditions where paved linings are required. The objectives of this study are to establish criteria and extend existing procedures for conditions intermediate between these two. The major emphasis of the research will be placed on developing a procedure for the design of armored channels, with investigations into the critical tractive force of gravel and crushed stone.

The project report covering the initial phase and portions of the continuation phase dealing with channel bends and nonsymmetrical channel shapes has been published as:

NCHRP Report 108, "Tentative Design Procedures for Riprap-Lined Channels."

A field evaluation of the tentative design procedures is in progress as the final portion of the continuation phase of the study.

Project 15-3 FY '68

Rational Structural Analysis and Design of Pipe Culverts

Research Agency: Northwestern University
Principal Invest.: Dr. R. J. Krizek
Dr. R. A. Parmelee
Effective Date: October 1, 1967
Completion Date: December 31, 1968
Funds: $49,937

Various methods are currently being used in the design of pipe culverts, and considerable research is in progress that examines these methods. There is a general lack of agreement between theory and field experience. Current methods being used in design of culverts fail to reflect in a rational way many of the major aspects of behavior observed in the field.

The objective of this study was to evaluate previous research and current practice for the purpose of developing rational design methods for both rigid and flexible pipe culverts.

Research has been completed and a project report has been received containing an extensive bibliography and synthesis of current knowledge on the design and installation of pipe culverts. It is apparent that information is not available at this time to develop a completely rational structural design procedure, due largely to lack of a generally accepted definition of pipe failure. However, several specific factors, such as installation practices, construction techniques, soil type, and safety factor, can be given greater consideration in design criteria.

The project report has been published as:

NCHRP Report 116, "Structural Analysis and Design of Pipe Culverts."

Project 15-4 FY '68

Estimating Runoff Rates from Small Rural Watersheds

Research Agency: The Travelers Research Center
Principal Invest.: Dr. Paul Bock
Isadore Enger
Effective Date: September 1, 1967
Completion Date: March 16, 1970
Funds: $299,902

A basic problem in designing highway bridges and culverts for stream crossings is the determination of the flow to be accommodated. This involves estimating the magnitude of peak flows at various frequencies for the drainage area under consideration. Most small rural watersheds are ungaged, thus the engineer is required to estimate the design flow for these areas on the basis of limited topographic and climatic data.

Many state highway departments and other agencies are participating with the U.S. Geological Survey in programs to collect runoff information from small rural watersheds that is intended to provide a better understanding of the generation of runoff. With this background, it appeared possible to develop improved procedures for estimating the magnitude and frequency of peak flows for small rural watersheds (approximately 20 sq mi or less). The objective of this project was to develop such procedures that (1) require only data readily obtainable by designers, (2) use parameters that are logically justified, (3) take cognizance of differences due to geographic characteristics, and (4) present the results in readily usable form.

The objectives have been partially met in that methods for estimating the magnitude and frequency of runoff from small rural ungaged watersheds have been developed. The question of whether they provide better estimates of runoff than currently used methods for a given watershed is not easily answered. Indications are that they may provide better estimates in some cases. Of probably greater significance is the compilation of information for 493 rural watersheds with an area of 25 square miles or less and at least 12 years of surface runoff data that can be used by others to develop better methods of prediction for a particular locality.

The research has been completed, and the project report has been published as:

NCHRP Report 136, "Estimating Peak Runoff Rates from Ungaged Small Rural Watersheds."

Project 15-5 FY '68

Dynamic Characteristics of Heavy Highway Vehicles

Research Agency: General Motors Corporation
Principal Invest.: D. E. Pollack
Effective Date: August 15, 1967
Completion Date: January 10, 1969
Funds: $135,000

The dynamic loading of bridges and pavements by heavy highway vehicles influences the life expectancy of these highway structures by an unknown amount. Increasing permissible vehicle loads and speeds may increase the dynamic loading and shorten the life of these structures.

Dynamic pavement loading is influenced by the pavement roughness characteristics and by certain characteristics of the vehicle. It is necessary to consider these factors in order to predict the loads that will be produced.

With the foregoing in mind, information was gathered on those vehicle characteristics that make a significant contribution to the dynamic forces. Equipment for measuring these characteristics was constructed and the characteristics of representative types of heavy vehicles were determined.

The research has been completed, and the final report has been published as:

NCHRP Report 105, "Dynamic Pavement Loads of Heavy Highway Vehicles."

Project 15-6 FY '68

Development of Criteria for Safer Luminaire Supports

Research Agency: Texas A & M University Research Foundation
Principal Invest.: Dr. T. C. Edwards
Effective Date: September 1, 1967
Completion Date: August 31, 1968
Funds: $150,000

Conventional luminaire support poles are, of necessity, mounted close to the traveled roadway. In this location, they constitute a severe roadside hazard and are frequently struck by vehicles that are out of control, with attendant severe vehicle damage and injury or death to occupants.

The purpose of this study was the development of luminaire support design criteria to minimize the hazard described. Consideration was given to the hazard presented to both the striking vehicle and to nearby traffic.

Five classifications of safety devices for luminaire supports, as presently being specified by state highway departments or industry, were investigated. These are: (1) frangible bases for use with aluminum or steel shafts, (2) the progressive failure-shear base, (3) a stainless-steel shaft with integral transition base, (4) an aluminum shaft on a cast-aluminum shoe base, (5) the multidirectional slip base.

The research has been completed, and the final report has been published as:

NCHRP Report 77, "Development of Design Criteria for Safer Luminaire Supports."

AREA 16: ROADSIDE DEVELOPMENT

Project 16-1 FY '66

Effects of Deicing Compounds on Vegetation and Water Supplies

Research Agency: Virginia Polytechnic Institute
Principal Invest.: Dr. R. E. Blaser
Effective Date: March 1, 1966
Completion Date: April 30, 1972
Funds: $217,300

This study was conducted in two parts. The objectives of Part I were to determine the adverse effects of deicing compounds used in winter maintenance operations in snowbelt areas on vegetation along the highway. Means were sought to counteract any detrimental effects resulting from the use of these compounds and to make recommendations for the implementation of the research findings. As Part II of the study, the state of the knowledge was established concerning the effects of deicing compounds on water supplies for domestic, agricultural, and fish and wildlife uses. Recommendations for needed research in this area were made.

For Part I of the project, more than 30,000 plants of various types, as well as turf plots, were established on soils of three distinctly different physiographic regions. These are located at Blacksburg (mountain), Warsaw (coastal), and Organ, Va. (piedmont). During three winters, plots were treated with sodium chloride and calcium chloride at various rates. A number of plots received no treatment for (1) comparison and (2) future treatment as more mature plants. After three winters, there was evidence of detrimental effects from the chlorides, variations in plant tolerance, and some variation of effect with soil and climatic conditions. Plant and soil samples were collected for laboratory analysis.

Part I (Phase II) of the study has been completed and the preliminary draft copy of the report is in the review stage.

Part II (Phase I) of the study has been completed, and the report on this part of the project has been published as:

NCHRP Report 91, "Effects of Deicing Salts on Water Quality and Biota—Literature Review and Recommended Research."

Project 16-2 FY '68

Evaluation of Research on Roadside Development

Research Agency: Western States Landscape Associates
Principal Invest.: Wayne O. Earley
Effective Date: October 1, 1967
Completion Date: March 31, 1969
Funds: $100,000

The objective of this project was to review, interpret, and evaluate past and present research on roadside development, describe areas where additional or continued research is needed, and recommend procedures for resolving these needs. The study included, but was not limited to, consideration of the relationship of roadside development and (1) highway location and design; (2) vegetation (planning, establishment, and management by plant growth zones in consideration of erosion control and roadside plantings); (3) resource conservation; (4) rest areas, scenic turnouts, and overlooks; (5) safety; and (6) right-of-way, scenic areas, and adjacent land use. Recognition was given to research under way or accomplished in legal authority, but it was not evaluated in this project.

The research has been completed, and the project report has been published as:

NCHRP Report 137, "Evaluation of Research on Roadside Development."

Project 16-3 FY '73

Erosion Control During Highway Construction

Research Agency:
Principal Invest.:
Effective Date: To Be Determined
Completion Date:
Funds:

Soil erosion is one of the principal causes of water pollution and it results in numerous other harmful effects on the quality of the environment. If the sedimentation occurs in

scenic private or public ponds, reservoirs, residential yards, or scenic rivers or creeks, it is to be expected that considerable public resentment may occur. Soil erosion during highway construction increases costs and causes needless delays and repairs. Rapid seeding of slopes is the most appropriate procedure in rural areas, but if appreciable sedimentation cannot be tolerated, other extraordinary measures must be taken. The serious consequences of soil erosion are many and cannot be overemphasized. On April 30, 1970, mandatory restrictions and requirements during construction activities were stated in a Federal Highway Administration Instructional Memorandum titled, "Prevention, Control and Abatement of Water Pollution Resulting from Soil Erosion." Research is contemplated to develop more effective techniques and materials to control erosion during construction activities at any time of the year until permanent protection is achieved. This includes protection of soil by vegetation or by other means, such as the liquid products that are appearing on the market and purport to provide a temporary layer on soil to shed water. NCHRP Project 20-5, "Synthesis of Information Related to Highway Problems," has completed a synthesis on "Erosion Control on Construction Projects," that is being used as the point of departure for Project 16-3 to accomplish the aforementioned objective. As research on this project is to be carried out in phases (Phase I having the objective of synthesizing all current information and then developing a research plan for the entire project) the Project 20-5 results will provide a sound point of departure.

AREA 17: SAFETY

Project 17-1 FY '66

Development of Improved Methods for Reduction of Traffic Accidents

Research Agency: Cornell Aeronautical Laboratory
Principal Invest.: John W. Garrett
Effective Date: February 1, 1966
Completion Date: May 31, 1968
Funds: $247,847

The objective of this research was to develop motor vehicle accident investigation procedures, records, and statistics, which will more accurately reveal accident causation than the current accident record system. An extensive review of the state of the art revealed that the current data collection forms and procedures do not meet research requirements; few statistically trained personnel are employed for data analysis. Also, safety findings are assimilated slowly by the agencies responsible for the design, maintenance, and operation of the highway system. Long-term recommendations included an improved centralized accident record system in which accident data were integrated with appropriate nonaccident data. Also proposed was a multilevel accident reporting scheme providing minimum data on all accidents, intensive investigative data on a small percentage of accidents, and special study data collected for a statistical sample of accidents. Improved cooperation between operating agencies with similar objectives was regarded as essential. Short-term recommendations included increased dissemination and utilization of current safety knowledge; utilization of modern technology at all levels of the system through the initiation of continuing education seminars and a safety review board; use of trained statistical personnel and techniques for better utilization of data; and use of accurate accident location methods. Location methods were reviewed and evaluated for guidance. Demonstration studies were performed to illustrate the feasibility of the proposed system and the techniques required. The study demonstrated the use of police to gather factual data in a study where they were provided with special report forms, written instructions, special training, and equipment. Utilization of intensive accident investigation procedures and the use of both accident and nonaccident data in a study also were demonstrated.

The project report has been published as:

NCHRP Report 79, "Development of Improved Methods for Reduction of Traffic Accidents."

Project 17-2 FY '72

Methods for Evaluating Highway Safety Improvements

Research Agency: Operations Research
Principal Invest.: Harry Denning
Effective Date: January 10, 1972
Completion Date: June 20, 1972
Funds: $29,973

Methodology for measuring the effectiveness of potential safety improvements has been established. This methodology includes statistical design and analysis for before-and-after and parallel studies. In addition, cost-benefit methodology has been documented in the research literature. However, in terms appropriate to engineers and technicians who actually do studies, a single document does not exist that contains the techniques for applying all aspects of the above-mentioned analytical tools.

The objective of the research is to provide a detailed technique in the form of guidelines from which calculations can be made that will allow officials to judge the effectiveness of highway improvements in terms, not only of reduced accidents, but also of cost-benefit of such improvements.

Progress through June 30, 1972, included detailed planning for the project, preparation of a detailed working plan, and termination of the contract.

Project 17-2A FY '72

Methods for Evaluating Highway Safety Improvements

Research Agency: Roy Jorgensen Associates
Principal Invest.: John C. Laughland
Effective Date: Contract pending
Completion Date:
Funds: $97,134

Methodology for measuring the effectiveness of potential safety improvements has been established. This methodology includes statistical design and analysis for before-and-after and parallel studies. In addition, cost-benefit methodology has been documented in the research literature. However, in terms appropriate to engineers and technicians who actually do studies, a single document does not exist that contains the techniques for applying all aspects of the above-mentioned analytical tools.

The objective of the research is to provide a detailed technique in the form of guidelines from which calculations can be made that will allow officials to judge the effectiveness of highway improvements in terms, not only of reduced accidents, but also of cost-benefit of such improvements.

AREA 18: CONCRETE MATERIALS

Project 18-1 FY '68

Revibration of Retarded Concrete for Continuous Bridge Decks

Research Agency: University of Illinois
Principal Invest.: Dr. H. K. Hilsdorf
Effective Date: September 1, 1967
Completion Date: December, 1, 1969
Funds: $103,895

Transverse and longitudinal cracking of continuous concrete bridge decks can be caused by changes in deflection and rotation over supports during construction, in addition to the possible effect of restraint to subsidence (bleeding) afforded by the top reinforcing steel. Such cracking is of significance with respect to the development of spalling. Revibration of retarded concrete may be useful in eliminating such occurrences in continuous bridge decks placed in one operation; therefore, this research had the objectives of (1) conducting a survey to determine the extent to which either delayed vibration or revibration has been used in placing bridge deck concrete, including the purpose, conditions, and results; (2) determining by laboratory and/or field tests if transverse and longitudinal cracking can be significantly reduced by revibration after retarded concrete has been placed over the entire deck of a continuous bridge or a complete segment of several spans supported by a continuous girder system; (3) determining the effect of revibration and subsequent finishing on the durability of bridge deck surfaces exposed to deicing chemicals; and (4) determining the most effective and practical means of revibration in the field.

The research has been completed, and the final report has been published as:

NCHRP Report 106, "Revibration of Retarded Concrete for Continuous Bridge Decks."

Project 18-2 FY '73

Use of Polymers in Highway Concrete

Research Agency: Lehigh University
Principal Invest.: Dr. John A. Manson
Effective Date: October 1, 1972
Completion Date: September 30, 1975
Funds: $300,000

Deterioration of concrete bridge decks, reduction of skid resistance on concrete surfaces, unacceptable concrete wear rates, and a need for thinner and stronger concrete slabs are problems that confront every state highway department. The public experiences considerable inconvenience and expense as a result of obstruction to traffic caused by reconstruction and making repairs as necessary. Among the major deficiencies of some of the concrete presently used are high permeability, low strength, cracking, low wearing ability, and spalling. The mechanisms causing deterioration include frost action, differential expansion and contraction, reinforcement corrosion, chemical attack, traffic loads, and wear.

Polymer-impregnated concrete has been reported to provide significant increases in strength and durability. However, present developments and techniques have not progressed to the extent that they are adequate for field use; therefore, more work in this area is required.

The over-all objective of this project is to develop the technology for the economical use of polymers to improve the serviceability of concrete in highways. The immediate goal of this project concerns economically feasible methods for impregnation of both old and new concrete bridge decks in place.

To avoid unnecessary duplication of effort, the work will be structured to consider all known related work completed or in progress at such institutions as the U.S. Bureau of Reclamation, Brookhaven National Laboratory, and the University of Texas.

More specifically, the work will include the following:

1. Selection of a chemical system such as methyl methacrylate or polyester-styrene and appropriate catalysts, accelerators, etc.
2. Development of field techniques and apparatus for surface impregnation of concrete using the selected chemical system. The apparatus will be scaled for field use on bridge decks, although not necessarily developed to the stage of a production item.
3. Evaluation of the effectiveness of the technique as related to (a) properties and condition of the concrete to be impregnated, (b) preparation of concrete for impregnation, and (c) properties of impregnated concrete (especially durability, skid resistance, abrasion resistance, strength, impermeabilty, etc.)
4. Demonstration of the techniques in the field on one or more existing bridge decks, and tests thereon as in Task 3(c). At least one of the decks will be chloride-contaminated but otherwise sound except for areas of steel corrosion. Impregnation to the bottom of the top layer of reinforcement, or to a depth of 4 in., will be sought.
5. Preparation of a manual describing procedures that may be used to routinely impregnate concrete bridge decks.

The program is being conducted jointly by Lehigh University and The Pennsylvania State University.

AREA 19: FINANCE

Project 19-1 FY '68

Budgeting for State Highway Departments

Research Agency: Ernst & Ernst
Principal Invest.: F. W. Hinck, Jr.
Effective Date: September 5, 1967
Completion Date: September 4, 1968
Funds: $45,000

Effective budgeting is interwoven with and is basic to the whole management and decision-making process. In seeking its fullest benefit, budgeting needs to be applied to all potential uses. The modern concept of the total budget process views budgeting as an integral part of planning, administration, and policy making.

Although budget plans of varying effectiveness now exist in the several state highway departments, there is no indication that highway administration recognizes and utilizes the budget process to its full potential.

Research is needed with the long-range objective of devising a concisely defined framework of budget systems, together with detailed documentation for implementing policies and procedures. To meet this need, the researchers analyzed the organization plans and funding arrangements controlling state highway departments. They determined in detail the prerequisites which must be satisfied and the problems requiring resolution for effective state highway budgetary systems to be instituted. Documented recommendations were developed for devising a concise universal state highway budgeting system with detailed aids for implementing appropriate policies and procedures.

Research has been completed. The project report will not be published in the regular NCHRP report series, but the essential findings from the report have been published in NCHRP Research Results Digest 20.

Project 19-2(1) FY '69

Develop Performance Budgeting System to Serve Highway Maintenance Management

Research Agency: Booz • Allen & Hamilton
Principal Invest.: H. L. Wilsey
Effective Date: September 2, 1968
Completion Date: October 31, 1968
Funds: $6,000

With highway maintenance expenditures rapidly increasing due to completion of the Interstate System, rising traffic volumes, trends toward higher standards of physical maintenance, and more traffic services, it becomes increasingly important that maintenance operations be based on reasonable and effective maintenance budgets.

The scope of this project was to develop independent work plans to be used as the research plan for the second-phase work. The work plan has been received but will not be published. Refer to Project 19-2(4) for description of the over-all project objectives and details of Phase II of this study.

Project 19-2(2) FY '69

Develop Performance Budgeting System to Serve Highway Maintenance Management

Research Agency: Ernst & Ernst
Principal Invest.: F. W. Hinck, Jr.
Effective Date: September 2, 1968
Completion Date: October 31, 1968
Funds: $6,000

With highway maintenance expenditures rapidly increasing due to completion of the Interstate System, rising traffic volumes, trends toward higher standards of physical maintenance, and more traffic services, it becomes increasingly important that maintenance operations be based on reasonable and effective maintenance budgets.

The scope of this project was to develop independent work plans to be used as the research plan for the second-phase work. The work plan has been received but will not be published. Refer to project 19-2(4) for description of the over-all project objectives and details of Phase II of this study.

Project 19-2(3) FY '69

Develop Performance Budgeting System to Serve Highway Maintenance Management

Research Agency: Roy Jorgensen & Associates
Principal Invest.: J. L. Garner
Effective Date: September 2, 1968
Completion Date: October 31, 1968
Funds: $6,000

With highway maintenance expenditures rapidly increasing due to completion of the Interstate System, rising traffic volumes, trends toward higher standards of physical maintenance, and more traffic services, it becomes increasingly important that maintenance operations be based on reasonable and effective maintenance budgets.

The scope of this project was to develop independent work plans to be used as the research plan for the second-phase work. The work plan has been received but will not be published. Refer to Project 19-2(4) for description of the over-all project objectives and details of Phase II of this study.

Project 19-2(4) FY '69

Develop Performance Budgeting System to Serve Highway Maintenance Management

Research Agency: Roy Jorgensen & Associates
Principal Invest.: Roy E. Jorgensen
J. L. Garner
Effective Date: February 1, 1969
Completion Date: November 30, 1971
Funds: $220,000

With highway maintenance expenditures rapidly increasing due to completion of the Interstate System, rising traffic

volumes, trends toward higher standards of physical maintenance, and more traffic services, it becomes increasingly important that maintenance operations be based on reasonable and effective maintenance budgets.

Performance budgeting represents a method by which budgeting can be an effective management tool. The development of a performance budgeting system for highway maintenance must be based on at least the following factors: the work load; the criteria for establishment of maintenance levels; the levels of maintenance desired for various functions; resource requirements necessary to provide the selected levels of maintenance; records and reports required to serve the budget system; and procedures for management planning, evaluation, and control.

The objectives of this project were to develop a model highway maintenance performance budgeting system and to pilot test the installation of the system in a state highway department.

The objectives have been accomplished in terms of the development of a model system that can be adapted for use by a state highway department to make most effective use of available maintenance funds and to assist in the process of highway budget and management planning. Pilot installation of the model system in cooperation with the State Highway Department of Georgia indicates that implementation is feasible.

The research has been completed, and the project report has been published as:

NCHRP Report 131, "Performance Budgeting System for Highway Maintenance Management."

Project 19-3 FY '71

Economic Effects of Changes in Legal Vehicle Weights and Dimensions on Highways

Research Agency: Wilbur Smith and Associates
Principal Invest.: R. E. Whiteside
Effective Date: September 15, 1970
Completion Date: June 14, 1972
Funds: $96,728

The Congress and State legislatures have the continuing responsibility for considering legislation respecting legal maximum limits of motor vehicle weights and dimensions. When laws are changed, highway designers must take into consideration the effects of the new legal limits on such things as vehicle design, vehicle use of the highways, axle configurations, road axle-weight distribution and frequency, and trucking practices. These factors, among others, affect management decisions relative to pavement design, bridge design, and highway geometric design; over-all highway maintenance policies and procedures; methods of upgrading existing highways and bridges; and budget for highway construction, betterments, and maintenance. Also affected are road-user tax incomes and highway cost allocations. However, absence of a clear definition of such things as the interrelationship between changes in the law and axle weights on the highway contributes to uncertainty and makes legislation and management decisions difficult. A further difficulty is that knowledge helpful to the making of decisions on the many factors involved is relatively scarce and widely scattered throughout the literature and the disciplines. A synthesis of the knowledge and a development of guidelines for evaluating the effects of such legislative changes are needed to make this knowledge more readily usable to state highway departments and others making decisions relative to the consequences of changes in the legal limits of vehicle weights and dimensions.

The objectives of this research were: (1) to critically review past and current research and methodologies relating to the consequences of possible changes in legal vehicle weight; (2) to evaluate methodologies and procedures identified in the review as to their reliability, adequacy, ease of application, and other attributes; (3) to assemble from existing knowledge a recommended methodology or methodologies identifying all decision points involved in reaching a conclusion regarding costs and benefits associated with changes in legal weights and dimension limits for vehicles; and (4) to recommend additional research and development as may be found necessary to fill gaps in present knowledge.

The project report, "Some Economic Effects of Changes in Legal Vehicle Weights and Dimensions on Highways," will be published in the NCHRP series. In the interim, loan copies are available from the NCHRP Program Director.

AREA 20: SPECIAL PROJECTS

Project 20-1 FY '65, FY '66, and FY '67

Highway Research Information Service

Research Agency: Highway Research Board
Principal Invest.: Dr. Paul E. Irick
Effective Date: March 16, 1964
Completion Date: October 31, 1967
Funds: $455,000

The objectives of the Highway Research Information Service were: (1) to select and store input information from current and past highway research that will be of value to users of highway information, (2) to disseminate current information to users, and (3) to retrieve relevant information on request.

All storage and retrieval procedures are now operational. The service, available to anyone interested, includes abstracts of publications, new reports on research in progress, and the updating of previously stored reports for ongoing research.

Project 20-2 FY '66

Research Needs in Highway Transportation

Research Agencies: Bertram D. Tallamy Associates
Wilbur Smith and Associates
Principal Invest.: Lloyd G. Byrd
Paul E. Conrad

Effective Date:	April 1, 1966
Completion Date:	December 31, 1967
Funds:	$98,760

This project developed a coordinated framework of needed short- and long-range research in the field of highway transportation. Major areas of needed research were identified and arranged in the general framework. Technical priorities of need and an estimate of the appropriate level of funding for each are included. The framework was designed in such a manner as to permit updating with minimal effort.

The project report gives method or concept for structuring research as developed by the research, which includes a method for assigning priorities and costs to proposed research. The methods developed under this research were applied to 900 proposed research project statements considered in the study to formulate an example research program.

The final report has been published as:

NCHRP Report 55, "Research Needs in Highway Transportation."

Project 20-3 FY '67 and FY '68

Optimizing Freeway Corridor Operation Through Traffic Surveillance, Communication, and Control

Research Agency:	Texas A & M University Research Foundation	
Principal Invest.:	Dr. J. A. Wattleworth Kenneth G. Courage	
Effective Dates:	Dec. 15, 1966	Jan. 1, 1967
Completion Dates:	Jan. 31, 1969	Dec. 31, 1968
Funds:	$419,000	$200,540 *

To meet present and future traffic demands, the combined freeway and surface street system must operate more efficiently. Practical measures for increasing operational efficiency by judicious application of traffic surveillance, communication, and control were studied for the heavily traveled corridor of the John C. Lodge Freeway in Detroit.

The initial research program included an evaluation of the effectiveness of the existing National Proving Ground surveillance, communication, and control system, and its individual components. Methods were determined for increasing the effectiveness of the freeway and surface street system, and equipment configurations were recommended to improve the system based on a cost-effectiveness study.

A technical report, "An Evaluation of Two Types of Freeway Control Systems," covering the 1967 research work was submitted and accepted. The report includes an evaluation of the initial NPG television and advisory speed and lane-control signs and a description and evaluation of the ramp-metering system. Six additional reports were prepared covering the 1967 research work.

The major work items proposed for completion in 1968 were a pilot study of a freeway-frontage road driver information system, further freeway operations studies using improved detection and refined control techniques, environmental effects studies, pilot equipment studies for traffic-responsive signal control throughout the corridor, and a preliminary design for a more extensive driver-communication system to include the surface streets within the corridor. The project report for the 1968 work, "A Freeway Corridor Surveillence, Information, and Control System," has been accepted. It, along with the 1967 reports, will not be published but will be included in the work described under Project 20-3B.

At the end of 1968 the research agency requested, due to extensive other research commitments, to be relieved of further work. A continuation proposal was requested from the University of Michigan. The research was continued under Project 20-3A.

* NCHRP funds obligated under the $314,340 four-way agreement among the National Academy of Sciences, Michigan Department of State Highways, Wayne County, and the City of Detroit.

Project 20-3A FY '69 and FY '70

Optimizing Freeway Corridor Operation Through Traffic Surveillance, Communication, and Control

Research Agency:	University of Michigan	
Principal Invest.:	Dr. Donald E. Cleveland	
Effective Dates:	Nov. 20, 1968	Jan. 1, 1969
Completion Dates:	May 31, 1971	Dec. 31, 1969
Funds:	$505,642	$20,000 †

To meet present and future traffic demands, the combined freeway and surface street system must operate more efficiently. Practical measures for increasing operational efficiency by judicious application of traffic surveillance, communication, and control are being studied for the heavily traveled corridor of the John C. Lodge Freeway in Detroit.

The research program conducted during 1967 and 1968 by the Texas Transportation Institute is described under Project 20-3.

The basic tasks and their respective components of the 1969 research work were designed to develop information required for the ultimate synthesis of a traffic surveillance, driver information, and control system capable of real-time control of traffic throughout an entire network of arterial streets and freeways. The necessity to utilize existing equipment and facilities as fully as possible and to carry previous research activity to a logical conclusion placed some constraints upon the nature of the topics selected for study. The topics included (1) detection of capacity-reducing incidents, (2) improved ramp control techniques and environmental effects, (3) pilot studies of freeway-frontage road informational system, (4) an experiment in traffic routing within the freeway corridor, and (5) observation of freeway operations.

Draft reports on the topics of the 1969 research work have been accepted by the advisory committee.

† NCHRP funds obligated under the $70,000 five-way agreement among the National Academy of Sciences, Michigan Department of State Highways, Wayne County, the City of Detroit, and the University of Michigan.

The 1970 research had the general objective of improving and refining the existing system aimed at improving the combined level-of-service on the Freeway and the supporting street network. The work was divided into four principal tasks, all of which have been completed: (1) improvement of ramp metering and freeway corridor flow; (2) improvement of Davison-Lodge interchange operation; (3) determination of the effect of weather on freeway corridor operations; and (4) long-term motorist response to the information system.

Draft final reports on the results from the work under the tasks have been accepted. They, along with the 1969 reports, will not be published but will be included in the work described under Project 20-3B.

Project 20-3B FY '70

Optimizing Freeway Corridor Operation Through Traffic Surveillance, Communication, and Control—Summary Reporting

Research Agency:	Patrick J. Athol
Principal Invest:	Patrick J. Athol
Effective Date:	July 1, 1972
Completion Date:	November 30, 1973
Funds:	$50,000

To meet present and future traffic demands, the combined freeway and surface street system must operate more efficiently. Practical measures for increasing operational efficiency by judicious application of traffic surveillance, communication, and control are being studied for the heavily-traveled corridor of the John C. Lodge Freeway in Detroit.

The National Proving Ground for freeway surveillance control and electronic traffic aids located on the John C. Lodge Freeway in Detroit has been extensively equipped for freeway surveillance, and this freeway and the adjacent corridor are designated as the study sites to develop and evaluate improved surveillance, communication, and control techniques. The objectives of this study are to:

1. Prepare a report summarizing the main findings of freeway surveillance and control on the John C. Lodge Freeway in Detroit. The end product of this synthesis is to be one report that summarizes all historic and technical activities of the research conducted by the State of Michigan, and under the NPG and NCHRP Project 20-3. The major emphasis is to be placed on reporting on usable results that have been found to be practical on the John Lodge Freeway Surveillance Project.
2. Write a report in the vein of "Getting the Most Service from Freeways," using published research reports and the experience available from past and ongoing freeway traffic operations projects.

Progress through December 31, 1972, included review of all reports produced by NCHRP Project 20-3A, FY '69 and FY '70, analysis of all international experience reported on the subject, and interviews with responsible professionals involved with freeway surveillance.

Project 20-4 FY '68

Public Preference for Future Individual Transportation

Research Agencies:	Chilton Research Services (CRS) National Analysts (NA)
Principal Invest.:	Robert K. McMillan James M. Marshall
Effective Date:	May 2, 1967
Completion Dates:	January 21, 1969 (CRS) January 2, 1968 (NA)
Funds:	$279,171

Reliable information is needed on public attitudes and behavior relating to transportation and the factors that influence these, to permit more effective planning for the allocation of resources for transportation purposes. The objective of this research was to determine the attitudes and behavior of the public related to transportation, and identify the factors that influence such attitude and behavior.

To determine the foregoing, two independent national samples of 2,500 interviews each were surveyed in May 1967 by the two separate agencies. The surveys used the same questionnaire, so that after an initial statistical evaluation between the two surveys the results could be combined for a more detailed analysis. The survey was designed to determine what people think about the importance of various transportation modes and the sources and distribution of transportation financing. Attitudes were related to people characteristics, transportation and community values, transportation needs, and recorded behavior. This project presents a valid national description of transportation attitude and behavior patterns with determination of differences in social, economic, demographic, and geographic subgroups.

A first-phase report was published in 1968 as:

NCHRP Report 49, "National Survey of Transportation Attitudes and Behavior—Phase I Summary Report."

This report presents a preliminary analysis of the nationwide survey data. It includes a comparison of household and individual characteristics for both survey samples, and a question-by-question analysis of the total sample.

A second-phase report has been published as:

NCHRP Report 82, "National Survey of Transportation Attitudes and Behavior—Phase II Analysis Report."

This report presents results of a more advanced statistical analysis of the data. This analysis is multi-variant in nature; that is, it considers many variables simultaneously to obtain a comprehensive view of transportation attitudes, their relation to behavior and demographic characteristics, and profiles of people holding these views.

The report includes 16 charts that indicate attitudes, according to eight demographic variables, toward spending for roadways and highways and public transportation. The report deals comprehensively with data by describing the methodology, statistical methods used, and the detailed findings.

Project 20-5 FY '68 and continuing

Synthesis of Information Related to Highway Problems

Research Agency:	Highway Research Board
Principal Invest.:	Dr. Paul E. Irick
	T. L. Copas
Effective Date:	December 15, 1967
Completion Date:	Continuing
Funds:	$100,000 annually, FY '68-'71
	$200,000 annually, FY '72-'73

Administrators, practicing engineers, and researchers are continually faced with highway problems on which much information exists, either in documented form or in terms of undocumented experience and practice. Unfortunately this information is often fragmented, scattered, and unevaluated. As a consequence, full information on what has been learned about a problem is frequently not brought to bear on its solution. Costly research findings may be unused, valuable experience may be overlooked, and due consideration may not be given to recommended practices for solving or alleviating the problem.

In this project particular highway problems, or sets of closely related problems, will be designated as topics for information synthesis.

For each topic the objectives are:

1. To locate and assemble documented information.
2. To learn what engineering practice has been used for solving or alleviating the problem.
3. To identify all ongoing research.
4. To learn what problems remain largely unsolved.
5. To organize, evaluate, synthesize, and document the useful information that is acquired.
6. To evaluate the effectiveness of the synthesis after it has been in the hands of its users for a period of time.

The following reports have been published:

NCHRP Synthesis of Highway Practice 1, "Traffic Control for Freeway Maintenance."

NCHRP Synthesis of Highway Practice 2, "Bridge Approach Design and Construction Practices."

NCHRP Synthesis of Highway Practice 3, "Traffic-Safe and Hydraulically Efficient Drainage Practice."

NCHRP Synthesis of Highway Practice 4, "Concrete Bridge Deck Durability."

NCHRP Synthesis of Highway Practice 5, "Scour at Bridge Waterways."

NCHRP Synthesis of Highway Practice 6, "Principles of Project Scheduling and Monitoring."

NCHRP Synthesis of Highway Practice 7, "Motorist Aid Systems."

NCHRP Synthesis of Highway Practice 8, "Construction of Embankments."

NCHRP Synthesis of Highway Practice 9, "Pavement Rehabilitation—Materials and Techniques."

NCHRP Synthesis of Highway Practice 10, "Recruiting, Training, and Retaining Maintenance and Equipment Personnel."

NCHRP Synthesis of Highway Practice 11, "Development of Management Capability."

NCHRP Synthesis of Highway Practice 12, "Telecommunications Systems for Highway Administration and Operations."

NCHRP Synthesis of Highway Practice 13, "Radio Spectrum Frequency Management."

NCHRP Synthesis of Highway Practice 14, "Skid Resistance."

NCHRP Synthesis of Highway Practice 15, "Statewide Transportation Planning—Needs and Requirements."

The following topic reports have been completed and are in the NCHRP editorial and production process: "Guidelines for Design and Construction of CRCP"; "Pavement Traffic Marking—Materials and Application for Maximum Serviceability."

The following topic reports are in the review stage: "Erosion Control on Construction Projects"; "Getting Research Findings Into Use"; "Design, Construction, and Maintenance of PCC Pavement Joints"; "Rest Areas—Design, Operation, and Maintenance."

The following topics are in the research stage: "Roadway Design in Frost Areas"; "Minimizing Deicing Chemical Use"; "Maintenance Management of Traffic Signal Equipment and Systems"; "Accident Location Methods"; "Treatment of Soft Foundations"; "Cold-Weather Construction Methods."

Project 20-6 FY '69 and continuing

Right-of-Way and Legal Problems Arising out of Highway Programs

Research Agency:	Highway Research Board
Principal Invest.:	John C. Vance
Effective Date:	November 1, 1968
Completion Date:	Continuing
Funds:	$200,000 FY '69-'71
	$125,000 FY '72
	$50,000 FY '73

A major and continuing need of state highway departments involves the assembly, analysis, and evaluation of operating practices and the legal elements of special problems involving right-of-way acquisition and control and highway law in general. Individual State experiences need to be compared and made available for possible application nationally. Need exists with respect to both immediate and longer-range right-of-way and legal problems.

In spite of this critical need today, there is really no present mechanism that is capable of responding in time to be of practical assistance to state highway departments. The Right-of-Way and Legal Affairs Committee of the American Association of State Highway Officials has tried all of the known channels in an effort to initiate such research, but the response has been negative for one reason or another.

Accordingly, state highway officials have agreed that an appropriate mechanism be initiated under which needed research of the type suggested can be undertaken and with dispatch. Prototypes of such a device may be found in the various AASHO and HRB road-test projects that have been

undertaken and, perhaps more closely related, in the 1956-60 special HRB Highway Laws Project.

NCHRP Project 20-6 has been established to meet the aforementioned need and is a continuing effort involving research on a priority listing of topics selected by the cognizant NCHRP project advisory committee. The topics of concern to date are:

Study No. 1—Relocation Assistance Under Chapter Five of the 1968 Federal-Aid Highway Act (Research Results Digest No. 3)

Study No. 2—Standing to Sue for Purposes of Securing Judicial Review of Exercise of Administration Discretion in Route Location of Federal-Aid Highways (Research Results Digest No. 6)

Study No. 3—Valuation Changes Resulting From Influence of Public Improvements (Research Results Digest No. 11)

Study No. 4—Advance Acquisition Under the 1968 Federal-Aid Highway Act (Research Results Digest No. 19)

Study No. 5—Valuation in Eminent Domain as Affected by Zoning (Research Results Digest No. 22)

Study No. 6—Federal Environmental Legislation and Regulations as Affecting Highways (Research Results Digest No. 25)

Study No. 7—Changes in Existing State Law Required by the Uniform Relocation Assistance and Real Property Acquisition Policies Act of 1970 (Research Results Digest No. 32)

Study No. 8—Proposed Legislation to Authorize Joint Development of Highway Rights-of-Ways (Research Results Digest No. 31)

Study No. 9—Legal Effect of Representations as to Subsurface Conditions (Research Results Digest No. 39)

Study No. 10—Right of State to Recover Contract Payments Made Under Contract Violating Competitive Bidding Statute (Final report being revised)

Study No. 11—Personal Liability of Highway Department Employees (Final report postponed)

Study No. 12—Tort Liability of Highway Departments Arising Out of Skidding Accidents (Final report being revised)

Study No. 13—Appeal Bodies for Relocation Assistance (Research Results Digest No. 40)

Study No. 14—Admissibility and Use of Severance Studies in Condemnation Litigation (Terminated due to insufficient data on which to base the study)

Study No. 15—Trial Strategy and Techniques to Exclude Noncompensable Damages and Improper Valuation Methods in Eminent Domain Cases (Research Results Digest No. 41)

Study No. 16—Supplemental Condemnation: A Discussion of the Principles of Excess and Substitute Condemnation (Research Results Digest No. 42)

Study No. 17—Liability for Design Defect (In progress)

Study No. 18—Compensability and Valuation of Noise, Pollution, and Other Environmental Factors (In progress)

Study No. 19—Right of State to Secure Judicial Review of Federal Administrative Decisions (Study abandoned due to insufficient amount of case law)

Study No. 20—Meaning of "Highway Purpose" (In progress)

Study No. 21—Duty to Warn Against Highway Defects (Study abandoned due to insufficient amount of case law)

Study No. 22—Compensability for Consequential Damages Resulting from Partial Take or Taking Without Appropriation and Entry Upon the Land (In progress)

Study No. 23—Exclusion of Valuation Changes Resulting from Influence of Public Improvement: A Study of the Provisions of 42 U.S.C. 4651 (3) (In progress; supersedes Study No. 3)

Project 20-7 FY '69 and continuing

AASHO Standing Committee on Engineering Policies Research

Research Agency: Texas A & M University
Principal Invest.: C. J. Keese
Effective Date: December 2, 1968
Completion Date: Continuing
Funds: $100,000 annually

The American Association of State Highway Officials (AASHO) Committee on Engineering Policies is continually called upon to rule on planning and design policies as a guide for state highway departments to follow. The Committee desires a continuing research project geared to its needs and wishes so that it may have a means of generating the necessary information for decisions concerning the development of planning and design guides, standards, policies, and other AASHO activities. The Committee determined that the most expeditious means of obtaining the desired research output is by a continuing project with the Texas Transportation Institute, thus permitting TTI to retain capable research staff specialists on a permanent basis.

The project includes a series of tasks specified by the Committee and conducted by TTI to obtain data required by the Committee to fulfill its responsibilities.

The tasks undertaken in this project and the status of each are as follows:

Task 1, "Development of a Cost-Effectiveness Approach to the Programming of Roadside Safety Improvements." The final report has been accepted by the AASHO Committee and approved for publication by NCHRP. The report describes a hazard model that can be used to evaluate the effectiveness of a roadside safety improvement program.

Task 2, "The Relation of Side Slope Design to Highway Safety." Two phase reports have been accepted by the

AASHO Committee and recommended for publication by NCHRP as a single report. Tentative criteria for the selection of safe slope and ditch combinations are proposed. The recovery and return-to-roadway situation is to be explored more fully.

Task 3, "Development of an Effective Earth-Berm Vehicle Deflector." The final report has been completed and transmitted to the AASHO Committee.

Task 4, "Lateral Accelerations and Lateral Tire-Pavement Forces in a Vehicle Traversing Curves Relative to Available Pavement Skid-Resistance Measures." The final report has been completed and transmitted to the AASHO Committee. The Committee recommended that the report be condensed and published by NCHRP. The report is being revised.

Task 5, "Effect of Curb Geometry and Location." The final report for this task has been received and is undergoing review.

Task 6, "Development of Impact Attenuators Utilizing Waste Materials." TTI will develop and evaluate one or more prototype crash cushions made of waste materials such as rubber tires and reprocessed aluminum. Work on this 18-month task is scheduled for completion by April 30, 1973.

Project 20-8 FY '71

Interactive Graphic Systems for Highway Design

Research Agency: Control Data Corporation
Principal Invest.: C. W. Beilfuss
Effective Date: September 1, 1970
Completion Date: July 31, 1971
Funds: $49,672

Improved techniques and procedures making extensive use of computer and computer-graphics technology are being developed to enhance highway location and design. One prominent highway design evaluation capability under development is the ability to produce, on a variety of computer-controlled graphic display devices, perspective views based on computed design information and actual terrain data. Highway engineers, by making use of these new capabilities, will be better able to achieve optimal highway designs expeditiously.

To make effective use of the new graphic display evaluation techniques, there is a need for a man-machine interaction capability for revising highway designs. The man-machine interaction is the ability of the highway designer to make discrete changes to design parameters as a result of evaluating graphic displays, including animated perspective views, and directing the computer to modify all stored data and produce new displays that reflect the design parameter changes.

This project was a feasibility study to determine the costs and benefits associated with the development of an Interactive Graphics Road Design System (IGRDS). The agency determined that IGRDS is feasible and produced cost and benefit figures to support that finding. The final report will not be published in the NCHRP report series; however, a summary is included in the *NCHRP Summary of Progress Through 1972*. Unedited draft loan copies of the report are available on request to the NCHRP Program Director.

Project 20-9 FY '73

Socioeconomic Consequences of Right-of-Way Acquisition Induced Resident Dislocation

Research Agency: RMC Inc.
Principal Invest.: Jon E. Burkhardt
Effective Date: August 1, 1972
Completion Date: October 31, 1974
Funds: $199,944

Residential dislocation is one of the major direct consequences of urban highway projects. Geographic and socioeconomic characteristics are of critical importance in predicting the impact of such dislocation on both the dislocatees themselves and on residents remaining in the area from which the dislocation occurs. There is a critical need:

1. For improved methodologies to serve as a basis for highway route location and design decisions and to conform to study and reporting requirements of pertinent federal legislation and regulations.
2. To identify the needs for further equity adjustments in relocation assistance activities and programs.

The objectives of this research are (1) to identify the relevant variables and develop techniques for using these variables in predicting the dislocation consequences of alternate route and design proposals, and (2) to identify related legislative or regulatory constraints and recommend legislation and policy and program modifications to assure equity to the displacees.

Progress through December 31, 1972, included reviewing and correlating previous experience, methodology, and data sources; identifying issues, problems, and variables in dislocation experience; and initiation of preparation of an interim report describing the case study approach for the analysis of dislocation problems in major metropolitan areas.

Project 20-10 FY '73

The Costs and Benefits of Separating Pedestrians and Vehicles

Research Agency:
Principal Invest.:
Effective Date: To Be Determined
Completion Date:
Funds:

Severe traffic congestion occurs on the street networks in central districts and other high-activity centers of many urban areas. When streets become jammed, capacity and operational efficiency are degraded, resulting in suboptimum utilization of existing facilities. In many cases high

levels of activity by pedestrians and other classes of nonhighway users (i.e., equestrians, cyclists, intermodal passengers, and other nonvehicular traffic) intensify the problem. Density of land use in many centers is trending upward; hence, the problems of oversaturated street networks may increase in severity. Coupled with this is the widespread lack of adequate and specific warrants and design guides for planning, locating, and constructing nonhighway user facilities adjacent to or across streets, roads, and highways. The present disparities among the various states concerning these facilities lend themselves to design criticism, increasing highway-nonhighway user incidents, and legal complications. Establishment of these warrants is necessary as an aid in properly locating, designing, and constructing facilities that will be functional and effective for nonhighway users as well as vehicular traffic. Also needed for the total decision-making process are quantified costs and benefits to be expected from providing these facilities. Although it will ultimately be necessary to study all conditions that must be considered for the establishment of warrants for nonhighway user facilities in urban and rural locations and to provide cost-benefit figures, the initial efforts in this project are to focus on the costs and benefits from separating pedestrians and vehicles. Even though there is almost universal agreement that pedestrian-vehicle separation in cities is desirable in terms of safety, mobility, efficient use of street systems, etc., little cost-benefit work has been done thus far. Consequently, the initial research in the over-all problem contemplates examination of the existing tools for determining cost-benefit relationships and determination of their relevance to analyses of pedestrian-vehicle separation. Then, if deemed necessary, new tools and procedures would be evolved that would establish meaningful cost-benefit relationships taking into account socioeconomic environmental consequences. Study results would be immediately applicable to urban renewal planning, to TOPICS program planning, and to CBD improvement efforts.

Development of this project is being delayed pending results from similar studies within FHWA.

Project 20-11 FY '73

Toward Environmental Benefit/Cost Analysis—Measurement Methodology

Research Agency: Polytechnic Institute of Brooklyn
Principal Invest.: Dr. Edmund J. Cantilli
Effective Date: September 1, 1972
Completion Date: November 30, 1973
Funds: $100,000

Environmental factors are being given increasing consideration in the provision, and operation, of public facilities, including highways. Consequently, it is frequently necessary not only to compare facility effects on various aspects of the environment, but also to compare effects on the environment of one facility alternate to another. It is also necessary, in order to choose among alternative facility plans, designs, and construction techniques, to assess their differential environmental effects and costs in the context of total benefits and costs.

Whereas various analytical methods are recognized as providing assessments of transportation benefits and costs, only very limited methods that are readily understood by the public have been developed for the assessment of environmental benefits and costs.

The basic objective of this project is to develop methods that are readily understood by the public for the qualitative evaluation of environmental values. Moreover, the methods are, in themselves, to be practical and immediately implementable by responsible agencies.

The specific research objectives are to:

1. Identify and categorize environmental elements that are affected by the provision and operation of transportation facilities. These elements may be positive and/or negative, local and/or regional, long- and/or short-term.
2. Determine the significant elements and the relationships among these elements that may be altered by transportation facilities.
3. Develop quantitative scales for measuring quality levels of those environmental elements or categories, as appropriate, that have been identified as significant in Item 2.
4. Develop a method to identify threshold level(s) of adverse and beneficial effects on the quality scales defined in Item 3 for selected environmental elements and/or categories as appropriate.

Progress through December 31, 1972, included a detailed literature review, design and distribution of a questionnaire to transportation agencies, and initiation of a review of case studies on environmental issues.

AREA 21: TESTING AND INSTRUMENTATION

Project 21-1 FY '70

Instrumentation for Measurement of Moisture

Research Agency: Research Triangle Institute
Principal Invest.: Dr. L. F. Ballard
Effective Date: August 25, 1969
Completion Date: February 24, 1971
Funds: $35,027

Water in its various states, when insufficient or in excess in the components of a highway system, adversely affects the service behavior. Despite recognition of the importance of the relationship between the presence of water and service behavior, the engineer has been hampered in his effort to provide predictable performance by the lack of instrumentation and techniques for adequate water or moisture measurement. The economic significance of the problem in highway construction and maintenance is particularly evidenced by the large financial investment aimed at removal of excess water which causes loss of supporting capacity of subgrade soils and aggregate bases, embankment instability, and deterioration of pavements.

The techniques currently in use in the highway field for measurement of moisture content in situ are generally insufficient to meet the researchers' needs because of their

high cost, time requirements, disturbance of the site, long-term instability, or a combination of these factors. Instrumentation is specifically needed for remote readout of local sensing, for remote sensing of subsurface conditions, for high-precision measurements, and for long-term continuous monitoring. Devices that can be installed permanently and portable devices for sampling at random locations are needed to provide data to allow for the development of new designs and the use of new materials.

The objective of this project was to evaluate, on the basis of a comprehensive literature review, the suitability of existing instrumentation and techniques to measure the amount and state of water in highway components such as embankments, subgrades, base courses, and structures.

The research has been completed, and the project report is in the NCHRP editorial and publication process.

Project 21-2 FY '71

Instrumentation for Moisture Measurement—Bases, Subgrades, and Earth Materials (Sensor Development)

Research Agency:	Southwest Research Institute
Principal Invest.:	Dr. C. G. Gardner
Effective Date:	February 1, 1972
Completion Date:	January 31, 1974
Funds:	$64,976

There is an immediate need for reliable instrumentation to measure the moisture in situ in soil and untreated granular materials used in such highway substructures as subgrades, embankments, slopes, backfills, and base courses.

It is recognized that the moisture sensor is the critical component of any moisture measurement instrument or technique. For this reason, this project is to concentrate on the development of new and innovative, or modification of currently available, sensors for moisture measurement. Although essential to any experimental verification process, the data collection and analysis equipment is not to be developed at project time and expense. Readily available equipment of this type should be utilized in the verification.

The specific objectives of this project are to:

1. Design, on the basis of generally new and innovative concept(s), one or more sensors capable of measuring moisture in granular and soil materials that offer reasonable prospects of satisfying highway needs.
2. Produce a prototype of the sensor, or sensors, developed.
3. Plan and conduct an experimental verification program to demonstrate the ability of the developed sensor, or sensors, to satisfy the above criteria.

The technical approaches under study in this project to meet these objectives are to exploit the moisture measuring capabilities of (1) nuclear magnetic resonance (NMR) absorption of radiofrequency energy, and (2) resonant dielectric absorption of microwave energy. The two approaches are being investigated independently.

Conceptual designs have been prepared using the two approaches and breadboard-type models have been fabricated. Data have been collected in the laboratory and evaluated. In general, satisfactory performance was achieved using the NMR approach. Considerable difficulties were encountered with the microwave approach. Although these difficulties appear to have been overcome, the research effort required substantially exceeded original estimates.

An interim report covering accomplishment of Objective 1 has been submitted and is in the process of being reviewed by the advisory panel. Work on Objectives 2 and 3 is expected to begin early in 1973.

Project 21-2(2) FY '72

Instrumentation for Moisture Measurement—Bases, Subgrades, and Earth Materials (Sensor Development)

Research Agency:	State U. of New York at Buffalo
Principal Invest.:	Dr. E. T. Selig
Effective Date:	April 1, 1972
Completion Date:	September 30, 1973
Funds:	$29,953

There is an immediate need for reliable instrumentation to measure the moisture in situ in soil and untreated granular materials used in such highway substructures as subgrades, embankments, slopes, backfills, and base courses.

It is recognized that the moisture sensor is the critical component of any moisture measurement instrument or technique. For this reason, this project is to concentrate on the development of new and innovative, or modification of currently available, sensors for moisture measurement. Athough essential to any experimental verification process, the data collection and analysis equipment is not to be developed at project time and expense. Readily available equipment of this type should be utilized in the verification.

The specific objectives of this project are to:

1. Design, on the basis of generally new and innovative concept(s), one or more sensors capable of measuring moisture in granular and soil materials that offer reasonable prospects of satisfying highway needs.
2. Produce a prototype of the sensor, or sensors, developed.
3. Plan and conduct an experimental verification program to demonstrate the ability of the developed sensor, or sensors, to satisfy the above criteria.

The techenical approach under study in this project to meet these objectives is the use of fringe capacitance as a measure of the soil moisture.

A literature review on soil conductivity, dielectric constants, frequency of oscillation, and capacitance in relation to soil moisture has been completed. A laboratory model sensor has been built and data have been collected. Evaluation of the initial sensor data indicates satisfactory correlation with moist sand but unsatisfactory performance with clay soils at moisture contents above 25 percent by dry weight. It is anticipated that proper choice of operating frequency and design of the electrical network coupling the sensor electrodes to the oscillator will improve performance.

AREA 22: VEHICLE BARRIER SYSTEMS

Project 22-1 FY '69

Concepts for Improved Traffic Barrier Systems

Research Agency: Walter W. White
Principal Invest.: Walter W. White
Marvin A. Shulman
Effective Date: October 1, 1970
Completion Date: December 31, 1971
Funds: $25,000

Conventional traffic barrier systems are presently being applied widely by highway and bridge engineers. All of these existing systems have some deficiencies that make their performance somewhat less than ideal. New concepts are therefore needed for economical, standardized, longitudinal traffic barrier systems that can provide a consistent degree of protection when installed as highway shoulder guardrails, median barriers, and bridge rails. The system should present a reasonably consistent appearance to the motorist as he moves along the highway and over structures, although parameters (such as height, post spacing, section properties, and anchorage) may vary to suit the application. Emphasis should be given to conceiving integrated systems that maintain continuity across bridges and avoid abrupt transitions.

The objective of the research was to produce one or more traffic barrier system designs, described with sketches and narrative to the degree necessary to convey understanding, that offer promise of: preventing penetration by a standard-size U.S. automobile weighing 4,000 to 5,000 lb and impacting at 25° and 65 mph; smoothly redirecting errant vehicles relatively parallel to traffic flow; providing a range of controlled dynamic deflections by varying design parameters; retaining longitudinal continuity following a collision; permitting adequate visibility; being capable of quick and easy repair; performing satisfactorily in various foundation conditions; limiting decelerations at the center of gravity of the vehicle to 5g lateral, 10g longitudinal, and a total of 12g when averaged over any 200-millisec period; having reasonably low first cost and pleasing appearance; and minimizing vehicle damage. The design was analyzed and technical information was presented to demonstrate the degree of achievement of the foregoing. Working drawings suitable for fabrication and installation of a prototype were prepared for each barrier system.

The final report will not be published in the NCHRP report series; however, a summary is included in the *NCHRP Summary of Progress Through 1972*. Loan copies of the unedited agency draft are available on request to the NCHRP Program Director.

Project 22-2 FY '69 and FY '72

Traffic Barrier Performance and Design

Research Agency: Southwest Research Institute
Principal Invest.: M. E. Bronstad
Effective Date: January 1, 1972
Completion Date: June 30, 1973
Funds: $125,000

Conventional traffic barrier systems are presently being widely applied by highway and bridge engineers. All of the existing systems have some deficiencies that make their performance somewhat less than ideal. New concepts are therefore needed for economical, standardized longitudinal traffic barrier systems that can provide a consistent degree of protection when installed as highway shoulder guardrails, median barriers, and bridge rails. The systems should present a reasonably consistent appearance to the motorist as he moves along the highway and over structures, although parameters—such as height, post spacing, section properties, and anchorage—may vary to suit the application. Emphasis must be given to conceiving integrated systems that maintain continuity across bridges and avoid abrupt transitions.

Among the most important of current needs in the area of vehicle barrier systems is a safer terminal design. The work of Project 22-2 is structured to emphasize the systematic experimental development of terminal treatment that will fulfill this need. Terminal treatments for a number of selected guardrail systems are being investigated. The new work builds on earlier preliminary NCHRP effort that is described in NCHRP Reports 118 (1971) and 129 (1972).

The initial work task in this project included a review of terminal concepts previously developed under Project 15-1(2), the development of several new concepts, and an examination of concepts developed outside the NCHRP. More than 20 of these concepts have come under consideration. This work was covered in an interim report that was submitted to the advisory panel in April 1972, and was subsequently accepted. Although the report will not be published, it is available on a loan basis. Appropriate material from the interim report will be included in the final report for the project. Concluding work under the initial task includes testing of a proprietary friction-lock device designed to reduce the longitudinal resistance of W-beam elements for end-on impacts.

Based on the interim report, the advisory panel has selected designs and established priorities for full-scale testing of several terminal combinations. Interest in this testing will be concentrated on a breakaway cable terminal (BCT) in combination with the W-beam guardrail and median barrier systems now most often used. A combination BCT and W-beam terminal for steel box median barriers, and probably various combinations involving the friction-joint concept, also will be included in the full-scale testing.

Through December 31, 1972, the agency essentially completed work on the barrier terminal test program consisting of 25 full-scale crash tests. In the time remaining efforts will continue on the development of concepts for reducing the column strength of the rail in order to minimize the tendency for spearing. The results of some of the tests in this project have been published in NCHRP Research Results Digest 43.

SUMMARIES OF UNPUBLISHED REPORTS

Research reports emanating from NCHRP projects normally are published in the *NCHRP Report* or *Synthesis of Highway Practice* series of the Highway Research Board. When final reports are not published in this manner, a summary is included in an issue of the annual NCHRP *Summary of Progress* to provide adequate circulation of the outcome of the research, or is published as an NCHRP *Research Results Digest.* The summaries contained herein were prepared during the past year.

The opinions and conclusions expressed or implied in this summary are those of the research agency that performed the research. They are not necessarily those of the Highway Research Board, the National Academy of Sciences, the Federal Highway Administration, the American Association of State Highway Officials, or the individual States participating in the Program.

Persons having a deeper interest in the subject matter of a project may obtain, on a loan basis, an uncorrected draft copy of the agency's report by request to the NCHRP Program Director, Highway Research Board, 2101 Constitution Avenue NW, Washington, D.C. 20418.

Project 9–2 FY '65

Asphalt Durability and Its Relation to Pavement Performance—Adhesion

By: D. W. McGlashan
Research Agency: Montana College of Mineral Science and Technology

Introduction and Research Approach

Asphalt cements exhibit electrokinetic properties that are fundamental to the measurement of the adhesion of an asphalt and a mineral aggregate. Electrokinetic measurements permit comparative assessment of adhesion; that is, the relative motion between charged surfaces of mineral aggregates and bulk asphalt solutions are interpreted and described in electrical quantities. These quantities evidence the interfacial activity occurring between an asphalt cement and an aggregate in which the inherent and diverse properties of both materials are of significant influence. Within the interface or boundary layer between an asphalt cement and an aggregate, reactions occur, the intensity of which is influenced by variations in the quality of asphalt cements and variations in the natural or synthetic mineralogical properties of aggregates. These interfacial reactions and changes are manifestations of the existing or resulting synergy of the system. The cumulative synergy of an asphalt cement-aggregate system will be affected by changes in either one of the materials involved.

Asphalt quality, on which performance depends, is related to the following physical and chemical properties: consistency (viscosity), polar character (electrochemical properties), rheological character (colloidal properties), chemical reactivity, and volatility (molecular weight properties). Although all of these properties are involved, this research is particularly concerned with the electrochemical properties and chemical reactivity. That asphalt cements do exhibit electrochemical properties is fundamental to the understanding of the adhesion and cohesion of an asphalt cement and a mineral aggregate. Adhesion of an asphalt cement and its cohesiveness is frequently referred to as the "polar character" that results from the distribution of electrical charges within the asphalt molecules. Likewise, performance of a pavement is influenced by the physical and chemical nature of the mineral aggregate, because mineral aggregates possess distinctive polarities or electrochemical properties. Smith (*1*, pp. 213–214) states that ". . . adhesive and cohesive properties of an asphalt are influenced greatly by the type of mineral aggregate employed in a paving mix."

This investigation of electrokinetic and adsorption phenomena in polar and nonpolar systems presents many significant and appropriate factors that are important to an understanding of the interfacial reactions between an aggregate and an asphalt. Background information pertaining to these systems has been summarized.

Electrokinetic effects relate to the liquid flow occurring along solid-liquid interfaces as a result of applied potential gradient, and, conversely, to the potential developed when a liquid is made to flow along an interface. Thus, the interfacial activities can be measured in electrical quantities that permit description of adhesion and changes in adhesion between an aggregate and an asphalt cement.

To account for the occurrence of these electrical phenomena it is necessary to accept the electrical double layer theory and to accept the diffuse layer as at least a partially mobile layer because of the fundamental natures of the solid and fluid phases. The zeta potential is constant for any given combination of materials; that is, the zeta potential is an independent variable that, although it varies with

temperature, does not depend on streaming potential. On the other hand, basic study shows that streaming potentials are dependent variables and are directly proportional to both pressure and zeta potential. Zeta potential (ζ) is an absolute unit; that is, a reference point is not required.

Of the several theoretical concepts of the electrical double layer, the Stern concept is applicable for nonaqueous systems at higher temperatures or at those temperatures likely to be encountered in the preparation of asphalt-aggregate mixtures. At lower temperatures, the Gouy-Chapman theoretical concept is applicable for nonaqueous systems.

Porous plugs (aggregate filled) are capillaries of arbitrary diameter. A porous plug is an assemblage of particles having a given size distribution. It is a random array of many capillaries, enclosed in a tube or a large capillary. Even though a porous plug system is much more complicated than a single capillary system, the same equations can be applied to closely approximate and accumulate relevant data.

In contrast to those systems involving aqueous media, nonaqueous systems, such as asphalt cement and mineral aggregates, present interfacial situations that have received limited consideration. Of course, intermolecular forces and dipole moments are likely to be of significant influence, whether in an aqueous or a nonaqueous environment.

Factors influencing interfacial reactions at solid-liquid interfaces are chemical bonding, Van der Waal's forces, and hydrogen bonding. The influence of hydrogen bonding deviates importantly between aqueous and nonaqueous solvents. All three types of adsorption—chemical, physical, and ion exchange—contribute to interfacial reactions. Multilayer adsorption is, in a sense, polymerization at an interface. It must be remembered that the amount adsorbed decreases with increasing temperature. This situation is modified by changes in compositional structure of asphalt cements with increasing temperature.

The reactivity between an asphalt cement and an aggregate is complicated by the fact that the asphalt cements have inherent properties that change with temperature. The existence of a new configuration of the reactant molecules in the bulk of the solvent is derived from the characteristic of the solution. Thus, it is likely that the characteristics of the adsorbed substance from the asphalt cement (or asphalt solution) differ as temperature varies.

The electrical properties, degree of dehydration, polarity, and polarizability of the solid phase are surface influencing factors that affect the chemical constituents adsorbable at the liquid-solid interface. A polar solid prefers interaction with polar liquids. An acid solid reacts more easily with a basic liquid. Thus, the chemical composition of the liquid influences the type of bonding (adhesion) and bond strength. Every molecule of the adsorbent or surface active substance is partially polar and nonpolar, and thermodynamic stability at an interface may be increased by the formation of hemimicelles and micelles, the properties and configurations of which depend on the solvent. Adsorption of mixed solutions is influenced by molecular weight and by chemical affinities of the components.

Research Approach

Mixing of asphalt cement and aggregates brings about tangential movement of these phases against each other and thus creates electrokinetic effects. These electrokinetic effects are related to the liquid flow occurring along a solid-liquid interface as a result of an applied potential or pressure gradient. Previously, theoretical interpretations of these effects were explained in terms of the electrical double layer that sheaths the surface. For quantitative assessments, techniques and instrumentation were developed that permitted the measurement of streaming potential and streaming current.

Streaming potential (E_{str}) and streaming current (I_{str}) are the basic electrokinetic quantities to be measured; the former proved to be the more expressive parameter. These quantities are variable, depending on the interfacial reaction of the liquid and solid phases. Other variables that must be controlled and measured (some concurrently) include pressure, temperature, viscosity, permittivity, and conductivity. All of the properties enumerated, which are to be controlled and measured, depend on (1) the physical and chemical characteristics of the media for streaming, and (2) the variables required for data processing. The extent to which the variables require quantitative measurements depends on the experimental objectives. For example, plots of E_{str}/P (pressure) vs T (temperature) are often sufficient to describe the adhesion between asphalt cements and aggregates. For electrokinetics to describe quantitatively the adhesion and the changes in adhesion occurring at an interface, measurements of streaming potential, streaming current, temperature, and pressure must be rapid, reliable, and accurate.

Streaming potentials are determined by measuring the potential difference between the ends of a porous plug of particles when liquid is forced through the plug. For asphalt cement-aggregate systems, the aggregate forms the porous plug through which the asphalt cement is forced. Mathematically, streaming potential (E_{str}) can be expressed as follows (cgs):

$$E_{str} = \frac{\zeta \epsilon P}{4\pi\eta\sigma} \text{statvolts} \qquad (1)$$

in which the zeta potential (ζ) is the potential difference between the plane of shear and the body of the solution; ϵ is the permittivity of the media in statcoulomb^2 per dyne-cm^2; P is the pressure difference between the ends of the porous transducer in cm of mercury (or dyne-cm^2 of Hg); η is the viscosity in poises; and σ is the specific conductance of the fluid medium in statohms^{-1}-cm^{-1}. Streaming potential is a dependent variable and directly proportional to both pressure and the zeta (electrokinetic) potential.

Zeta (electrokinetic) potential is calculated from streaming potential data by the following (cgs):

$$\zeta = \left(\frac{4\pi\eta\sigma}{\epsilon}\right)\left(\frac{E_{str}}{P}\right)\left(\frac{1}{3\times 10^5}\right) \text{millivolts} \qquad (2)$$

in which η is the viscosity; ϵ is the permittivity of the media; σ is the conductivity; E_{str} is the streaming poten-

tial; and P is the applied pressure difference. Zeta potential is obtainable in absolute units that represent only the work required to bring the unit charge from the bulk of the solution to the immobile layer of solution next to the solid wall. It is an independent variable that, although it varies with temperature, does not depend on streaming potential. Thus, varying pressure will not alter the value of zeta potential.

Mathematically, streaming current (I_{str}) can be expressed as:

$$I_{str} = -\frac{P\epsilon\zeta a^2}{4\eta\, l}\text{statamperes} \qquad (3)$$

in which a is the radius of the capillary; l is the length of the capillary; and P, ϵ, ζ, and η are, respectively, the pressure, the permittivity, the zeta potential, and the viscosity. Also, $\frac{a^2}{4\,l}$ can be assumed to be constant under the experimental conditions. Direct measurement of the streaming current avoids the problem of surface conductance (*2*, p. 122).

For non-Newtonian fluids, $E_{str}/\Delta P$ and $I_{str}/\Delta P$ ratios are constant for constant temperatures. These ratios are obtained from rearrangement of Eqs. 1 and 3:

$$\frac{E_{str}}{P} = \frac{\zeta\epsilon}{4\pi\eta\sigma} \qquad (4)$$

and

$$\frac{I_{str}}{P} = \frac{\epsilon\zeta a^2}{4\pi\, l} \qquad (5)$$

Of these two parameters, E_{str}/P vs T was found to be more quantitatively descriptive for asphalt-aggregate systems. Zeta potential provides an important parameter as well; e.g., changes occurring in the electrical double layer are reflected in charge sign and magnitude. Derivations of these electrokinetic parameters appear in Appendices 1 and 3 of the full report.*

A data-acquisition system was developed that is an integrated assembly of instruments for the measurement of electrokinetic quantities. It is essentially an analog to digital system. A prerequisite for the system was the measurement of small signals produced by very high impedances, which was dictated by the nature of the phenomenon being observed, such as the interfacial reactions between an asphalt cement and an aggregate. The system takes into account the fact that streaming potential, streaming current, and pressure are time-dependent variables and, also, that streaming potential and streaming current are temperature-dependent variables. All of these variables can be observed, measured, and recorded separately or consecutively as experimentally required. For instance, pressure may be held constant and the temperature may be cycled through a predetermined program; the result would be that the streaming potential and the streaming current would exhibit change. In this case, the magnitudes of these quantitatively changing variables are measured and amplified by analog instruments where the amplified signal is analogous to the input. When sequential measurements are made, the data-processing link (device) responds to each input signal individually in accord with predetermined instructions from the control unit. During processing, the input signal, which is an electrical analog, is converted rapidly into a signal of digital form. Subsequently, the digital signal is transmitted to the recorder where it is stored as a printed decimal number. The operation then is repeated on the next signal. Whichever the experimental direction, the analog-digital method is convenient for the acquisition of electrokinetic data. The developed data-acquisition system and techniques are described in Appendix 4 of the full report.*

* Available on request to the Program Director, NCHRP.

Data Presentation and Analysis

By use of the developed data-acquisition system for electrokinetic measurements, the adhesive qualities of 15 viscosity-graded (AC10) asphalt cements † were measured against three high purity minerals (quartz, calcite, and dolomite), several natural highway aggregates (Indiana limestone, Indiana dolomite, New York Graywacke sandstone, New York diabase, Oregon Iron Mountain basalt, and Whipple Quarry basalt), and three synthetic highway aggregates (electric-furnace phosphate slag, blast-furnace slag, and open-hearth slag). With the exception of three of the asphalt cements (B2975, B3036, and B3051), the properties, characteristics, and methods of refining were advisedly not known to the researchers. Basic properties of the AC10 series of asphalt cements include:

Viscosity at 140° F (poises)	1,000–1,500
Viscosity at 275° F (centistokes)	200
Ductility at 77° F (min)	100
Solubility in CCl_4 (%)	99.5
Flash point, C.O.C. (° F)	42.5

Each asphalt cement tested bears an FHWA identification number, and the data presented are identified by the number and the particular aggregate under consideration.

Comparative E/P vs temperature data plots for the 15 asphalt cements against the minerals, the natural aggregates, and the synthetic aggregates appear in Appendix 2 of the full report.* For three other asphalts mentioned above (selected for divergence and intermediate characteristics), ζ vs temperature data plots and tabulations also are included. Because the accumulated data are extensive, the data presented here concern only two asphalt cements juxtaposed against the mineral aggregates, the natural highway aggregates, and the synthetic highway aggregates. These data serve to illustrate quantitatively the adhesion and change in adhesion occurring as this asphalt flows through each of the various aggregates. The electrokinetic technique developed for measuring adhesion between asphalt cement and aggregates is illustrated in a brief but informative manner.

† AC10 viscosity-graded asphalt cement samples supplied through the courtesy of J. York Welborn, Principal Research Engineer (Bituminous), FHWA.

Experimental Procedure

With the electrokinetic data-acquisition system, measurements are rapid and the multi-cell assembly accommodates six samples of asphalt cement and aggregate, either all the same asphalt cement and aggregate, or each cell can contain different asphalt cements and aggregates or a combination thereof. Prior to electrokinetic measurements, a strip-chart recorder was used to determine the data cycle times. The reason for this initial step is that the applied pressure is switched from one manifold to the other. A finite time is necessary for the streaming potential or streaming current to reach a finite value. This phenomenon can be attributed to the momentum possessed by liquid flowing through the aggregate in the porous plug. Because the time necessary to reach constancy varies with a particular fluid, the strip-chart recorder provided a graphical time-output measure that was used to determine the proper flow cycle time.

Early investigators of the streaming potential and the streaming current of particulate solids systems encountered many difficulties in the manipulation of the various instrumental modules connected with this type of electrokinetic research. Consequently, an instrumental unit was developed to completely automate the electrokinetic measuring systems. The subsystem developed to perform the automating function is the data programmer. This automating device functions as follows:

1. A set equilibrium period is timed for fluid flow in one direction; e.g., for flow from left to right through the porous plug.
2. Toward the end of the equilibrium period a data-collection cycle is initiated. During this cycle the streaming potential (or current) is measured sequentially for each of the cell assemblies in the environmental chamber.
3. At the end of the data-collection cycle the solenoid valve in the nitrogen drive system is activated, and the nitrogen pressurization is switched from one manifold to the other. Consequently, the flow through the porous plug is reversed; i.e., the fluid now flows from the right reservoir flask, through the porous plug, to the left reservoir flask.

In an investigative procedure, the rate programmer changes the temperature in the interior of the environmental chamber at a known rate while the data programmer is executing its various functions. Consequently, a correlation between cycle time and temperature variance is obtained.

For temperature control, an environmental chamber was employed as a part of the instrument system. Both chamber temperature and rate of temperature change were controlled by the rate programmer. To obtain electrical output from a streaming transducer, the asphalt cement must be made to flow through a packed bed of aggregate particles. The pressure control system reduced the high-pressure gas (nitrogen) feed from a cylinder into a console from which the gas pressure was further reduced to the selected test pressure. The reduced pressure supply flows through one of two manifolds for a time (a part of the cycle time) and a certain volume of asphalt cement is driven from one reservoir flask (a part of the multi-cell assembly) through the transducer (porous plug) into the other flask. Within the programmed cycle time the flow is reversed and the asphalt cement flows in the opposite direction through the aggregate plug. Measurements are taken in both directions. This method of pressure control and regulation was devised for two reasons: (1) to collect data that correspond to fluid flow in both directions; and (2) to ensure that neither of the two reservoir flasks becomes empty during any particular experimental series.

The aggregate size ranged from 28 mesh (Tyler sieve or 30 mesh ASTM) to 65 mesh (Tyler sieve or 70 mesh ASTM). Aliquot samples were reduced in particle size accordingly. Initially, it was deemed a requirement that conditions for laminar flow prevail. The asphalt cements are Newtonian in flow characteristics at the investigated temperatures. Subsequent background studies strongly indicate that streaming potential measurements can be made in turbulent fluid conditions (App. 3), providing the electrical double layer is small in comparison with the laminar sublayer.

The sized aggregate samples were rinsed with deionized distilled water and dried for 24 hr at 110° C. Other than the water washings, no chemical treatment was given the aggregate to remove any surface entities. However, the water treatment does not preclude the likely interfacial presence of metal hydrocomplexes or other entities derived from the aggregate. In fact, quartz and probably the silicate minerals of the natural highway aggregates are hydroxylated.

The transducers (porous plug) used were designed for the particle size range determined for the electrokinetic measurements. The usual particle-size distribution of highway aggregates could be used in a porous plug to form a streaming transducer. However, a test cell must be designed to accommodate the expectable range in particle sizes. Particle size and applied pressure must be controlled so that the conduction of the solid-fluid mixture, when streamed with a viscous medium such as asphalt cement, is sufficiently low for satisfactory measurement of streaming potential or streaming current.

Data Interpretation

An objective of the experimental work was to determine the parameters most expressive of the adhesive qualities of the asphalt cement-aggregate systems. The parameters investigated were E_{str}/P vs temperature, I_{str} vs temperature, and ζ vs temperature. Of the three, E_{str}/P vs temperature is the more experimentally convenient parameter to measure. In a plot of E_{str}/P vs temperature data, the resultant curve reaches a maximum for a particular asphalt cement-aggregate system, indicating maximum interfacial reactivity. In such systems, the E_{str}/P ratios with respect to temperature are quantitative expressions and thereby definitions of the adhesion between an asphalt cement and an aggregate. It is valid and significant and differentiates between the adhesiveness of a particular asphalt cement for a particular aggregate and that of another similar system.

The ζ vs temperature data demonstrate that adsorption of entities from asphalt cement is taking place before and

after the maximum adhesion has been achieved. This is to be expected. At increasing temperatures, the micelle size decreases, ionic dissociation increases, and mobility of these entities increases. Chemical adsorption takes place. Chemical adsorption, at least in part, is irreversible and may increase with temperature (*3*, p. 26). Adsorption of specific fractions of the asphalt cement occurs. Such occurrences do not mean that the adhesiveness of the asphalt cement is increased with increasing temperature.

In addition to E_{str}/P, ζ vs temperature data require the measurement of viscosity (η), permittivity (ϵ), and conductivity (σ). For the three asphalt cements (B2975, B3036, and B3051), the viscosity information required was obtained from an extended range viscosity-temperature chart (supplied by the Federal Highway Administration). Conductivity and permittivity were measured in a specially designed cell at the temperatures required (App. 4).

As illustrated later, I_{str}/P vs temperature is not an expressive parameter for asphalt cement-aggregate systems. Streaming current is a charged displacement generated by mechanical flow; that is, as the asphalt cement is streamed through a porous plug containing aggregate, a charged displacement occurs. The reason for consideration of streaming current is that it is independent of surface conductivity.

Systematic and detailed procedures for analysis of data appear in the Operations Manual (App. 4). Such matters as the self-generated potential termed "no-flow" are considered. Operationally, no-flow potential is essentially eliminated by using the potential difference produced by flow conditions only. Experimentally, the raw data output obtained by the operational procedures described consists of a printed tape of voltage output of the streaming transducer as programmed temperature increases. Once the E_{str}/P ratio (or the I_{str}/P ratio) has been proven to be constant for a particular asphalt cement-aggregate system, it is possible to record the output of the streaming transducer with changing temperature at constant pressure and to obtain the streaming potential pressure ratio (or streaming current pressure ratio) by graphic methods.

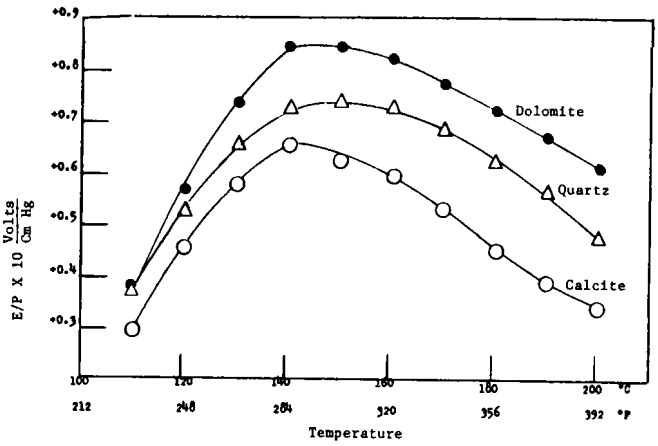

Figure 1. E/P *vs temperature for quartz, calcite, and dolomite with asphalt AC10-B3036.*

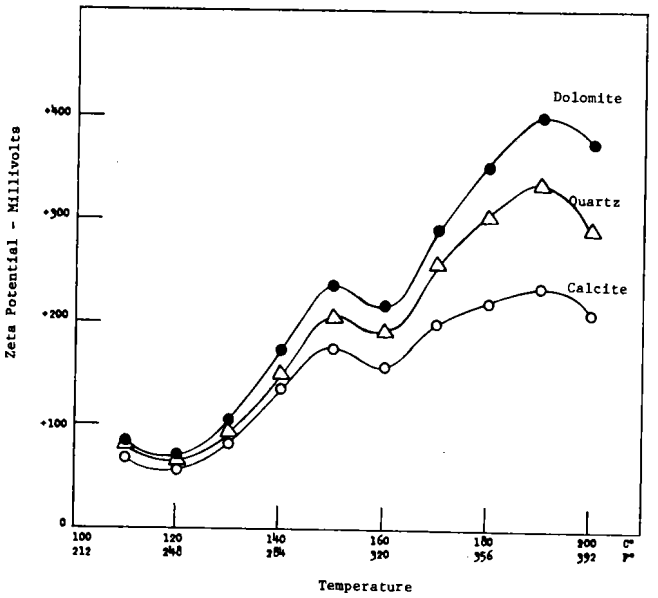

Figure 2. ζ *potential vs temperature for quartz, calcite, and dolomite with asphalt AC10-B3036.*

Interfacial Reactivity of Asphalt Cement AC10–B3036 Streamed Through Quartz, Calcite, and Dolomite

Depending on the rock type, quartz, calcite, and dolomite are frequently the predominating mineralogical constituents in highway aggregates. Consequently, it was necessary to evaluate the adhesive qualities of asphalt cements against these minerals prior to consideration of natural aggregates. Quartz crystals were obtained from Hot Springs, Ark.; calcite crystals were obtained from Cherokee County, Kan.; and a very high purity variety of crystalline dolomite was procured from Snarum, Norway. The adhesive characteristics of these minerals with asphalt cement AC10–B3036 are shown in Figures 1, 2, and 3.

As attested by the E_{str}/P vs temperature curves (Fig. 1), asphalt cement AC10–B3036 reacts strongly with all three minerals; these maxima were attained at 284° F. However, this asphalt cement reacts more with dolomite. Of the 14 other AC10 asphalt cements tested, 2 gave even stronger reactions when streamed through dolomite (B3013 and B3059, App. 2).

The ζ vs temperature curves (Fig. 2) show that as the temperature is raised, entities from the asphalt cement continue to be strongly adsorbed until the temperature reaches approximately 374° F; thereafter, a decline in adsorption at the surface occurs. It is likely that those constituents having a very strong polarity are being adsorbed on release from micelle clusters. That part of the micelle that is physically adsorbed at low temperatures is now being chemically adsorbed at the higher temperatures, for these products seek thermodynamic stability. Monolayer adsorption, electron donor and electron acceptor mechanisms, and polymerization may be occurring.

Obviously, I_{str}/P vs temperature curves are not particularly expressive of the interfacial reactivity between asphalt

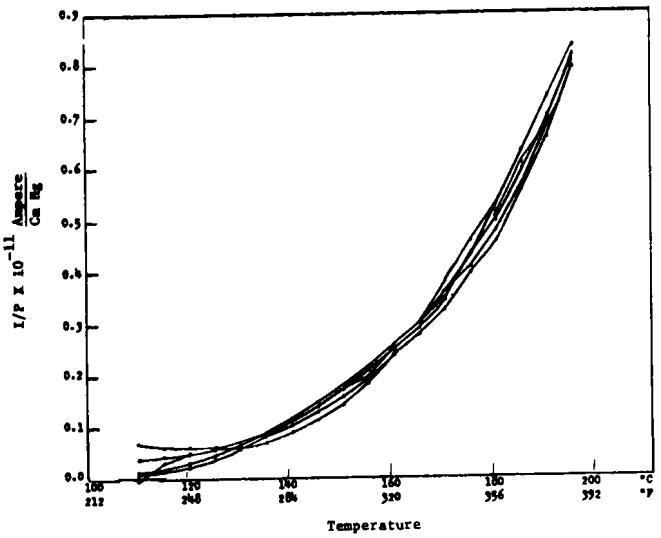

Figure 3. I/P *vs temperature for quartz with asphalt AC10-B3036.*

cement AC10-B3036 and quartz. Nevertheless, there is the possibility of correlating streaming current with viscosity. Streaming current is an electron flow and viscosity that determines the physical flow rate is mechanical. Perhaps a direct correlation between electrical and physical characteristics of an asphalt might be obtained. However, the lack of observable expressiveness of this parameter precluded further measurements.

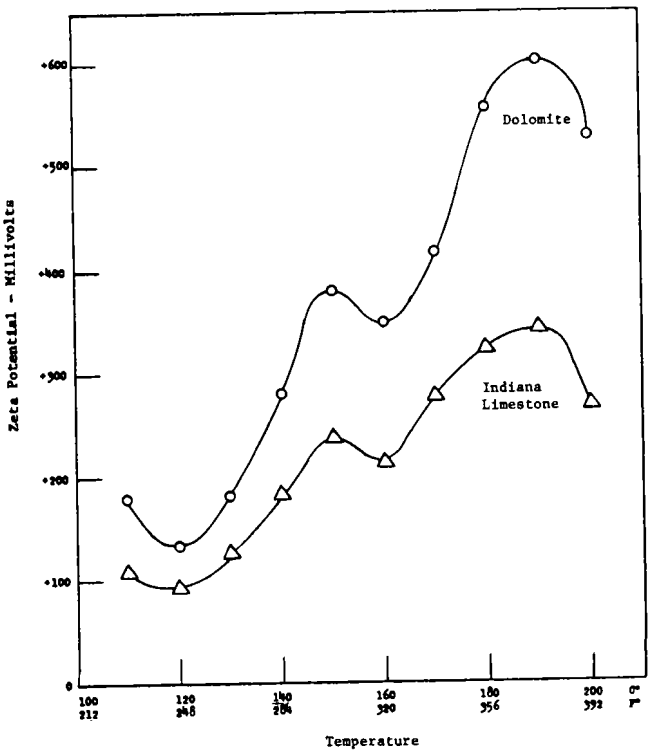

Figure 5. ζ potential vs temperature for Indiana limestone and dolomite with asphalt AC10-B3036.

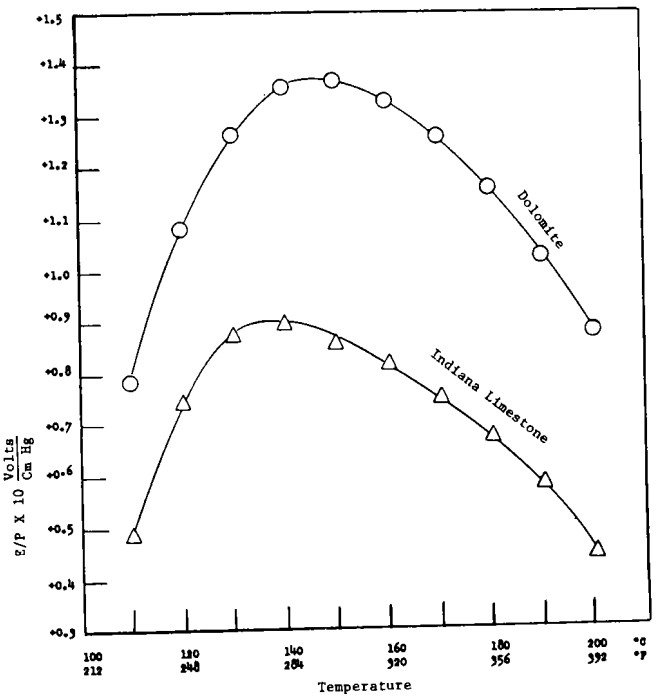

Figure 4. E/P *vs temperature for Indiana limestone and dolomite with asphalt AC10-B3036.*

Interfacial Reactivity of Asphalt Cement AC10–B3036 Streamed Through Natural Highway Aggregates

The adhesive characteristics were determined for six natural highway aggregates representative of igneous, sedimentary, and metamorphic rocks. The compatibility of a particular asphalt cement for a particular highway aggregate is illustrated by the data presented for each of these aggregates.

Adhesive Qualities of Asphalt Cement AC10-B3036 for Indiana Limestone and Indiana Dolomite.—The E_{str}/P vs temperature curves (Fig. 4) show that asphalt cement AC10–B3036 reacts strongly with Indiana dolomite (Geneva) * and Indiana limestone (St. Genevieve), and that the maximum was obtained at 293° F and 280° F, respectively. As was expected, the asphalt cement is considerably more reactive with the Geneva dolomite. The ζ vs temperature curves (Fig. 5) confirm the strong adsorptive reaction of entities from this asphalt cement—the maxima for both aggregates occurring at 374° F.

Another asphalt cement (B3013, App. 2) has adhesive qualities that react strongly with these aggregates. A number of other asphalt cements are extremely reactive for the St. Genevieve limestone (B2959 and B2963); and the Geneva dolomite (B2959, B2963, B3055, B3059, and B3109, App. 2).

Adhesive Qualities of Asphalt Cement AC10–B3036 for New York Graywacke Sandstone and New York Diabase.—The adhesive qualities of asphalt cement AC10–B3036 for the Graywacke sandstone (Rensselaer Gray-

* Samples supplied by State Highway Commission, State of Indiana.

wacke Formation) * and diabase (Palisades Diabase Formation) are poor. This lack of interfacial reactivity is shown by the E_{str}/P vs temperature curves (Fig. 6) and the ζ vs temperature curves (Fig. 7). However, several of the AC10 asphalt cements reacted strongly with the Graywacke sandstone (B2963 and especially B2975, App. 2) and the diabase (B3602 and especially B3579 and B2936, App. 2).

It is interesting to note that the E_{str}/P ratio is zero at 240° F, and the ζ potential is zero at the same temperature. This may be the zero-point-of-charge of both of these aggregates in the liquefied asphalt cement. At the zero-point-of-charge, the electrical double layer becomes negligible; that is, there is no potential gradient between the outer portion of the immobile layer and the bulk of the liquid. In a sense, this point may be regarded as nullification of surface potential. The fact that the zero-point-of-charge was obtained with increasing temperature indicates from the asphalt cement that polar asphaltenes and the high-molecular-weight fractions of the asphaltenes are beginning to be surface active and probably are responsible for the surface potential nullification.

Adhesive Qualities of Asphalt Cement AC10–B3036 and AC10–B3579 for Oregon Iron Mountain Basalt and Oregon Whipple Quarry Basalt.—The adhesive qualities of asphalt cement AC10-B3036 for Oregon Iron Mountain basalt and Oregon Whipple Quarry basalt † were extremely low (Figs. 8 and 9). It is interesting that a zero-point-of-charge was obtained at a temperature of 266° F. Also, these data indicated that with increasing temperature, the polar asphaltenes, the high-molecular-weight fractions of the maltenes, or other entities were not being adsorbed at the aggregate interface.

Obviously, the adhesive qualities of asphalt cement AC10–B3579 were very strong, as shown in the Group A curves of Figure 10. Four aliquot samples of this asphalt cement were streamed through Iron Mountain basalt in the multi-cell assembly; that is, each of four cells of this assembly contained the same asphalt cement and the same aggregate (programmed time = 4 hr). These curves showed excellent reproducibility from cell to cell. Group A curves quantitatively depicted adhesion (or adsorption) in electrokinetic terms.

This asphalt cement-aggregate system was cooled to room temperature. Again, the asphalt cement was streamed through the aggregate at the same programmed time period. The results were the Group B curves in Fig. 10. Again, excellent reproducibility was achieved. Group B curves were considered to be cohesion of the asphalt cement; that is, a quantitative depiction of London dispersion forces or van der Waal-London forces.

Salomon states: "Adhesion leads to *sorption;* this may be *adsorption on* a surface or *absorption into* a surface layer" (*3*, p. 3). These data bear a possible resemblance to the heats of immersion data collected by Ensley and Scholz, who propose that ". . . the initial peak height is a function of the properties of adhesion and the tail height is a function of cohesion between the multilayers surrounding the aggregate" (*4*, p. 43). By "tail height" these investigators mean the exothermic reaction progressively decreasing with time.

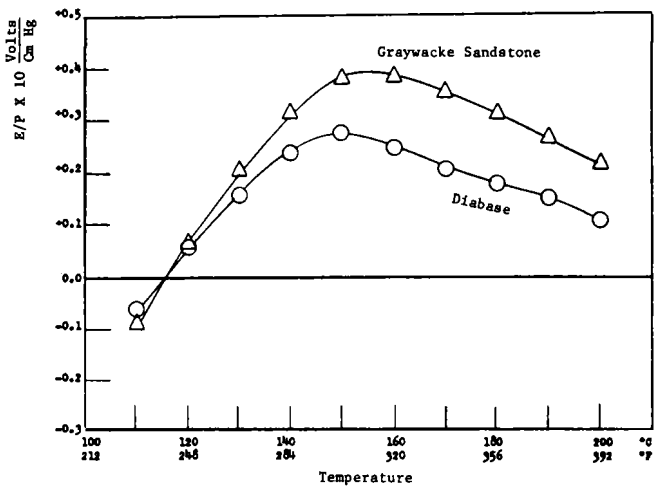

Figure 6. E/P vs temperature for New York Graywacke sandstone and diabase with asphalt AC10-B3036.

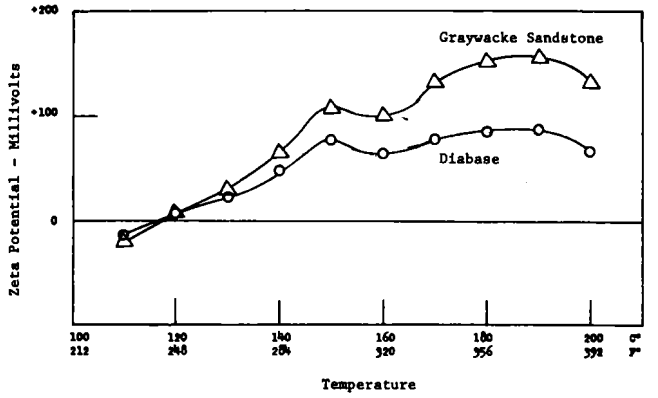

Figure 7. ζ potential vs temperature for New York Graywacke sandstone and diabase with asphalt AC10-B3036.

Interfacial Reactivity of Asphalt Cement AC10–B3036 Streamed Through Synthetic Aggregates

Adhesive qualities of asphalt cement AC10–B3036 for electric-furnace phosphate slag ‡ and blast-furnace slag § were strong, but the reactivity of this asphalt cement for open-hearth slag § was relatively weak (Figs. 11 and 12). For the phosphate slag, the maximum interfacial reactivity occurred at 302° F; for the blast-furnace slag, the maximum was at 311° F. For these two synthetic aggregates, entities continued to be adsorbed at the interface with increasing temperature, as shown in Figure 12.

* Samples supplied by Department of Public Works, State of New York.
† Samples supplied by State Highway Department, State of Oregon.
‡ Sample supplied by Stauffer Chemical Co., Silver Bow, Mont.
§ Arrangements for samples made by the National Slag Assn., Washington, D.C.

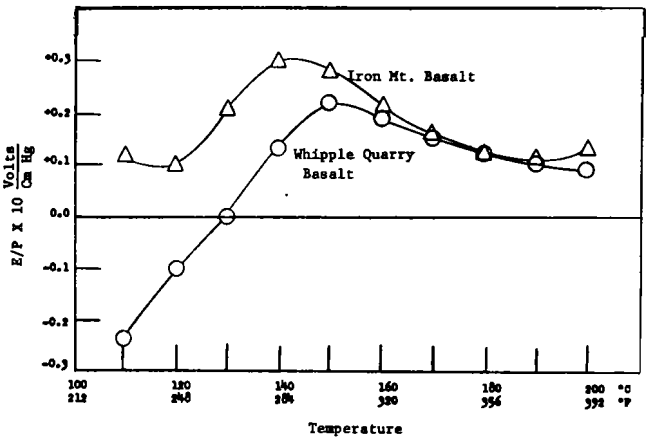

Figure 8. E/P *vs temperature for Oregon Iron Mt. basalt and Whipple Quarry basalt with asphalt AC10-B3036.*

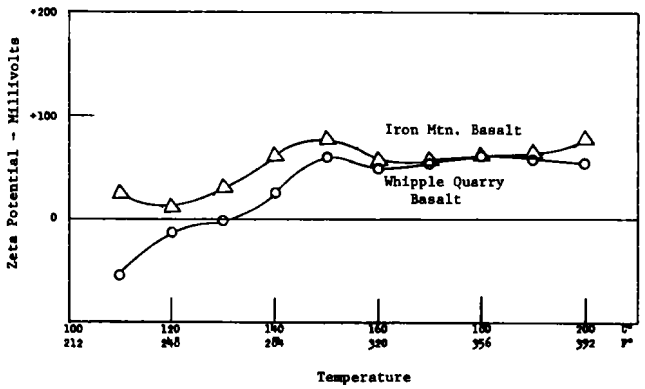

Figure 9. ζ *potential vs temperature for Oregon Iron Mt. basalt and Whipple Quarry basalt with asphalt AC10-B3036.*

The phosphate slag has strong interfacial reactivity with many of the AC10 asphalt cements investigated (B2921, B3013, B3029, B3055, B3059, and B3109, App. 2). This slag (40% SiO_2, 45% CaO, 2% P_2O_5 and other minor constituents) was relatively homogeneous, and the aggregate particles exhibited rough and pitted surfaces.

The sample of air-cooled blast-furnace slag had rough and pitted surfaces that would tend to ensure good mechanical binding between an asphalt cement and the aggregate. Actually, several of the other AC10 asphalt cements (B3013 and B3055, App. 2) reacted strongly with this slag. No attempt was made to alter the chemical composition or phases present in this type of slag. Alteration of the chemical composition or phases for optimum bonding of an asphalt cement with this type of slag seem feasible now that a quantitative method for assessment of the adhesive qualities has been developed.

The open-hearth slag consisted of two distinct phases—an extremely dark phase and a light-colored phase (probably CaO)—and included spheroidal granules of metallic iron. The slag had a tendency to degrade in aqueous environments. Nevertheless, two of the AC10 asphalt cements (B2959 and B3029, App. 2) reacted strongly with it.

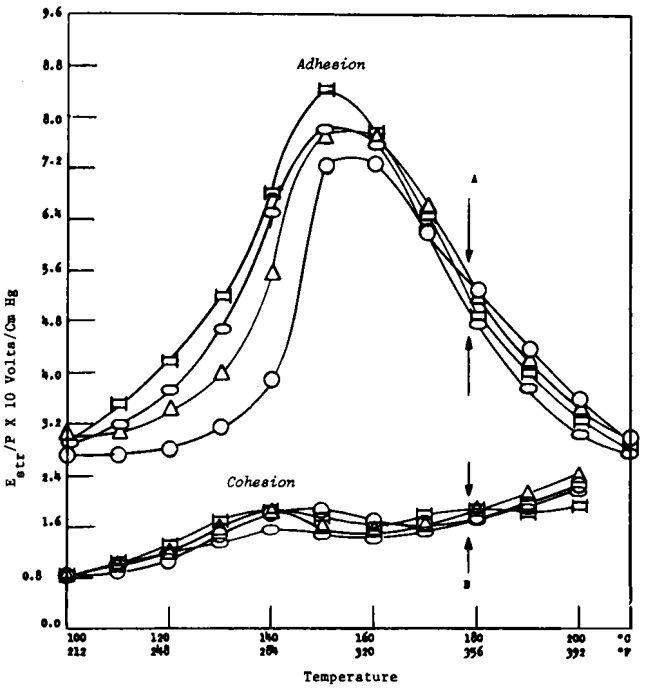

Figure 10. E/P *reproducibility curves for Iron Mt. basalt with asphalt cement AC10-B3036. "A" designates initial run; "B" designates repeat run after 24 hr elapsed time.*

Conclusions

In accord with the objectives of the research project, a new technique was developed for measuring adhesion (and cohesion) between asphalt cements and aggregates. Because asphalt cements and aggregates exhibited electrokinetic properties, electrokinetic measurements permit comparative assessment of adhesion.

By the developed technique and instrumentation system, an asphalt cement is caused to flow through the aggregate under applied pressure generating streaming potentials (or streaming currents). Actually, the mixing of an asphalt cement and an aggregate brings about tangential movement of these phases against each other and thus the creation of electrokinetic effects. These effects are explained in terms of electrical double layers which sheath the surfaces of the aggregate particles.

The developed data-acquisition system is essentially an analog to digital system. A prerequisite for this system was the measurement of small signals produced by very high impedance such as encountered in asphalt cement-aggregate systems. This data-acquisition system proved to be accurate and reliable, providing quantitative evaluation of adhesion by measurements of electrokinetic properties.

Indeed, the adhesive qualities of an asphalt cement and an aggregate are influenced by the inherent and diverse properties of both these materials. Both physical and

chemical adsorption occur. The interfacial reactivity of an asphalt cement depends on the contained entities, whether ionic, molecular, micellar, polar or nonpolar, or complexes of whatever nature; the reactivity of aggregates depends on their variable physical and chemical properties. In the evaluation of a temperature-controlled asphalt cement-aggregate system, streaming potential-pressure ratios and zeta potentials demonstrate the adhesive and adsorptive qualities of a particular asphalt cement for a particular aggregate.

Suggested Research

To advance the newly developed technique for the quantitative measurement of the adhesion between asphalt cements and aggregates to engineering use and to acquire information for the identification and evaluation of the factors affecting the adhesion between these materials, the suggested research directions are as follows:

Instrumentation Systems Development:

1. Cell configuration and shape.
2. Development of a cell assembly for the whole highway aggregate size grade (turbulent flow conditions may prevail).
3. Electrode configuration, position, and shape.
4. Suitability of cell and electrode assemblies for intended purpose (i.e., aqueous and nonaqueous fluids in laminar flow subject to the inherent viscosities of the respective fluid under investigation).
5. Temperature sensing and recording.
6. Development of a measuring cell for dielectric constant and conductivity.
7. Instrumentation for dipole moment determination.
8. Instrumentation for direct data processing.

Data Acquisition and Correlation:

9. Use of multi-capillary system to investigate the effect of surface area on the streaming potential.
10. Investigation and determination of the significance of surface area and particle-size distribution of aggregates on streaming potential and ζ potential measurements.
11. Determination of the Nernst potential from experimental data and its significance in interfacial adhesive reactions.
12. The significance of no-flow EMF and its reflection on the basic characteristics of the double layer.
13. Collection and analysis of streaming potential and ζ potential data for high-energy solids and low-energy solids.
14. Procurement of E/P vs temperature and ζ potential vs temperature data for viscosity-graded asphalt cements (other than AC10) streamed through mineralogically pure aggregates and typical highway aggregates.
15. Procurement of E/P vs temperature and ζ potential vs temperature data for solvent-extracted constituents of asphalts dispersed in media of varying dielectric constants streamed through mineralogically pure aggregates and typical highway aggregates.
16. Procurement of E/P vs temperature and ζ potential vs temperature data for asphalt cements and other types of asphalt products dispersed in media of varying dielectric constants streamed through mineralogically pure aggregates and typical highway aggregates.
17. Procurement of streaming potential and ζ potential data for asphalt cements streamed through surface-activated aggregates.
18. Collection of streaming potential and ζ potential data for binder-adjusted asphalt cements streamed through aggregates.

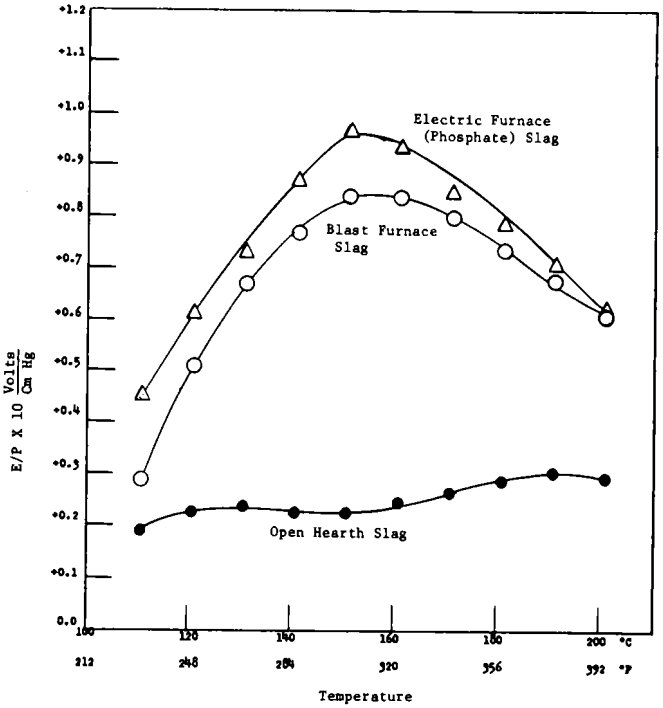

Figure 11. E/P vs temperature for various synthetic aggregates with asphalt AC10-B3036.

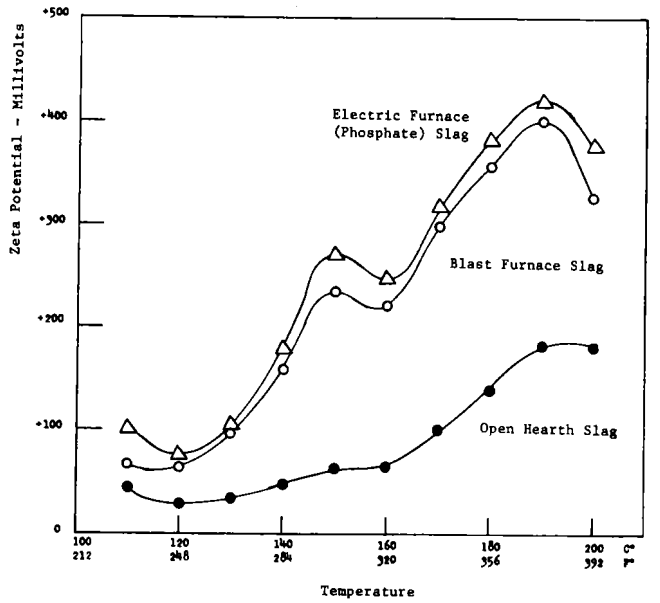

Figure 12. ζ potential vs temperature for various synthetic aggregates with asphalt AC10-B3036.

19. Continuation of efforts to gather scientific and technical information for interpretation and understanding of the factors that influence adhesion between an asphalt cement and an aggragate. Such a study will continue to be concerned with (1) the electrokinetic phenomena, (2) interfacial attraction at the solid-liquid interface, (3) adsorption at the solid-liquid interface for nonaqueous systems, and (4) interfacial reactions in aggregate systems.

Engineering Applications:

20. The development of a miniaturized data-acquisition system for field use. A prototype of a unitized system has been visualized and partly developed.
   a. Disposable cell assemblies.
   b. The flow pressure system.
   c. Environmental control.
   d. Data-acquisition system.

21. Development of a compact laboratory instrument for materials laboratories.
   a. Cell assembly systems and cell design.
   b. The flow pressure system.
   c. Environmental control.
   d. Establishment of parameters for engineering applications.
   e. Testing and calibration procedures.
   f. Data processing.

Overriding these suggested research directions is the adequacy of financial support for continuing effort. Electrokinetic measurements are an innovative approach to the understanding of adhesion and cohesion and the influencing factors. This approach is a translation of scientific principles to engineering applications, the acceptance of which may not be readily forthcoming.

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Additives to Market Value

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The courts are in agreement that just compensation is required to be paid to a property owner when his property is taken by eminent domain. The question on which they are not in harmony is: What does the term "just compensation" include?

The federal government and every state (with the exception of North Carolina, which allows it anyway) have constitutional provisions requiring just compensation in the event of eminent domain. Historically, the courts of the United States have equated the just compensation requirement with the term "market value." The courts have allowed recovery for the market value of the property but have been very restrictive as to what is included.

The general rule is that the taking authority need pay only for what it actually takes and does not have to pay for what the owner has lost. This reasoning thus excludes for consideration payment of such items as relocation costs, business losses, attorney fees, appraiser costs, and the ordinary costs of the eminent domain proceeding. This reasoning prevails in U.S. federal courts and in the great majority of the state courts. It was long ago decided that the term "just compensation" is what the courts define it to be. This was necessary because the legislative branches had neglected to define it.

With few exceptions, it may safely be stated that the courts have defined just compensation to mean "market value." Therefore, a discussion of "Additives to Market Value" actually is synonymous with "Additives to Just Compensation." Most of the "additives" have occurred through specific legislation. Others have been allowed, independent of statute, by the courts.

This report examines some outstanding cases concerning additives to market value in highway condemnation cases and delves into legislation materially affecting the law of eminent domain as it relates to just compensation.

Relocation Costs

The general rule is that, in the absence of statutory authority, the relocation costs of the property owners affected by eminent domain cannot be paid by the condemning authority. Primarily, in referring to relocation costs, the property owner is concerned with the movement of personal property. This is so because ordinarily all other property is included in the condemnation action.

The 1962 case of *State of Arizona v. Chun,* 372 P.2d 324, is illustrative of the reasoning involved on a plea for payment of relocation costs. Chun owned a grocery and variety store combination that was taken for highway construction. The question before the Arizona Supreme Court was whether Musil, the tenant of Chun and the operator of the store, was entitled to his cost of moving personal property from the grocery store and also for damages to his personal property. The lower court had allowed Musil the damages. The Supreme Court stated:

> . . . Error is assigned by the State as to the admission of testimony of the tenant's cost of moving personal property from the leased premises. . . .
>
> . . . .
>
> The second assignment of error is to the effect that the trial court erred in admitting into evidence as an element of the tenant's damages testimony of the value

> of unsold merchandise retained by the tenant after the leasehold has been terminated. . . .
>
> . . . .
>
> The third assignment of error concerns the admission of testimony describing monetary damages to personal property of the tenant's trade fixtures which were removed and retained by him. . . .
>
> . . . Therefore any loss resulting from the removal of fixtures is not compensable and the testimony as to the monetary depreciation of the fixtures in the amount of $1,313 which the tenant removed was improper.

The courts and legislative branches are jointly responsible for the failure to justly pay the expenses incurred by the tenant in this case. The legislative branch should have set forth precisely what is to be covered by "just compensation" and the court should have been more realistic in its holding. The three basic reasons for disallowing moving costs are not convincing. The argument that the tenant would have to move anyhow defies all logic. Just as groundless are the other two reasons that the expense of relocating is not a "taking" and that the verdict would be based on conjecture because different tenants must move different places. If a person is displaced by a condemnation action, his property right to remain has been taken and he is entitled to recover all reasonable damages. This includes moving costs, which costs he must prove, and the injuries in such cases will be no harder to prove than an injury inflicted in many other types of cases, such as personal injury.

Because of the obvious injustice of such decisions, many courts have been lenient in allowing exceptions to the general rule that relocation damages are not allowed. The most historical case involved is the *United States v. General Motors,* 89 L. Ed. 311 (1945). In this decision the United States Supreme Court recognized that ordinarily a tenant is not allowed his moving costs when ousted by an eminent domain proceeding. But the court stated that this rule did not apply when he was only temporarily ousted, because, in such event, he would later have to move back and then ultimately abandon the premises again. Thus, his moving expenses were allowed for the temporary vacation of the premises, because otherwise he would suffer the expense of two moves.

Another exception to the general rule is illustrated by the Connecticut decision of *Harvey Textile Co. v. Hill,* 67 A.2d 851 (1949). The property owner involved was allowed the cost of disassembling, moving, and reassembling the machinery in the factory from which he was ousted. The court allowed the recovery, reasoning that the cost had a bearing on the market value of the property. The court said that if the owner was a "willing seller" he would take into consideration his moving expenses in affixing the price on which he would sell to a "willing" buyer.

An extension of the reasoning in this case is shown by the New Jersey Supreme Court in *State v. Gallant,* 202 A.2d 401 (1964). A fabric-weaving factory was involved. The lower court had refused to allow the moving costs of six large looms from the factory in a condemnation case. It had been established that it would cost approximately $40,000 to move them. The New Jersey Supreme Court held as follows:

> We return now to the immediate problem before us, i.e., whether the concept of just compensation as outlined above may require that defendants receive an award for their looms. We believe they may. . . .
>
> . . . .
>
> The value of a factory containing industrial equipment employed in the business for which the property is being used is ordinarily greater than that of an empty and idle building. Such equipment in place adds more to the value of the realty than its second-hand salvage value separated from the premises. An owner, who is under no duress, and where the building and machinery are a functional unit, would undoubtedly sell only at a price which would reflect that increased value. Where, therefore, a building and industrial machinery housed therein constitute a functional unit, and the differences between the value of the building with such articles and without them, is substantial, compensation for the taking should reflect that enhanced value. This, rather than the physical mode of annexation to the freehold is the critical test in eminent domain cases.

The reasoning of the courts in allowing exceptions to the general rule that relocation damages are not allowed is wrong only in that it evades the main issue. In other words, the courts should not be seeking reasoning for exceptions—they should be going to the heart of the matter. For example, the Florida Supreme Court, in 1959, met the issue squarely in the decision of *Jacksonville Expressway Authority v. DuPree,* 108 So. 2d 289. The question was whether the ousted owner was allowed compensation for the moving cost of his business. The court stated:

> Although the contention that moving costs have no bearing on the fair market value of the premises may be meritorious in other jurisdictions, it has no merit in Florida, where an owner is constitutionally guaranteed full or just compensation. The theory and spirit of such a guarantee require a practical attempt to make the owner whole. . . . A person who is put to expense through no desire or fault of his own can only be made whole when his reasonable expenses are included in the compensation.

Relocation costs due to highway construction are currently being allowed in a number of jurisdictions and soon the allowance will be universal as it relates to federally funded highway programs.

Business Losses

It may generally be stated that injury to business or to good will or a loss of profits are not included in the element of damages under the common law. Thus, to strictly apply the common law means that the owner of a business is entitled to no remuneration from the taking authority. This is particularly devastating to the business of a tenant because where the business is operated by the fee owner the injury is often lessened by the rendition of a liberal award.

Cases denying compensation for business losses have been based on various nebulous reasons; illustrative of these is the decision of *United States ex rel. T.V.A. v. Powelson,* 87 L. Ed. 1390 (1943).

Also illustrative is the case of *A. G. Davis Ice Co. v. United States,* 362 F.2d 934 (1st Cir. 1966), which involved the taking of a business property located in downtown Lexington, Mass., as a site for a new post office. The

property was leased by Davis to Fawcett, who subleased it to Atlantic for the use of large underground tanks for the storage and distribution of heating oil. Fawcett paid a fixed sum rental, whereas Atlantic's rental was based on volume of storage. The question was whether the profits realized from the storage tank lease could be used in the ascertainment of market value. The trial court excluded any evidence as to the storage tanks. The United States Circuit Court of Appeals also held that "under the circumstances in this case the trial court did not err in excluding the evidence of business profits under the Atlantic sublease."

A further extension of such reasoning is shown in *R. J. Widen Co. v. United States and Commonwealth of Massachusetts,* 357 F.2d 988 (Ct. Cl. 1966). Plaintiff owned a tannery plant specifically designed for the manufacture of specialty leathers. Plaintiff's property included a dam constructed across a river one-half mile upstream and a set of headgates behind the dam to control the flow of water from the river into a canal belonging to plaintiff. The canal carried water to the plant and away from the plant. Without notice, the Corps of Engineers moved in and destroyed the dam and headgates as preliminary work on a flood control project. Because of this plaintiff lost many hides, and the lack of water also damaged his machinery. Plaintiff received compensation for the real estate actually taken and then brought action to recover his damage to personal property, business expenses incurred as result of the loss of water, and loss of profits. The court held the losses were not compensable.

The hard-line reasoning of the courts has led to the various statutory allowances which are pointed out subsequently. With or without such statutes some states have allowed recovery of business losses. In the decision of *In re Ziegler's Petition,* 97 N.W.2d 748 (Mich. 1959), the court allowed recovery for business interruption. This involved a highway condemnation where the owner was forced to move his manufacturing business because of the taking.

In the Connecticut decision of *Housing Authority of City of Bridgeport v. Lustig,* 90 A.2d 169 (1952), the Connecticut Supreme Court held that it is proper to take into consideration existence of a growing business on condemned land as indicative of the highest economic use to which the land may be put.

In the Texas case of *City of LaGrange v. Pieratt,* 175 S.W.2d 243 (1943), the plaintiff sought loss of profits, together with other damages caused by the vacation of his service station site for highway purposes. The Texas Supreme Court stated:

> . . . It is the law that where a breach of a contract or a tort results in damages to an established business, in the form of loss of profits, which would have been derived therefrom absent such breach of contract or tort, the owner of such business may recover damages from the party causing such loss, measured by the amount of such loss of profits. . . . We have already shown that the same rule applies in condemnation proceedings. . . .

The Supreme Court of Georgia in *Bowers v. Fulton County,* 146 S.E.2d 884 (1966), has held that fair market value alone is not in every case the proper criterion for determining just and adequate compensation and that destruction of an established business is and must be a separate item of recovery from value of land taken.

The Oklahoma Supreme Court has recently allowed evidence concerning the income and profits from a business [*State, ex rel. Department of Highways v. Robb, et al.,* 454 P.2d 313 (1969)] as being admissible evidence because it bears on the question of the fair market value of the property.

It must be kept in mind that this discussion is limited to additives to market value. The cases discussed involved either the taking of the whole parcel or a partial taking. Abutting property owners, who have no realty taken, are not allowed recovery for loss of business.

Interest

When the landowner is deprived of his property he is at that moment entitled to compensation. If there is a delay in the payment of compensation he is also entitled for payment for the delay. The right is a constitutional one, and the payment for the delay is known as interest. This reasoning is concisely set forth in the decision of the *New Hampshire Water Resources Board v. Pera,* 226 A.2d 774 (1967).

Interest is generally recoverable from the date of taking, although different states may have varying rules of procedure and conditions precedent required of the landowner before the accrual of interest begins. The condemning authority usually has the right to terminate the running of the interest by depositing the initially determined award in the court. The landowner is then entitled to draw down the award and may thereafter only receive interest on any excess subsequently granted. If it is later determined that the initial award was too great, many states require the landowner to pay interest on any excess that he received on his initial draw down.

Costs

The law of eminent domain is a field in itself. Because of the peculiarity of the action, it is universally held that the owner is generally not responsible for the court costs incurred in the trial of the taking of his property. However, because of the nature of the action, the costs are not awarded to either party unless a special statute exists. Condemnation proceedings are not within the purview of the general statutory provisions as to costs in civil actions; therefore, there must be a special statute. The only exception to the rule that the landowner is not responsible for the costs is where some authorities assess the costs against the landowner if he is involved in an unsuccessful appeal from the award.

The costs involved in the trial of an eminent domain case include the litigation costs, attorney fees, expert fees, and cost of appeal. Also included are the court appointed appraiser fees, and often surveys, photographs, and other demonstrative evidence necessary for the trial of the case.

Attorney Fees.—The right to recover attorney fees as part of costs of litigation did not exist at common law, and such fees are not allowable unless there is special statutory authority for them. The owner's attorneys' fees are not

embraced within the definition of "just compensation" for land taken by eminent domain. A statute merely allowing for costs, expenses, and just compensation is not sweeping enough to also cover attorney fees. The reason for the common law rule is the fear that the allowance for attorney fees will encourage litigation. The problem is not an easy one. It is difficult to reason that the landowner is receiving just compensation when he has to pay a portion of his award to an attorney, yet the encouragement of litigation problem definitely exists. The only fair answer is to discourage all litigation of eminent domain takings by just negotiation. This means that the taking authority must be immediately fair to the landowner in the negotiating process. Attempts to save money in the negotiating area are not reasonable, fair, or economical.

Expert Fees.—It is the common law rule that the landowner's experts must be paid by the landowner, and their fees are not taxed as part of the costs or included within the definition of just compensation. This is not a fair treatment of the situation, and many states have rectified the situation by statutes that allow reasonable fees for the landowner's experts.

Miscellaneous Additives

Real Estate Taxes

The time of the attachment of a tax lien depends on the local rules. The problem is where the lien attaches, the taking authority later takes possession, an award is granted, and then the taxing authority moves against the award for full payment of the tax. This is especially true where the taking authority is exempt from paying a property tax. Undoubtedly, equity demands that the property owner not be responsible for the payment of property tax for a period in which the taking authority has possession; but the decisions vary. The only just answer for a landowner is the reasoning set forth in the recent decision of *District of Columbia v. Sussman,* 352 F.2d 683, wherein the court said:

> . . . Our decision that land in the District cannot be relieved of its liability for taxes already assessed when it is the subject of condemnation by the federal government does not mean that the former owner must silently pay the taxes for the entire year even though he has use and possession of the land for only a part of it. . . .
>
> A condemnee does not have to accept in full payment for his property the sums deposited in court at the time of taking. He is entitled to try to persuade a court or jury that he has been damaged in a larger amount, and to support that claim by all relevant and competent evidence. That evidence may, in our view, include the taxes payable to the District with respect to a period when his property is in the hands of the Government. Given this opportunity, he cannot complain of action by the condemnation court to assure payment, as they fall due, of tax liabilities that run against the land in the first instance, or alternatively, against the deposited cash which takes its place.

Special Assessments

Two problems exist in the case of special assessments: (1) Can the landowner recover as "costs" the amount of a special assessment lien that previously existed against the property being taken? and (2) Can the landowner recover the amount of assessments that may be added to his remaining property because of the improvement that is the object of the condemnation?

Both questions can be answered quickly with a negative. The Colorado Supreme Court answered the first question in *Department of Highways v. Kelley,* 379 P.2d 386 (1963). The Oregon decision of *City of Eugene v. Wiley,* 358 P.2d 286 (1960), answers the second question.

The courts go both ways as to whether to allow the lien of the previously existing special assessment to follow the award.

The Federal-Aid Highway Act of 1968

Because of the general common law exclusion of additives to market value, and the many inequities rendered, the federal and state laws have been changed by statutes in many respects. This is especially true relative to relocation damages and certain costs. The Federal-Aid Highway Act of 1968 (U.S.C., Title 23, §§ 501–511) is the legislation that is revolutionizing the law. This Act applies to any highway that is federally funded; its provisions became mandatory on the states on July 1, 1970.

The Statutes—Relocation Costs and Business Losses

Congress has declared its policy to be that disproportionate injuries will not be suffered by a few for the benefit of the whole on federal highway programs. Section 505 of the Act allows payment of actual reasonable expenses in moving a family, business, or farm because of a federally funded highway program. This includes personal property. Certain optional payments are allowed in lieu of actual moving expenses. These optional payments will be useful to tenants who are allowed small lump sum payments without the bother of detailing actual expenses. Optional payments are also allowed businesses and farm operations wherein they are given fixed relocation or discontinuation payments based on previous average annual net earnings. The optional payment to a business is not allowed if the business is part of a commercial enterprise having at least one other establishment that is engaged in the same or similar business. The blooming of the franchise business will present many interesting questions under this provision. If an individual is ousted, is he entitled to the optional payment if he operates as an individual businessman under a franchise agreement with a national concern? It would appear that to deny him the equality of treatment of the optional payments would be an unjust classification that should amount to an unconstitutional act.

Section 506 of the Act provides for replacement housing under certain conditions. Thus, if the person ousted meets the requirements set forth, he is entitled to an extra allowance that will put him in comparable housing to the premises from which he was ousted. This provision recognizes the failure of the prior laws wherein the award received was often insufficient to put the persons affected into comparable housing.

The Statutes—Other Additives

The Act also allows reimbursement to an ousted owner for his reasonable expenses incurred for recording fees, transfer taxes (and similar expenses), mortgage prepayment penalties, and the pro rata portion of real property taxes paid that are allocable to a period subsequent to the date of vesting of title in the state, or the effective date of possession of such property by the state, whichever is earlier. Also, none of the payments received under the Act is considered as income under the Internal Revenue Code. In other words, the Act simply authorizes the payments (in a mandatory manner) that should have originally been included in the term "just compensation."

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Valuation and Compensability of Noise, Pollution, and Other Environmental Factors

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The power to take private property for a public purpose by eminent domain is a basic right of government. However, in the United States, private property shall not be so taken without the payment of just compensation. The question discussed herein is whether highway-produced noise, and air and water pollution—and other similar environmental factors—are the type of injuries for which compensation must be paid.

The law may concisely be stated as follows: Unless there is a partial taking of the property involved, there can be no recovery for damages that are caused by highway-produced noise, and air and water pollution—and other similar environmental factors.

Examples:

1. Thus, if no portion of a landowner's property is actually taken for highway construction, the landowner cannot recover for any damages to his property that he may claim for noise and similar environmental factors.
2. If a portion (partial taking) of a landowner's property is taken for highway construction, the general rule is that the landowner can recover for noise (and similar environmental factors) damage to the remainder of his property.

Cases Not Involving Partial Taking

The partial-taking cases are discussed later. The reasons for the basic rule of no recovery in the absence of a partial taking are discussed in the following, primarily through use of the leading cases concerned.

1. The doctrine that this type of damage does not constitute a "taking" has become so well established that it amounts to a rule of property, and should be modified, if at all, only by the lawmaking power.

In *Richards v. Washington Terminal Co.,* 233 U.S. 546 (1914), plaintiff's house was approximately 100 feet from the railroad track of the defendant. Plaintiff claimed that passing trains caused smoke and vibration damage and disturbing noise. The United States Supreme Court, in this decision which is still the federal law, stated as follows: ". . . Any diminution of the value of property not directly invaded nor peculiarly affected, but sharing in the common burden of incidental damages arising from the legalized nuisance, is held not to be a 'taking' within the constitutional provision. . . ."

The *Richards* case correctly infers that all state constitutions may not be substantially in the form employed by the Fifth Amendment of the Federal Constitution. The Fifth Amendment provides compensation for property "taken" for public use. Twenty-three states have similar "taken" provisions, whereas 26 states provide compensation for property "taken or damaged," or contain language with an equivalent meaning. In a discussion of the compensibility of highway noise and similar environmental factors the question is ever present as to whether the states with "taken or damaged" provisions will be more liberal in allowing recovery. The answer is that they are not. The states with the "taken or damaged" provisions adopted such provisions to allow certain types of consequential damages (loss of the right of access, change of grade) but it has never been their intent to allow for damages caused by highway-produced noise and similar environmental factors. A recent California decision [*Goldberg, Inc. v. State,* 55 Cal. Rptr. 159 (1966)] is in point, wherein the California court stated:

> The amendment of state constitutions, including California's, to provide compensation when private property is "damaged" as well as "taken" for public use, indicates an intent to expand the area of compensability, requiring the courts to fix its limits by placing the economic interests of the public in balance against the sacrifices imposed on the landowner. . . . Not every impairment . . . is compensable in eminent domain. Compensability, rather, requires an individualized finding of substantial impairment, a finding of fact delegated to the trial court and not the jury. . . .

2. The Fifth Amendment, which requires just compensation, undertakes to redistribute certain economic losses inflicted by public improvement so that they will fall on the public rather than wholly on those who happen to lie in the path of the object. It does not undertake, however, to socialize all losses.

In *United States v. Willow River Power Co.,* 324 U.S. 499 (1945), the power company had been awarded damages by a lower court as just compensation for impaired efficiency of its hydroelectric plant caused by an action of the United States in raising the water level of a river. The question was whether the damage was the result of a "taking" of private property, for which just compensation is required by the Fifth Amendment. The United States Supreme Court reversed the decision, stating that "the Fifth Amendment, . . . does not undertake, however, to socialize all losses, but those only which result from a taking of property. . . ."

3. Damage alone gives courts no power to require com-

pensation where there is not an actual taking of property.

The *Willow River* decision covers this aspect as does the *Northcutt* decision, discussed next.

4. If damages for highway noise, etc., were allowed it would be impossible to determine with any degree of accuracy a reasonable budget for the construction of highways.

In *Northcutt v. State Road Department of Florida,* 209 So. 2d 710 (Fla. 1968), plaintiffs brought an action for damages to their residence resulting from increased noises, dust, and vibrations allegedly caused by Interstate highway construction close to their property. Plaintiffs said the highway department had constructed, maintained, and operated the Interstate highway so as to cause heavy industrial and commercial traffic to use it so near to their property as to cause excessive shock waves, vibrations, and noises at all hours of the day and night which impaired their health and deprived them of the use and beauty of their property, causing it to lose its value for residential purposes. Plaintiffs asked the court to order the State Road Department to institute eminent domain proceedings against their property. Plaintiffs relied primarily on a Florida inverse condemnation * case involving an airport, wherein the court upheld that the complaint was sufficient to state a cause for relief. In this *Northcutt* decision the Florida court denied the plaintiff's action in stating as follows:

> . . . To sustain the amended complaint of the plaintiffs as sufficient for inverse condemnation would bring to an effective halt the construction, operation and maintenance of access roads and highways within the State of Florida. It would be impossible to determine and prepare with any degree of accuracy, a reasonable budget for the construction of highways and access roads in the future in Florida. . . .
>
> . . . It seems clear that there has been no "physical" taking or actual "appropriation" of the plaintiff's property under the laws of Florida. In Florida, in order for the "taking" or"appropriation" of private property for public use, under the power of eminent domain, to be compensable, there must generally be a "trespass or physical invasion." . . .

5. If compensation was allowed for every inconsequential inconvenience, discomfort, and displeasure suffered by reason of highway noise, etc., the cost of the construction of highways would be prohibitive.

In *People v. Presley,* 48 Cal. Rptr. 672 (1966), the California court held that landowners, who owned apartment houses that were next to a street condemned for a freeway, could not claim damages for increase of noise, fumes, and annoyance. The court stated as follows:

> . . . [C]ourts will not award compensation for every inconsequential inconvenience, discomfort and displeasure suffered by the abutting owner as the result of the building of each new public improvement. To so hold would make the cost of public improvements prohibitive.

6. There is no right to recover for all elements of damage caused by the construction of a public highway.

People v. Symons, 357 P.2d 451 (Calif. 1960), was an eminent domain case in Los Angeles. None of Symons' property was actually condemned for the freeway but a small portion of it was condemned to provide a turn-around area for a cul-de-sac that was made necessary by the freeway construction. Symons sought to introduce expert testimony of the decreased value of the property arising from such factors as the change from a quiet residential area, loss of privacy, loss of view, noise, fumes, and dust from the freeway. The court denied the admission of this testimony with the following reasoning:

> . . . It has long been recognized that there is no right to recover for all elements of damage caused by the construction of a public improvement. . . .
>
> It is established that when a public improvement is made on property adjoining that of one who claims to be damaged by such general factors as change of neighborhood, noise, dust, change of view, diminished access and other factors similar to the damages claimed in the instant case, there can be no recovery where there has been no actual taking or severance of the claimant's property. . . . Accordingly, in the case at bar, had the parcel for the cul-de-sac not been taken, the defendant would not be entitled to recovery based on the general diminished property values due to the construction of the freeway on the adjoining property. It is manifest, then, that the crucial question here is whether the defendants, whose property was taken for purposes other than the construction of the freeway itself, are entitled to compensation, as severance damages, for those impediments to the property resulting from the objectionable features caused by the maintenance and operation of the freeway proper on lands other than those taken from the defendants.

The court then answered the question by denying recovery.

7. Noise, dust, and matters of that sort are incidents to living on a public highway or street and must be borne by all owners of abutting property without any compensation therefor.

In *Campbell v. Arkansas State Highway Commission,* 38 S.W.2d 753 (Ark. 1931), the property owner complained that the construction of the bridge and the approaches thereto caused annoyance by dust and dirt blown over his property and the sound caused by the vehicles going over the bridge. The Arkansas Supreme Court stated: ". . . We do not think the plaintiff . . . should recover anything for noise, dust, and matters of that sort, which, in varying form, are incidents to living upon a public highway or street, and, as such, must be borne by all owners of abutting property."

Cases Involving Partial Taking

The general rule is that, when part of a parcel of land is taken by eminent domain, the owner is not restricted to compensation for the land actually taken but also is entitled to recover for the damage to his remaining land. Included in the definition of the phrase "damage to his remaining land" are such items as highway noise and other similar environmental factors. It is impossible to completely recon-

* Inverse condemnation is a term used to describe a cause of action to recover the value of property which allegedly has been taken in fact although the government has never formally exercised its power of eminent domain. *Ferguson v. City of Keene,* 238 A.2d 1 (N.H. 1968).

cile the foregoing general rule with the basic rule that in the absence of a partial taking there can be no recovery for highway-produced noise, etc. This being the case, it appears to be the better reasoning to maintain that recovery for highway noise, etc., should also not be allowed in the partial-taking cases. Missouri so holds, and other states are reluctant to follow the general rule.

Much of the problem has been caused by the use of the term "consequential damages." In the law of eminent domain, damages that are recoverable are termed "actual damages," whereas damages that are not recoverable are sometimes termed "consequential damages." However, in the law of negligence, consequential damages are often recoverable because they are damages that are the consequence of a particular act or omission. Thus, confusion has existed in many legal writings as to the meaning of "consequential damages," and one of the results is that consequential damages are allowable in partial-taking cases.

Illustrative of the general rule is the California case of *Pierpont Inn, Inc. v. State,* 68 Cal. Rptr. 235 (1968). This involved a partial taking for freeway purposes of property owned by the Pierpont Inn. The California court held as follows:

> . . . Where the property taken constitutes only a part of a larger parcel, the owner is entitled to recover . . . the difference in the fair market value of his property in its "before" condition and the fair market value of the remaining portion thereof "after" the construction of the improvement on the portion taken. Items such as view, access to beach property, freedom from noise, etc. are unquestionably matters which a willing buyer in the open market would consider in determining the price he would pay for any given piece of real property. Concededly such advantages are not absolute rights, but to the extent that the reasonable expectation of their continuance is destroyed by the construction placed upon the part taken, the owner suffers damages for which compensation must be paid.

South Carolina State Highway Department v. Touchberry, 148 S.E.2d 747 (S.C. 1966), clarifies a further bothersome term—"special and peculiar damages." The South Carolina State Highway Department had brought suit to condemn 20.5 acres of a 146-acre tract for highway purposes. The question was whether increasing traffic noise at the landowner's residence could be considered in assessing compensation. The State Highway Department was the defendant in the appellate court:

> *As to traffic noise.* The defendant contends that increased traffic noise resulting from the construction of the highway near the Touchberry residence does not constitute special damage because "there is no showing that the alleged injury is special and peculiar to the landowner and not such as is commonly suffered by all others whose homes are in close proximity to that highway."
>
> This contention is apparently based upon a misconception of the law applicable in assessing damages to the remaining property of a landowner where a portion of an entire tract has been condemned for a public improvement. We quote from *4 Nichols on Eminent Domain,* Section 14.1, page 473: "A distinction must be drawn between consequential damages to a remainder area where part of a tract is physically appropriated and consequential damages to a tract no part of which is physically appropriated. In the latter case the damage must be peculiar to such land and not be such as is suffered in common with the general public. In the former case it matters not that the injury is suffered in common with the general public."

Then the court went on to say:

> As stated in 18 AM. JUR. 905, Sec. 265: "When part of a parcel of land is taken by eminent domain, the owner is not restricted to compensation for the land actually taken; he is also entitled to recover for the damage to his remaining land. In other words, he is entitled to full compensation for the taking of his land and all its consequences; and the right to recover for the damage to his remaining land is not based upon the theory that damage to such land constitutes a taking of it, *nor is there any requirement that the damage be special and peculiar, or such as would be actionable at common law; it is enough that it is a consequence of the taking.* The entire parcel is considered as a whole, and the inquiry is, how much has the particular improvement decreased the fair market value of the property, taking into consideration the use for which the land was taken and all the reasonably probable effects of its devotion to that use." (Emphasis added.) 242 S.C. 417, 131 S.E.2d 266.
>
> The grounds of the department's motion for a new trial which were based upon the foregoing contention with respect to traffic noise were properly overruled.

Obviously, the term "special and peculiar damage" applies basically to cases involving loss of access wherein there is no partial taking but the claimant is sometimes awarded damages if he can prove he received "special and peculiar damage" not suffered in common with the general public. The term has no application in eminent domain proceedings involving highway-produced noise and similar environmental factors. If there is not a partial taking, no recovery for highway noise may be had, and it makes no difference whether special and peculiar damages are involved. If there is a partial taking, the general rule is that recovery for highway noise is allowable regardless of whether special and peculiar damages are involved. The decision of *Mississippi State Highway Commission v. Colonial Inn, Inc.,* 149 So. 2d 851 (Miss. 1963), illustrates some of the confusion on special and peculiar damages. The Mississippi State Highway Commission condemned 0.02 acre of property of the Colonial Inn for highway purposes.

As in all eminent domain matters, there is a valuation problem in affixing the amount of damages due to highway noise and similar environmental factors. Generally, such damage items as noise are included in an all-inclusive plea to the court for a high award. There are basically three methods of valuation in the partial-taking cases:

1. The recovery shall be for the market value of the part taken, plus the damages to the remainder.
2. The recovery shall be the difference between the market value of the entire property before the taking and its value after the taking.
3. The damages to the remainder and the value of the part taken are included in one lump sum in the value of the part taken.

The number one rule is the usual rule; but, regardless of the particular rule used, it comes down to one point [*Pierpont Inn, Inc. v. State,* 68 Cal. Rptr. 234 (1968)]: "Items such as view, access to beach property, freedom

from noises, etc. are unquestionably matters which a willing buyer in the open market would consider in determining the price he would pay for any given piece of real property."

So, in partial-taking cases if noise, etc., will affect market value, it must itself be valued. This must be done in light of the particular valuation law of the state concerned, and although it is difficult to attach a dollar figure to this type of damage it is no more difficult than evaluating damages for loss of view and invasion of privacy.

The New York decision of *Dennison v. State,* 293 N.Y.S.2d 68 (N.Y. 1968), reveals some of the problems in the evaluation of damages for highway noise injuries. The Dennisons had built their dream home in a remote wooded area; the seclusion lasted until the new interchange was constructed. The lower courts stated that the complete privacy and quiet had been removed by virtue of the new highway. In awarding damages for a partial taking the lower courts took into consideration the loss of privacy and seclusion, the loss of view, the traffic noise, and lights and odors as factors causing damage to the remaining property. The State said that noise should not have been considered in making the award. The court upheld the decision.

Missouri specifically does not abide with the general rule of allowing highway noise damages, etc., in partial-taking cases. *State Highway Commission v. Turk,* 366 S.W.2d 420 (Mo. 1963), was a partial-taking case for highway purposes involving a modern residence and dairy barn. The Missouri court said:

> It appears to be settled in this state that "the amount of noise and speed of the traffic on the highway are not proper elements to be taken into consideration in arriving at the damage resulting from condemnation of land for State Highway uses or for railroad uses." *State ex rel. State Highway Commission v. Hoffman,* Mo. App., 132 S.W.2d 27, 30. . . .
>
> . . . .
>
> . . . Upon the more general subject, we have said that "traffic, great or small, is merely an incident of streets and highways and cannot be considered either as an element of damages or of benefits." *Wilson v. Kansas City,* Mo. Sup., 162 S.W.2d 802, 805.

Similarly, the Missouri court in *State Highway Commission v. Galeener,* 402 S.W.2d 336 (1966) (a partial-taking case) said:

> It may be said, to shorten consideration of the problem, that noise and speed, increased traffic and their resulting inconveniences are neither elements of damages nor of benefits and they are not proper matters of proof or for the jury's consideration. *State ex rel. State Highway Comm. v. Turk,* Mo., 366 S.W.2d 420; *State ex rel. State Highway Commission v. Sharp,* Mo. App., 62 S.W.2d 928; *State ex rel. State Highway Commission v. Pope,* 228 Mo. App. 888, 74 S.W.2d 265.

The Problem with Airplanes

A discussion of the leading airplane cases is relevant to highway-produced noise only because of the continual effort of litigants to use such cases in their behalf.

The U.S. Supreme Court has held that continuous invasions of the airspace immediately above the claimant's property by low-flying aircraft can constitute a taking that is compensable under the law of eminent domain. The restriction is that there must be continuous low overflights; if there are not, there is no taking. The distinction is clearly pointed out in *Batten v. United States,* 306 F.2d 580 (10th Cir. 1962), *cert. denied,* 371 U.S. 955, *rehearing denied,* 372 U.S. 925 (1963), wherein the plaintiffs asked for damages because of airplane noise, vibration, and smoke injuries. The plaintiffs did not rely on flights over their properties to sustain their claims.

The *Batten* case remains the federal law. It clearly holds that for compensability of airplane noise, etc., to be allowed there must be a physical invasion. Thus, unless the usable airspace immediately above the claimant's property is continually interfered with, there can be no recovery for noise damage. If the usable airspace immediately above his property is continually interfered with, the situation is analogous to the building of an overpass over a claimant's property. In the situation of the overpass, an easement has been taken; this constitutes a partial taking and, thus, damages for highway noise, etc., are allowable. Similarly, continuous low flights over land can constitute the taking of an easement—thus, a partial taking; therefore, damages for noise, etc., are allowed.

Proponents of a more liberal view argue that there need be no direct overflights to allow noise damage in airplane cases. This view has been adopted in Oregon and Washington simply by their courts allowing the jury to determine whether claimants should be allowed to recover such damage.

The use of the reasoning in the Oregon and Washington airplane cases has led to questionable statements in a New Jersey highway decision. In *Board of Education of Morristown v. Palmer,* 212 A.2d 564 (N.J. 1965), a New Jersey lower court reversed the dismissal of a complaint by the Board of Education relative to a highway noise, etc., case. The Board of Education alleged that a new highway would virtually encircle an elementary school and that the resultant highway noise, fumes, and danger would destroy the use of the property as a school. There was no partial taking involved. The lower court held that if the beneficial use of the school was destroyed there was a "taking," and justice demands that compensation be made whether or not a physical invasion of the property was involved.

Later the New Jersey Supreme Court reversed the ruling of the lower court when it became apparent that the new highway would not virtually encircle the school. The Supreme Court of New Jersey said the lawsuit was premature, and the damages were too speculative, and the court expressly reserved any ruling on the accuracy of the lower court's statements relative to whether there can be a taking without a physical invasion.

The best thing that can be said of the airplane cases as they relate to highway noise cases is that they do not. The Florida court has followed the correct reasoning in stating:

> We think there is a substantial difference between the use of an airport by airplanes and the use of highway and access roads by motor vehicles. The noise intensity factor is different; the safety factors are different; and the use factors are different.

Project 11–1(11) FY '68

Valuation Elements of Joint Development Projects, Including Air Rights

By: John M. Bohling
Research Agency: Real Estate Research Corporation

Introduction and Research Approach

The increasing pressures on land availability, particularly in urban areas, is making it necessary to look to existing inventories of property and particularly to examine the possibility and potential of multiple use of available properties, including rights-of-way and public lands. This project deals with the valuation of multiple-use projects.

According to the project statement:

> Interest is increasing with respect to joint development projects involving highways and other kinds of public and private facilities. There is actually little information available, however, about the application of known appraisal concepts to such joint development projects. Additionally, a whole valuation dimension has come into focus, involving the valuation of vertical planes of value (air rights). All of these aspects need to be explored.

This study briefly reviews the legal factors covering the valuation of air rights and of joint development projects and explores known appraisal concepts and valuation principles and their application to the valuation of multiple-use projects. The findings of this analysis should provide guidance for appraisal practitioners and public officials concerned with the valuation of joint development projects.

Multiple Use and Joint Development Concept

Definition of Terms

Although multiple use of property is not new, the concept of joint development has received much attention in recent years. Both have been written about and discussed, but confusion remains as to their definitions. Discussions have centered largely around the joint development concept and multiple use as they apply to rights-of-way, particularly highways. From those discussions the following definitions have developed:

1. Joint development is a *process* that integrates the planning of highway systems, especially in urban areas, with other governmental (or private industry) programs aimed at improving the urban environment and esthetically integrating the highway system to the areas it traverses.
2. Multiple use of rights-of-way is the use of parts of the right-of-way not needed for the road surface for other activities. It also includes uses of the airspace above and the ground beneath the right-of-way.

These definitions differ from the concepts that have normally been associated with these terms. Joint development has been recognized as a single undertaking by several owners within a given land area or use. Under the definition here, however, joint development is a planning process that is undertaken when the multiple use of property is contemplated. The process is concerned with coordinating the development of the total transportation corridor.

Multiple use implies several generally compatible uses within a given land area. This is in line with the concept of multiple use as space-oriented and joint development concepts as time-oriented (*1*). In the case of rights-of-way, it could be more than one form of transportation, or transportation plus uses having either a compatibility with transportation corridors or a need for location on or close to such corridors.

Joint development could take place even though there might be several owners of a given land area to be used for a multiple-use project. Thus, a shopping center, a motel, an office building, a privately developed garage or parking facility, and an apartment building could exist on a piece of property having a number of owners. Nevertheless, it would be planned as a coordinated and compatible development, regardless of the boundaries of ownership that might exist within the land area. Naturally, this type of development might present problems of measuring the benefits that would accrue to each owner. These could be equitably distributed by agreement, based on the resources of each of the owners and their contribution to the potential for more profitable development. Joint development as used herein describes the planning and coordinating process that must precede the development of any multiple use. Multiple use describes any project that combines more than one compatible use within a given area.

Historic Trends

The following are significant texts on the subject of multiple use:

"Multiple Use of Lands Within Highway Rights-of-Way" —*NCHRP Report 53* (1968), prepared by Barton-Aschman Associates, Chicago.

The report is a summary of examples of existing multiple uses that were being made of highway rights-of-way. It also envisions and describes potential new multiple uses. Owing to its highway orientation, the study deals primarily with multiple-use development having a linear configuration. Of most significance is the statement that ". . . the greatest opportunity for multiple use lies in the combining of sections of right-of-way with adjacent non-highway land to form developable parcels."

The Freeway in the City—Report to the Secretary, Department of Transportation (1968).

This report combines a discussion of planning and of multiple corridor use and contains a number of illustrations and photographs. It imparts invaluable suggestions and illustrations of advance planning, engineering, and the ultimate improvement of highway environments in urban areas. In describing a systems approach to planning there is discussion of value methodology. The following quote is significant:

> In urban freeway planning, while other factors have been considered, the conventional cost-benefit analysis of urban freeway systems was designed for the evaluation of alternative plans in terms of plans of a single objective —economic efficiency. Translation into monetary values is difficult, perhaps impossible, for intangible cost and benefits which may, indeed, have a significance for the community comparable to or greater than those which can be expressed in dollar units.

Joint Project Concept, Integrated Transportation Corridors—Prepared for the Department of Urban Housing and Development by Barton-Aschman Associates, Chicago (Jan. 1968)

This report is a comprehensive description of joint projects both in terms of their planning and opportunities presented by them. It covers planning methods and procedures for corridors, linear renewal projects, and interchange districts. The report presents a basic planning procedure pointed toward eventual project implementation. Also examined are legal aspects of joint development and multiple use. Profusely illustrated, it provides a helpful description and illustration of corridor property development.

Other publications describe the history of multiple use. Illustrations of this use, mostly air rights, include the Ponte Vecchio Bridge in Florence, Italy; Grand Central Terminal area in New York City; the Merchandise Mart and Prudential's Mid-American Building in Chicago; and Concourse Village in the Bronx, N.Y.

Although the uses they contain are not always different, condominiums contain a great number of individual owners. Thus, one might argue that the condominium concept is a form of multiple use—a form of multiple ownership—and a form of airspace ownership and valuation. Certainly the idea of owning a "cube in the sky" is unique to the layman, and the recognition by states of the validity of this style of ownership has contributed and will contribute greatly to airspace development and joint development concepts in communities.

The concept of joint development and multiple use is not new; therefore, the valuation of multiple use is also not new. As the multiple-use developments become more complex and the developers become more sophisticated it may be expected that new problems will be raised. The possibility of the potential valuation problems that may arise and the adequacy of current appraisal techniques and methodologies to solve these problems are discussed later.

Future Joint Development and Multiple Use

If the population growth projected for the United States in urban areas were to be used as the only criterion of projecting whether there would be extensive multiple use of property in the future, the outlook would have to be one of extreme optimism. If the pressure on cities for improvement of the urban environment—particularly that as relates to transportation corridors—is added to that population growth, the need for urban land or property on which development can take place will continue to increase at a compound rate. Recent illustrations of multiple use—the Prudential Center in Boston; the John Hancock Building in Chicago (a variety of uses under a single roof); the regional shopping center containing stores, entertainment facilities, offices, and even hotels or motels—all represent more intensive use of available space. The increased construction of freeways in urban areas and the need for space will develop a localized need not only for use of airspace over these corridors but also for additional properties to be acquired adjacent to rights-of-way. Some planners have already recognized that in some instances the taking of an entire parcel is equal to the cost of taking only a part of that property and paying severance damages to the owner of the remainder. In these instances—particularly in highway planning—acquisition will include those properties necessary to provide opportunities for enhancement of the corridor environment. Uses along these corridors will be governed by either the "private" demand for land in urban areas or the "public" demand. Thus, use for private development could become a source of income and offsetting benefit to the cost of highway corridors. In addition, social benefits of a public nature that would accrue from creation of playgrounds, schools, public housing, and other community uses could generate increasing needs for available airspace and adjacent land area.

As private or public demand for buildable space continues to increase, the multiple use of property, especially in urban areas, will continue to accelerate and the needs for joint development concepts in planning will doubly increase. Although it is difficult to pinpoint those areas where multiple-use development will take place, either geographically or conceptually, it is easy to predict that it will occur in almost every major U.S. city.

A striking example of multiple use of a combination public and private nature is illustrated in the *Los Angeles Times* (*2*). As suggested, it would combine uses in a structure spanning railroad rights-of-way, the Los Angeles River, and public streets. The structure would be a massive building containing terminal warehouses, office space, parking and retail sales facilities, and a proposed STOL (short takeoff and landing) field for commuter airways. The following lists apparent uses of this property and some of the most probable joint developers:

TYPE	LOCATION	USE
Public	Under	Los Angeles River
	Through	Freeway
	Inside	U.S. Post Office
	Inside	Passenger terminal
	Over (roof)	STOL port
Private	Under	Railroad
	Inside	Bank, offices, stores, hotel, restaurant, entertainment, etc.

Possible Joint Developers:

Los Angeles Flood Control District
Sante Fe Railroad (and others)
State of California, Division of Highways
U.S. Post Office
Store companies, operators, hotels, airlines, etc.

Variables of Multiple Use

Paramount in the variables that would affect multiple use are the physical relationships of the uses envisioned and the type or combinations of uses that would be incorporated into multiple-use projects. For example, joint development by physical relationship to a highway might be (1) adjacent to the right-of-way, (2) above the right-of-way, (3) below the right-of-way, (4) a combination of any of these.

These physical relationships would have a definite bearing on the cost of construction and on the manner in which the buildings might be constructed. The apartments over the George Washington Bridge approach in New York City have encountered a problem with traffic noise and exhaust fumes rising between the structures (*3*).

Provision for suppression of noise, adequate ventilation, construction of collision walls, column spacing, and other unique planning or construction costs are determined primarily by the physical relationship of the multiple uses.

In addition to the physical relationship, the types of projects and combination of uses must be considered. For private development, these types of projects could be almost any type of housing, commercial, industrial, or office use. In some cases there would be a mixture of many of these different uses. For example, the Massachusetts Turnpike Authority is contemplating the Gateway Center Development in Newton, Mass., which will include a motel, a garage, restaurants, and office space. Some of these uses might benefit from the turnpike location, whereas others might enjoy the same amount of business in an alternative location, but, by association with the others, can increase total business expectancy.

Public development will generate entirely different considerations than will private development. Cost-benefit analyses of community and social good attributable to these projects may be required to develop meaningful prices for disposition of property rights and/or land for these uses. An improved environment would affect value considerations. In addition, projects may be of a quasi-public nature, including privately owned and operated development that is financed publicly (e.g., the Sibley department store complex in Syracuse, N.Y., where the city constructed and operates a parking garage underneath and adjacent to the store, with connections to it. The store is constructed on air rights over the garage.)

Physical relationships are important to the valuation of multiple-use projects. For example, a highway may be depressed and a development constructed over it that would have all the aspects and characteristics of an air rights development. However, as in the Prudential Center in Boston, the highway right-of-way might be a tunnel easement taken from the fee ownership. On the other hand, where the highway is elevated, the area below might be used either for industry, stores, open parking, or some public use, such as a park. In this case, the property could be divided either into fee ownership plus an aerial easement for the highway, or fee ownership on the part of the highway with a "subsurface" easement or lease granted to the user of the surface.

In the instance of airspace development over rights-of-way (highway, rail, and water) the access to the development can take one of several forms. It could be over adjacent fee property either by ownership or by easement. Access could be granted by tunnel easements to elevators transporting occupants to the structure, or it could be by air rights over abutting ownership directly to the structure.

Of infinite importance to the appraiser is that these relationships must be clearly defined and described. As the multiplicity of uses expands, the need for clearer delineation and definition of these interests and their relationships will increase. What is most important is that the party requesting the appraisal know and adequately describe the property interest to be valued. One needs only to envision multiple use in the same sense as real estate has often been described—that of a bundle of rights. Each use in a multiple-use project may be considered as a part of the bundle, with the relationship of each to the others determining the value of the whole. The collective ability of these uses to generate income that can be attributable to the property interest on which they are constructed will determine the value of that property interest, no matter what it might be.

Feasibility of Projects

In evaluating the feasibility of multiple-use projects during the planning process, the difference between private and public demand must be recognized and each must be measured as to its feasibility.

Much has been written in appraisal and land economics articles on the highest and best use of properties. The *Appraisal Terminology and Handbook* defines highest and best use as

> . . . the most profitable likely use to which a property can be put. The opinion of such use may be based on the highest and most profitable continuous use to which the property is adapted and needed, or likely to be in demand in the reasonably near future. However, elements affecting value which depend upon events or a combination of occurrences which, while within the realm of possibility, are not fairly shown to be reasonably probable, should be excluded from consideration. Also, if the intended use is dependent on an uncertain act of another person, the intention cannot be considered (*4*, p. 92).

This definition considers only those uses that are reasonable, allowable, and independent of decisions by others.

Generally, designations of public use in a community transcend the concept of highest and best use. Public use may be legislated and a use may be created by ordinance different than that which would occur under free market movement. Thus, properties that might not otherwise be readily salable will find a market through the threat of condemnation for eventual use—such as for a park or school site.

The evaluation of private highest and best use necessitates meeting certain feasibility criteria; i.e., that the property can be developed within reasonable costs, provide a reasonable return on the improvements to the developer, and leave a reasonable amount of profit representing income to the property interest on which the improvements are constructed. On the other hand, the development of a public use does not always require only economic feasibility (e.g., a recreation area can provide community benefits not necessarily reduceable to dollars but that are apparently socially and politically feasible).

The feasibility of public uses depends on other factors. The retention of the community's existing tax base and the attraction of new additions to the tax base are tremendously important. Thus, the evaluation of public use must take into consideration the potential removal of property from

the tax rolls and the resultant costs of such removal. It is in this respect that airspace development for public improvements might provide a vehicle by which sites for public improvements can be created without removing tax-contributing properties from the tax rolls. The measurement of social or neighborhood benefit is almost completely subjective. However, once the need has been established, the measurement of alternative costs is made easier. From the appraiser's standpoint the basis on which the community decision was made is not so important as the fact that it is made and the "market" for that space has been designated. Thus, the feasibility of a public project is often determined by some evaluation of social or esthetic cost-benefit relationships to the community. This often involves intangibles (such as social good) which, by introduction of certain variables into the metropolitan equation, are presented as a source of economic good to the community. This is not intended to demean such cost-benefit analysis for community projects but only to point out that the cost-benefit analysis for privately developed projects (to test their economic feasibility) is far more well-defined by experience and acceptable methodology than a similar analysis for community projects.

Legal Background of Multiple Use

The legal basis for the use and consequent valuation of airspace is comprehensively covered by Robert R. Wright in *The Law of Airspace*. Essentially, the law today says that ". . . airspace is only valuable if he, the owner, can use it, possess it, or sell, or unless it contributes essentially to such use, possession or purchase" (*5*, p. 208). Thus, the old maxim that ownership of the land extends upward to infinity or as far as the eye can see no longer holds. This is a concept that recognizes value in airspace, whether the value is in peace and comfort to the owner or for economic gain through its development. An illustration of the former would be in recent aviation cases; of the latter would be the type of airspace that is being dealt with here.

This section is not intended to constitute an analysis of legal doctrine or to be an interpretation of the practice of law. Rather, it is a brief summary of what, from the appraiser's standpoint, constitutes the legal basis for value in air rights or multiple use projects (*5*, p. 305).

The legal validity of multiple use has largely been either disputed or affirmed by local ordinance—zoning, building code, or both. Multiple use is beginning to gain popular acceptance over public facilities such as highways, sidewalks, and rivers, as well as railroad rights-of-way. Usually, the combination of public and private uses over public thoroughfares has necessitated not only changes in local ordinances but also special permission of the public authority having jurisdiction over the thoroughfare.

The most important consideration in determining the legality of multiple use over, under, and on rights-of-way will be the nature of the title by which the right-of-way was originally obtained. Some railroads do not own rights-of-way in fee; parts may be by easement; some sections may be owned "for railroad purposes," with reversion to the state or to prior owners in case of abandonment. The same would hold true for some roadways, even state-owned.

Thus, unless absolute title to the property interest can be conveyed, neither joint development planning nor federal and state approval will be sufficient to guarantee that a project can legally be constructed. In some cases, legisla- at the state level may suffice, even to overcome title deficiencies. In others, the layers of authority in eminent domain may require a combination of state legislation with county or local ordinance.

Only recently has the Federal Highway Administration (FHWA) issued guidelines for the use of airspace and/or parts of the right-of-way of the Interstate system for air rights development and participation in federal funding. The Bureau of Public Roads' * *Policy and Procedure Memorandum 80–5* (Apr. 1967) specifies conditions under which air rights may be recommended for use. It also provides for use of rights "beneath the established grade line of the highway." Each proposed use will be considered on an individual basis by the FHWA and none that interferes in any way with free and safe flow of traffic will be permitted (*6*).

Of value to the appraiser as to assertion of meeting all of the legal criteria for project eligibility, and for providing information that will be invaluable in the appraisal process, is *Policy and Procedure Memorandum 20–8* (Jan. 1969). This memorandum sets forth criteria that must be met insofar as public hearings are concerned covering corridor development. Approval for air right development over public right-of-way should require similar considerations, although specific criteria are not detailed to this extent yet. In short, *Memorandum 20–8* calls for public hearings and for consideration to be given to, among others, the following (*1*, p. 2):

Economic activity
Employment
Recreation and parks
Esthetics
Residential and neighborhood character and location
Conduct and financing of government (including effect on local tax base and social service costs)
Natural and historic landmarks
Property values
Multiple use of space
Replacement housing

The memorandum does not weight any of these items as to their relative importance.

Of interest to the appraiser is that the request for approval of a route location or highway design must include a study report containing

> . . . descriptions of the alternatives considered and a discussion of the anticipated social, economic, and environmental effects of the alternatives, pointing out the significant differences and the reasons supporting the proposed location or design. In addition, the report must include an analysis of the relative consistency of the alternatives with the goals and objectives of any urban plan that has been adopted by the community concerned (*7*, p. 5).

A similar study report, submitted for approval of air

* Now the Federal Highway Administration.

rights development, would be of valuable assistance to the appraiser.

The limitations placed on use of airspace over the Interstate system are more comprehensively defined in BPR *Instructional Memorandum 21–3–62* (May 1962). This memorandum is reproduced and portions of it are analyzed in *A Study of Airspace Utilization,* issued by the FHWA. The memorandum sets forth the spatial limitations on either air rights development or for the development of space under Interstate highway systems. In any project involving air rights on Interstate systems this memorandum should be studied in detail. The specifications therein probably will be adopted by most state and local authorities, so the spatial alignment of this type of multiple use will become consistent throughout the U.S.

Multiple-use development is further being encouraged by federal authorities through participation in the acquisition of excess or remainder parcels. This involves the acquisition of more land than would be required for the highway right-of-way, so that surplus land would be available. This approach has at least two benefits—the necessity for engaging in a series of partial takings is obviated, and the potential for improving the neighborhood environment is enhanced. This latter condition plus the requirement that the net cost of acquisition (after disposition of excess properties) cannot exceed what would constitute a reasonable cost for acquisition of right-of-way provides the basis for eligibility for federal and state participation.

Although the legality of some of these programs may be contested in court, it would appear that, once a project has been fully approved, its legality, at least for valuation purposes, is assured. Furthermore, there seems to be little argument that evaluation of the project could be made on the assumption that its approval and consequent legality would be forthcoming in the future. The appraisal itself should list this as a Limiting Condition, however. From the appraiser's standpoint, the legal basis for value or for the project should be specifically defined and presented by lawyers. The appraiser should be sensitive to local and state legal requirements governing joint development or multiple use but should not presume to interpret the law. As has been the case in the evolution of this concept, almost every development will have to be separately reviewed.

As Wright points out, urban planning will occupy a role of increasing importance in joint development and multiple use. Any use, highway construction program, or substantial change in property use or appearance will be increasingly subjected to over-all urban plans. Even today, new transportation plans or highway programs are related to community benefits, civil rights, or other socioeconomic considerations that affect the entire community. States will have to adopt statutes that, in turn, could have jurisdiction over local law. Thus, for the near future at least, it may be necessary that every project receive its own stamp of legality until such time as uniform laws and ordinances are adopted, either on a state or national level. In the meantime, the appraiser can either assume legality of the proposed use (and include a disclaimer of not being asked to evaluate the legality of the project) or obtain legal counsel as to the interpretation of local, state, and federal regulations and law as it may be used to affirm the project's legality.

Present Appraisal Principles and Methodology

> The value of real property is created, maintained, modified, or destroyed by the interplay of four of the great forces which motivate the activities of human beings. These are social ideals and standards, economic adjustments and changes, political or govermnental regulations, and physical or natural forces. These four set the pattern for the variable in real estate values. Each force is dynamic. Combined, they are the essence of cause and effect, interweaving to become one vast and everchanging fabric surrounding and influencing every parcel of real estate on earth (*8,* p. 1).

Examples of social forces are population growth, decline, and shifts; social attitudes and reactions; changes in sizes of families. Economic forces include natural resources, commercial and industrial trends, employment, availability of money and credit, tax burdens, and price levels. Governmental regulations would include zoning laws, building codes, credit controls, and lending regulations. Physical forces would be either natural (climate, topography, fertility, or mineral resources) or man-made (transportation, schools, recreation, conservation).

Appraisal principles recognize and incorporate most or a combination of most of these factors in each and every estimate of value. The three basic approaches to value—cost, income, and market—take into consideration at some point virtually all of these elements.

Basically, property is valued either on the principle of substitution (Market Approach)—what would an alternative property of similar use and equal profitability cost at another location—or by the cost to reproduce or replace it, less depreciation (Cost Approach). The Income Approach is used primarily for improved properties to estimate the value to the owner of the income stream that the property (land and buildings) is capable of generating. Often the Income Approach represents a residual valuation and requires a higher degree of subjective judgments than do other methods. The properties that will be appraised in multiple-use projects resulting from joint development planning probably will most often use the Market Data and Income Approaches, with the Cost Approach entering into play only to the extent of estimating the cost of the improvements for eventual use in the Income Approach.

Applying the Income Approach to a parcel of vacant land necessitates the hypothetical construction of the improvements called for under highest and best use. Estimates of expense are then applied against the income these uses will generate to develop a net income available for return and amortization of improvement costs plus a fair return on the land. The amortization of the cost of improvements over a reasonable recapture period at a reasonable rate of return is then deducted. The net income remaining is then capitalized at a rate commensurate with the risk, liquidity, and benefits of land ownership in order to develop an estimate of the value of the underlying land. This is called the land residual technique of capitalization.

The Market Data Approach is based on the principle of substitution, which assumes that a property can be replaced

in the market and that its value would approximate the cost of acquiring a property equally desirable in an alternative location. This concept has some applicability in the other approaches to value but is most important in the Market Data Approach.

There are other principles and concepts that are applicable in the appraisal process, all of which depend basically on the principle of supply and demand.

Joint development concepts also are based on the principle of change. The transition of different types of property use weighs heavily in the consideration of multiple-use projects and joint development.

Recognized Appraisal Principles and Inputs

Every appraisal requires certain data that are necessary to the completion of the property valuation. Multiple-use developments resulting from joint development planning might require appraisal inputs that may be additions to or substitutes for the data required normally.

In the appraisal process the determination of the highest and best use of the land dictates the types of improvements that can reasonably and profitably be constructed on it. Although it is important to the appraisal of any type of property, the determination of highest and best use is particularly critical in the evaluation of multiple-use projects on or adjacent to rights-of-way. The highest and best use of a combination airspace and adjoining fee might be for a high-rise office building containing as much as 250,000 sq ft of space on 20 to 25 floors. However, if the zoning authorities refused to permit a building of that height, the alternative probably would be *not* to construct 250,000 sq ft of space in a building having only 10 floors. A measure of its feasibility might indicate greatly increased costs, unreasonable bridging and spanning of the right-of-way, and a prohibitive cost of putting together enough abutting fee property to accommodate this kind of development.

Too often the highest and best use evaluation has been circumvented in appraisals by the mere assertion on the part of the "expert" that in his "opinion the highest and best use of the property would be for a . . . ." Often this designation of the highest and best use of the property is based more on what the community and/or individuals would like to see constructed than what would be economically feasible at that location.

The highest and best use evaluation must consider all of the uses to which the property might be put. It then proceeds to discard those for which a market does not exist or whose construction would not be economically feasible on the site. Only through winnowing out the infeasible uses can the evaluation of the potentially best improvements be made.

This process of highest and best use study also must include and reflect not only the most profitable uses but also the compatibility of these uses with each other and with the adjoining environment. This would be especially critical in the planning of projects on or adjacent to expressways in urban areas where the objective would be to enhance the environment. Thus, the mere fact that a project might be economically feasible would not stand up to scrutiny unless it were also esthetically desirable and an improvement to its environment. The process of evaluating highest and best use will differ in every instance. What is most important is that no appraisal report is complete or should be acceptable unless it contains a reasonably logical evaluation of the property's highest and best use. Mere recitation of the allowable zoning or of considered opinion (". . . based on my . . . years of experience in real estate") should never be accepted in an appraisal report. This is particularly true in multiple-use projects resulting from joint development concept planning. Such a plan without economic or social feasibility, whether of a public or private nature, is meaningless.

Where substantial projects are envisioned or planned, a comprehensive market or economic study may be required to determine the highest and best use of the project as well as its economic feasibility. When one is evaluating the market demand and subsequent rent or value that the development would generate, several factors should be considered:

1. Adequacy of the site for the planned use.
2. Suitability of the location.
3. Needs for ancillary facilities (such as parking).
4. The demand for such space uses at this location.
5. Pricing of equally suitable and available alternative sites.
6. Estimation of project costs.
7. Evaluation of the adequacy of financing.
8. Adequacy of investment return (or, for public projects, the fulfillment of the social objectives desired by the project).

Depending on the type of project involved there will be other considerations, such as the experience of the developer and the political climate (for public projects).

When one is evaluating the general feasibility of public uses, the measure of feasibility is entirely different. The following are some of the factors that may be involved:

1. Diversion of public activities to airspace or combinations of airspace and fee so that scarce land may be preserved to produce tax revenues.
2. The creation of unique public use sites through development concepts.
3. Community benefit from multiple use of rights-of-way.
4. The revitalization of areas through joint development or multiple use.
5. The minimization of costs of providing sites for public improvements.

So far, this report has been concerned primarily with appraisal concepts and principles as they affect the appraisal of fee properties. However, the valuation of air rights places demands on the appraiser similar to those that will be required in the valuation of multiple use. This report has mentioned the concept of substitution where properties are valued on the basis of fairly comparable substitutes. Like air rights, these properties, even if they are a combination of airspace and adjoining fee, may or may not be of value, depending on the scarcity of alterna-

tive sites and the total special costs that will be connected with their development.

Often, the value of air rights is expressed as a percentage of the value of the underlying fee. For example, the Illinois Central has long had a practice of marketing their air rights at 80 percent of the estimated value of the underlying fee. Caisson lots, elevator pits, and other surface land requirements were sold or leased on the basis of full fee value (*9*). This pricing style has gained acceptance and is being used by many other firms and individuals. This concept may or may not be of good service to the user and may be full of pitfalls.

In the appraisal process, the use of a percentage of the fee as a basis for valuation of air rights automatically eliminates the consideration of the possible uniqueness of the air rights development in regard to fee development. There are likely to be instances of air rights development that were marketable over land that would not otherwise be successfully developed with similar improvements, even if it were cleared of its existing use. In addition, the automatic relationship thus established does not purport to take into consideration unique costs or even cost savings that might be affected by airspace development.

Finally, the pricing of air rights on the basis of the value of the underlying fee may actually bring inequities to the unwitting purchaser. For example, air rights may be sold over fee land having a value of $2.00 per square foot. As a general rule, experience and analysis have indicated that platforms (supporting structures) for airspace development may cost $15.00 to $20.00 per square foot at the surface (*9*). In this case, using the principle of substitution, land having values of less than $15.00 per square foot would not be capable of profitable air rights development. Unless the location were absolutely unique as to the air rights potential separated from the fee, even 10 percent of the value of the underlying fee for the air rights would represent a fantastic overcharge. [The researcher once valued almost 4 acres of air rights in a large eastern city and found a nuisance value of only $10.00. The easement in this case was for highway purposes, and the vertical plane at which the easement was located was so far above the surface fee that, even if a market for air rights in that city had been found (it was not), they could never have been developed at this location under the restrictions placed on them.]

In addition to platform costs for air rights developments there are other costs that must be analyzed for provision of parking spaces, mechanical equipment and storage space, loss of rents from "lost" ground-floor space, and special or exceptional maintenance that may be required on foundations. This does not necessarily dispute the belief that air rights are generally worth less than the fee on which they are located. Usually the restrictions and controls placed on airspace construction methods, and other detrimental factors (such as vibration and noise) will detract from the value of the air rights. At the same time, one must not conclude that *all* airspace has value for development.

> . . . [A]n arbitrary percentage, unless it is well-grounded on the economic situation of a specified area, cannot be employed; and even if it is based on the economy and land value in a given area, it cannot be applied uniformly in all circumstances but can only serve as a rule of thumb. In the last analysis, a determination of airspace value must be based on the economic facts of the particular transaction involved (*5*, p. 208).

Especially important is the description of the property interest to be appraised. In multiple use the need for specificity in the property description becomes acute. If the property interest is to be air rights, the exact dimension of the vertical plane must be described—minimum height above a given datum point, length, and width, and in some cases even height. In addition, caisson lots or easements for utility extensions, support columns, elevator pits, and other construction needs must be clearly described. In the case of a development involving a combination of airspace and adjacent fee land, the fee must be adequately described, together with the foregoing information listed for air rights, *plus* the restrictions of use that will apply to the combined properties, including accessibility, cantilever supports, vertical supports, and height restrictions, as well as lot coverage as pertains to the combined surface fee and air rights.

The use agreement should adequately describe all property rights that are being leased or conveyed. Occasionally construction requirements might be imposed that would be in addition to the use agreement and applicable only to the period of original construction. Such things as continued operations (in the case of right-of-way use), relocation of trackage or roadways, either permanently or during the course of construction, and the requirements for payment of the cost imposed on operations by construction of the multiple use project must be covered. In fact, the costs should be clearly presented, and the appraiser must have full understanding of their applicability to the valuation, if any.

Generally the use agreement will either resemble or actually be a lease for the property interest to be conveyed. Especially critical are the provisions of this agreement as they relate to either the substitution of normal physical alignment and/or to special provisions for accessibility.

Often, projects of this type will require either special zoning or a recognition by the local community of an admixture of existing zonings. In Chicago, for example, an air rights project must be approved as a "planned development" under a special provision of the Chicago zoning ordinance, and each project is a separate and distinct zoning consideration. Thus, in some cases it will not be sufficient that the appraiser assume that the highest and best use to which he thinks the property interests could be put will receive local approval either under zoning or existing building codes. A preliminary value could be estimated with this assumption, but a final value for lease or purchase negotiations of those property interests would require far greater definition. Depending on the property interests involved, the physical alignment of the improvements may often be changed. This will be especially true in highway development where a linear use would most likely prevail. Certain improvements would have to be positioned so as to facilitate rather than impede the flow of traffic from the highway, while minimizing the distraction to drivers. The "economically best" alignment may not be the one allowed.

For those projects that are above or span transportation rights-of-way (expressways or railroads) there must be special provisions for accessibility. On Interstate highways direct accessibility is not allowed, and usually can be obtained only at interchange areas. However, a project spanning a part of the Interstate system, if it met federal criteria for eligibility, would be allowed access from adjoining streets, provided no access were created directly to or from the expressway. The type of accessibility afforded a project will have a definite impact on its marketability and, consequently, its value. These provisions must be spelled out either in the use agreement or in property use restrictions.

In essence, the description of the property interest and the restrictions that will apply to its use would be similar to those used in urban renewal. The requirements for land use and marketability studies ask for specific information as to marketability, and the land-use plans that are later distributed are definitive as to allowable land use and restrictions that apply to them.

Basically, for multiple-use projects, the following would be required as minimum information, in addition to the description of the property interests involved:

1. Type and character of the use or uses for which the property interest is best suited.
2. The appropriate allocation of space (airspace, surface fee, tunnel easement, etc.) for each allowable use or combination of uses.
3. Alternative allowable uses and variations in the plan.
4. Detailed descriptions of restrictions to be placed on the development of the space.
5. Identification of any obstacles to the development because of the need for uninterrupted service of rights-of-way or other unique factors.
6. Special factors imposed on development by virtue of local or federal restrictions as to relocation and rehabilitation of inhabitants and environment.

These are basic requirements, and it may be expected that as new multiple-use projects develop so will additional requirements of an informative nature. What the appraiser needs is full disclosure of all items that might affect value.

Present Appraisal Methodology

This section examines existing appraisal methodologies and their relationship to the types of properties that will become available through joint development concepts and planning, and determines whether a "problem" exists that would require the development of new appraisal concepts and methodologies. Briefly examined are the various methodologies that have been proposed and used, mainly in the valuation of air rights, and the requirements of multiple-use projects that might develop a need for new appraisal concepts.

Every knowledgeable appraiser knows that there is one basic difference between all properties—that of location. Because each property has a specific and individual location, each will have individual peculiarities and cost variables that attach to it. What is presented here should not be construed as an attempt to instruct professional appraisers in either the best or the only way to value multiple-use projects. Instead, it is intended to draw attention to the more positive approaches that have thus far been developed and to suggest changes or variances, if any, in these approaches that would be applicable to and required by the valuation of multiple use.

The basic difference between price and value should be established. The value of a property is often hypothetical in that the definition of fair market value envisions a willing, intelligent, and patient seller and a willing, intelligent, and able purchaser, both of them free from duress and both knowledgeable in affairs of real estate and its use. Actually, a real estate transaction seldom involves parties meeting this definition. However, for valuation purposes, the definition is well taken and popularly used by the appraisal profession and recognized by courts throughout the U.S.

The price considered to be fair depends on which side of the transaction is represented. Thus, the price represents a compromise between the seller's and buyer's individual estimates of value. This price may or may not correspond with an appraiser's opinion of value. The foregoing may explain why, even within the appraisal profession, there is not always agreement as to the value of a property. And usually the divergencies in values that do occur are due to different assumptions being employed or to varying interpretations of instructions to the appraisers. The importance of the description and definition of the property interests to be appraised and the restrictions that will attach to their development cannot be overemphasized.

With the exception of air rights, not much has been written concerning the valuation of multiple use. Apparently the appraisal of multiple-use structure or developments can be adequately served by existing appraisal methodology and techniques. The fact that a development contains more than one use merely necessitates the application of the appraisal procedure, or parts of it, more than once during the appraisal of an individual property. The various values or incomes assigned to the uses in a multiple-use project must then be correlated so as to reflect their individual contributions to the over-all value of the project. Although this may seem to represent an oversimplification, the appraisal of a multiple-use property should not be made more difficult by the interjection of fanciful techniques that lend little to the value derived and contribute only to the confusion of the reader.

Multiple use, as it is envisioned herein, may require a harder look at existing appraisal methodologies and techniques. It would be far easier to appraise a combination office, hotel, apartment, and store structure or development than a development that carries eight lanes of high-speed traffic and involves apartments and a playground over and abutting this thoroughfare.

There are two methods of appraising airspace. The first is to hypothetically develop an airspace property with buildings, under its highest and best use, estimate gross income, deduct expenses for operating and for return and recapture of the building costs, and then capitalize the residual income into an indication of the value of the air

rights. This is a subjective methodology involving a myriad of judgments. Its accuracy depends wholly on the thoroughness of the cost estimations (both for platform and for the buildings), the formulation of rent rolls, the estimation of taxes and operating expenses, the fair return on investment on the improvements and the recapture of that investment over a specified period of time, and the development of a fair interest rate representing an adequate return on and a residual value of the airspace reserved for the development.

The American Institute of Real Estate Appraisers has suggested methodology—the Kuehnle and White formulas—for the valuation of air rights or tunnels. The formulas derive their basic justification from the before and after value concept used in condemnation cases. Both formulas recognize the value of the air rights or the tunnel easement to be the difference between the value of the land before the air rights or tunnel easement is granted and the value of the land after these property interests are conveyed to others. Of course, the formulas consider other costs or benefits, such as economic value lost because of reduction in functional utility due to construction, the additional cost of constructing the building in a manner different from that for erection on fee land, and additional interest expense that would be incurred because of the probability of a longer period of construction. (This approach was used in the valuation of a highway underpass for Cobo Hall in Detroit and an expressway underpass in Cincinnati.)

In a demonstration report on the apartment structures and air rights over the George Washington Bridge approach in New York City, White suggests a refined version of the Kuehnle formula. In addition to the extraordinary costs and loss of value from functional or economic obsolescence, White added savings to the purchaser or lessee in excavation and foundation costs, lack of demolition expense, relief from tenant relocation costs, and the income losses normally incurred during relocation and demolition (*10*, p. 34).

These formulas represent an excellent appraisal tool for multiple use on air rights. What the formula does not take into consideration, at least in its present state, is either the potential negative or positive effects of the multiple use that the development might incur. Certainly the uses contained in the oases on the Illinois Tollway would never be profitably developed if it were not for the amount of traffic the Tollway carries. Similarly, there are uses that would benefit greatly from the highway exposure afforded them by occupancy of adjacent lands. On the other hand, conflicts (such as experienced by occupants of the George Washington Bridge Apartments in New York City), possible limitations on expanding the fee use, and unanticipated hazards for the fee user detract from value.

The appraisal of this type of property on a residual basis, where income estimates would have to be made, should reflect this possible rent loss either in lower rents than would be found in competitive facilities, higher vacancy factors, a longer period required to obtain reasonable levels of occupancy, or a combination of all three. The same principles might also apply to development under a highway structure, such as is characterized by the Ginza in Tokyo, Japan. The formula approach assumes that the highest and best use of the air rights would be the same as the highest and best use of the surface fee. The reasonableness of this assumption is difficult to dispute. Caution suggests, however, that there could be instances wherein the highest and best use of individual property interests could be different. The appraiser should satisfy himself that they are one and the same before using either of the formulas.

The evaluation of highest and best use is extremely important when the appraisal separates property interests. In the appraisal of multiple-use projects as they may develop in the future, the analysis of highest and best use will be critical. The establishment of a transportation corridor may create a change, not only in the surrounding environment but also in the use of properties abutting the right-of-way and, in more urban areas, the air rights potential. Thus, what might have been the highest and best use of surface fee without the highway being put through might not necessarily be the highest and best use of abutting fee or of the air rights. This would make the application of the foregoing formulas more tenuous, unless the highest and best alternative use could be developed.

Existing appraisal techniques and methodology appear adequate to appraise virtually any type of property. However, when one is acquiring or disposing of certain property interests for special use, market value might not be the only measure of value or price to the user. For example, a developer often will find in assembling property within a city block that one or two property owners, once the acquisition effort is known, will prove difficult to deal with. Sometimes the price paid for these lots exceeds the price that was paid for any of the others. If development could not take place without acquisition of the lots, the price paid for the lots is not a function of their fair market value but the value they would have to the developer, measured in terms of his alternatives. The alternatives might include the acquisition of a different block, redesign of the project around that lot or lots, or possibly the complete abandonment of the project. After examining these alternatives the private developer may determine that he can afford to pay five times the fair market value of the last remaining lot because of savings in time, construction costs, and marketability of the completed project.

This would suggest that an alternative appraisal methodology is available that heretofore has been used mainly in negotiations rather than in the appraisal of real property. Based on the principle of substitution, the value of a property for ultimate development could be measured by the cost of the alternatives available to the developer. Examination of the "cost of alternatives" approach to valuation suggests that its use is probably more appropriate when the property use is the result of public imposition rather than free market movement. In effect, this is what acquisition strategists would do in determining the feasibility of the taking of whole properties for a right-of-way rather than a series of only partial takings with damages to be figured in. From an appraisal standpoint it is far simpler to estimate the value of the whole property than to develop a value of only part and attach damages to the remainder.

It is this latter element that causes most of the divergencies on acquisition appraisals. Thus, the highway or corridor taking would have excess properties available for disposition for ultimate development.

The value of any air rights would be figured on the cost of the alternatives; i.e., if land could be purchased for $12.00 a square foot and a platform created for $10.75 per square foot, including all special costs, the platform would have market value—in this case $1.25 per square foot. On the other hand, if an adequate platform for the type of use envisaged would require an expenditure of $14.50 per square foot on the same fee surface, the air rights would have no value at all. The foregoing assumes theoretically equal locational value of alternatives.

Applicability of Appraisal Methodology to Multiple Use

There are apparently elements of value that probably will be unique to air rights or multiple use resulting from joint development planning. The importance of a comprehensive highest and best use analysis and the clear presentation of the use restrictions that will attach to these properties or property interests are mentioned elsewhere. In addition, there are special elements not ordinarily found in other developments or that might be of special interest in the evaluation of these types of projects.

The development of air rights incurs (1) special costs for platforming, and vertical support for the platform; (2) potential rent loss from space that would otherwise be at-grade and rentable; (3) additional interest charged on construction funds for an extended period of construction over and above that which would otherwise be required; (4) special costs for protection (such as venting for fumes, light and air, collision walls); and (5) cost of access.

At the same time, special benefits might accrue to air rights development. These could be in the nature of savings of excavation costs and some foundation costs, lack of demolition costs of existing structures, no tenant relocation costs, no income loss from property to be demolished or during the period of tenant relocation, and a possible special benefit that might arise from identity with a transportation corridor or visual accessibility on account of location. Often too, air rights development can occur in areas where possible development of the fee would not be as successful unless linked to an unusual feature like air rights development.

Table 1 gives those valuation elements that have a degree of importance in the appraisal of multiple use and joint development. It gives the most probable degree of importance that these elements will have in an evaluation process. This is intended only as a guide and is not comprehensive; in certain instances these will have either greater or lesser impact on value than this checklist would indicate. They are listed relatively, and their purpose is to call attention to these items for possible consideration and inclusion in the appraisal process. Every project must be considered individually and each will have unique aspects. The appraiser must thoroughly examine all facets of the proposed project and determine what constitutes an item of special consideration that should be recognized in the appraisal process.

TABLE 1

VALUATION ELEMENTS

VALUATION ELEMENT	PROBABLE EFFECT ON VALUE [a]		
	MINIMAL	MEDIUM	CRITICAL
Highest and best use analysis			X
Property interest description			X
Property use restrictions			X
Special costs—air rights:			
Platform			X
Utilities		X	
Rent loss		X	
Additional interest	X		
Preservation of service	X	X	
Access			X
Protection (venting, collision walls, etc.)		X	X
Special costs—surface fee:			
Interruption of service		X	X
Tenant relocation		X	
Demolition		X	
Income loss		X	
Special benefits—air rights:			
Excavations (none needed)	X		
Demolition (none needed)		X	
Tenant relocation (none needed)		X	
Income loss (none incurred)		X	
Identity (unique location, visual)		X	X
Special benefits—surface fee:			
Access		X	
Identity (visual, proximity)	X	X	

[a] Where two effects are noted, this indicates a range.

The foregoing naturally would pertain always to private development. For public uses, it may be assumed by the appraiser that the social or environmental values and benefits created by the project—whether of a social, esthetic, or educational good—will not be considered in the appraisal process. If environmental improvement creates an economic good that can attach to the neighborhood and surrounding land uses, the appraiser might recognize an increased site value, assuming completion of the project as planned. If the value is to be determined prior to completion of the project, naturally the site valuation cannot include consideration of future economic good that might accrue by virtue of completion.

Each project must be scrutinized by the appraiser to determine the nature of the property interest to be developed, the restrictions that will attach to the development, the highest and best use of the property interest being appraised, the special costs of the project, the potential of special benefits accruing to the development, and the most appropriate valuation technique to be employed. Outside of these special items, there do not seem to be any problems of multiple-use valuation that cannot be solved by appraisal methodologies currently in use. What will be required is

the intelligent and perceptive application of existing appraisal techniques coupled with sound and perceptive economic reasoning in the appraisal process.

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Project 20–8 FY '71

Interactive Graphic Roadway Design System—Functional Specifications and Feasibility Study

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Introduction and Research Approach

Objectives and Background

The highway engineering community was one of the earliest users of, and has continued to be a leader in, the application of computers in engineering work. There has been a steady growth in the sophistication of the employed computer techniques. Even with this continued growth, the engineer has still not been able to realize the full potential of the computer because of restrictions placed on the capability to communicate with the machine and guide its decision-making process. These restrictions are a direct result of the manner in which information is transferred between man and machine by computer hardware and software.

Project 20–8 was initiated to determine the feasibility and method whereby the roadway design engineer can use the unique computer communication technique called "interactive graphics" to achieve increased benefits in computer use.

Original Problem Statement.—The problem statement for this project was as follows:

> Improved techniques and procedures making extensive use of computer and computer-graphics technology are being developed to enhance highway location and design. One prominent highway design evaluation capability under development is the ability to produce, on a variety of computer-controlled graphical display devices, perspective views based on computer design information and actual terrain data. Highway engineers, by making use of these new capabilities, will be better able to achieve optimal highway designs expeditiously.
>
> To make effective use of the new graphic display evaluation techniques, there is a need for a man-machine interaction capability for revising highway designs. The man-machine interaction is the ability of the highway designer to make discrete changes to design parameters as a result of evaluating graphic displays, including animated perspective views, and directing the computer to modify all stored data and produce new displays that reflect the design parameter changes.
>
> The total objective of the research is to develop an interactive computer-graphic software system capability for use by the highway designer in effecting revisions to designs. No hardware development is intended. The software system developed should be broadly applicable and written in a programming language that will minimize dependency on hardware.
>
> The total objective is to be achieved by carrying out several phases of development. This project (20-8) is limited to only those activities of Phase I which include: (1) review of procedures and techniques developed in previous and current research and development, including the Road Design System of the Texas Highway Department, and existing interactive computer graphic applications for uses other than highway design; (2) the development of a software system design that will describe

in detail the software required to achieve the total objective stated above; (The software system design shall be in such workable form that programming efforts may proceed directly in a subsequent phase of development. A programming language shall be recommended); and (3) the analyses of the computer and graphical display hardware requirements necessary to support the software system design.

Clarification of Objectives.—The NCHRP Project Advisory Committee, meeting with the researchers at approximately the one-third point of the project, clarified objectives on the following points:

1. The efforts of the project in the area of engineering computer applications would be oriented toward engineering procedures rather than toward computer software or hardware. The term "engineering procedure" was defined to mean those operations that an engineer would perform to effect interaction between himself and a computer (i.e., modification or creation of engineering data or graphics, or engineering decision-making). The project would consider that the roadway design programs used in conjunction with the interactive system would serve only as a data generator to provide it with the data that would allow the engineering procedural research to be performed. Therefore, there would not be substantial resources consumed in analyzing the relative merits of existing highway design systems or in determining what the capabilities of the ideal system should be. Rather, a roadway design system should be selected that would be flexible for this project's use and would contain capabilities that would permit the engineer to obtain desirable and useful design data that could be used to evaluate an interactive graphic system.
2. The Roadway Design System (RDS) developed by the Texas Highway Department would be used by this project as the prototype interfaced application program.
3. The initial problem statement of Project 20–8 indicated that the primary objective of Phase I would be to provide detailed programming specifications for work envisioned in Phase II. It would have been necessary to at least select a category of interactive devices, if not a unique device itself, to achieve the stated objective within the resources available to the project. The preparation of engineering procedures and program specifications for the two basic categories available would have been beyond the allotted resources. It was acknowledged that there would have been great difficulty in making such a selection because information was inadequate at that time. The decision was reached to concentrate the project resources on developing engineering procedures, analyzing the various devices, determining the cost and benefit relationships for both the interactive techniques and devices, and achieving the maximum development of program specifications that would be possible within the balance of the resources.
4. Every reasonable effort was to be made to avoid designing the interactive software for one specific hardware configuration or application program to the exclusion of others. All efforts were to be made to keep the engineering procedures general.
5. The resulting system was to be not only a "useful tool," but also an economically justifiable one.

(Editor's note: Following completion of the feasibility work reported herein, the NCHRP Advisory Committee met to discuss the feasibility findings, and the cost and time estimates to achieve the total research objective, and to formulate for the American Association of State Highway Officials (AASHO) the sponsoring agency, recommendations concerning the future course of action for the development of interactive graphic roadway design systems. The committee accepted the researchers' findings regarding feasibility of IGRDS, established its own estimates in dollars and time for taking IGRDS to an operational status in at least one state highway department. The committee evaluation was presented to AASHO, which directed that work on the development of IGRDS be terminated at Phase I. This decision was reached primarily on the basis of policy matters involved in the research mission for the NCHRP and was not centered on lack of confidence in the researchers' feasibility findings or the cost or time estimates. On the other hand, AASHO did not endorse the feasibility findings or the cost or time estimates. At this point in time, NCHRP work on IGRDS has been suspended and there are no plans to resume work at a future date.)

Interactive Graphics

The term "interactive graphics" implies the use of a computer and, in a more expanded form, could be expressed as interactive computer graphics. It defines a particular form of communication between the design engineer and the computer. Punched cards are the most widely understood form of such communication. The word "interactive" indicates that the user has full control of the computer and can interject his judgment at appropriate points in a program. It also implies that the design engineer will be satisfied with the time required by the computer to respond to commands and provide results. The satisfaction of the design engineer must continue throughout a series of commands and responses in pursuit of a design goal. The effect of interaction is to allow full advantage of the design engineer's judgment and decision-making ability, and to provide direct control of the computer's computational and data handling power.

The word "graphics" in the term describes the manner of communication between the design engineer and the computer. Communication will take the form of lines creating pictures, together with alphabetic and numeric characters forming notes, dimensions, or text to supplement the pictures. A computer-driven display device acts as an intermediary between man and computer, providing the user with a visual picture of the information and accepting graphic-oriented information.

The effect of interactive graphics is to provide the design engineer with computational results in the likeness of traditional graphical representations on engineering drawings. The difference between the screen and the traditional draw-

ings is that the screen will be dynamic in that it can be changed at the command of the design engineer to show whatever computed results are desired. In the highest form of interactive graphics, the user may point to portions of the graphic display, and add or delete lines.

There is not just one type of computer device or technique that provides interactive graphic capabilities but, rather, a range of devices that may be separated into several categories. The project effort has encompassed all of those categories and devices that had capabilities applicable to the system being designed.

Research Approach

Nature of Work.—The project involved systems design. The tangible end product of a follow-on development project would be a system resulting from this systems design, consisting of:

1. One or more computers.
2. Computer input/output devices of the interactive graphic class.
3. Computer programs, called operating systems, that control the operation of the computers themselves.
4. Computer programs that control the basic operation of the interactive graphic devices, called interactive graphic software, but that have no capability for the solution of a specific problem.
5. A program system to perform roadway design.
6. Computer programs that will cause all of the other components to perform as a system in the desired manner.

This project was concerned only with procedures and programs that will, insofar as possible, form the desired system by using standard hardware products of existing computer equipment vendors.

The resulting total system will be an Interactive Graphic Roadway Design System (IGRDS). The Roadway Design System, which is the application computation portion of IGRDS, is referred to as the RDS application, or simply RDS.

IGRDS will be a tool that will permit the practical in-service study of interactive graphic techniques by highway engineers. The results of this research study will provide a practical base for future interactive graphic developments in other areas of highway engineering.

The project was made up of work of two different, but related, kinds:

1. To conceive of and prescribe procedures for a roadway designer's use of a computer interactive medium.
2. To design and prepare specifications for computer programs that will cause RDS to work in conjunction with interactive hardware and software in a manner that will permit the performance of the prescribed procedures.

The first category of work consisted primarily of creating new procedural concepts. It involved analyzing each step of the roadway design process and determining what the designer needs and desires to do at each step. As each need of the designer was identified, it was necessary to determine what assistance RDS could be to the engineer at that design step, as well as what interactive graphic techniques could effectively be used to provide these roadway design capabilities. The resulting procedures were then recorded in documentary form.

The second kind of work included the study of existing interactive graphic hardware and software and the selected RDS to determine what additional interactive graphic program functions were necessary to create a combined system that would effect the desired procedures.

The study determined whether the proposed interactive engineering procedures were possible. Whenever it was found that the system could not perform in accordance with the procedures first proposed, another approach was sought that was more compatible with the interactive graphic capabilities. These two different work efforts were therefore cyclically interrelated, with the first being the initiator of a system specification, and the second being the responder as to whether and how the procedure could be realized by the system.

An additional characteristic of the project was that its purpose was to design new programs, rather than to make in-depth analyses of existing ones. Therefore, the review of existing roadway design programs and available interactive graphic programs was held to that minimum required to determine that their specified capabilities and structure would allow IGRDS concepts to be effective.

Another important consideration was to select a scope of effort for the needed follow-on work. Selecting a scope of work is predictive in nature. The nature of software development projects is that unexpected complexities can, and most often do, arise to cause expansion of the predicted work effort right up until the completion of final testing of a system. It is also typical that it is much easier to conceive of advanced and sophisticated program capabilities than to develop them.

In accordance with the clarification of the problem statement, the primary effort of this project involved the development of engineering procedures and the cost and benefit relationships of the interactive graphic devices. Because the program specifications were prepared in a trailing manner in response to the engineering procedures, they reached a lesser stage of development and must be considered to be general and functional in nature, rather than detailed. The program specifications require more design work in the form of at least one more cycle of relating the engineering procedures to the specifications and in expanding the specifications until each program is defined along with its specific description of processing function and data requirements. Thus, further detailing of specifications will provide greater assurance that the programs will do all that is required of them by the engineering procedures and that they can be adequately held in the memory of the selected computer.

Investigations of Interactive Graphics.—Three categories of investigations were undertaken in interactive graphics. These categories were:

1. Other uses of interactive graphics.
2. Available hardware devices.
3. Available software.

For all three, the method of investigation was initiated by a literature search to determine what was available. In the latter two categories, direct mail and phone contact was employed to obtain detailed information and specifications.

The state of the art is rapidly evolving and much of the desired information related to hardware and software is not readily available in printed form. New printed information and new devices continued to become available throughout the duration of the project.

It is expected that some new vendors of interactive graphic equipment may have been overlooked owing to the substantial numbers of new product announcements that continue to be made. It is also possible that some product was not recognized to be applicable to the desired application due to the, as yet, lack of existing common trade product terminology.

Selection of Roadway Design System

The nature of roadway design data, both specified and computed, is common to all highway organizations, but design procedures and methods of applying the data vary. The development of a prototype IGRDS requires that an RDS application system be selected as a source of engineering data. The selected system must have three attributes if IGRDS is to serve many potential users.

1. It must be reasonably comprehensive in order to determine the benefits of this type of computer technique over a range of design functions.
2. It must be as unrestrictive as possible in order to reduce the difficulties that might otherwise be encountered by individual design organizations, and individual designers, in adapting their own methods of design.
3. It must be modular so that deficiencies found in either of the first two attributes may be remedied with comparative ease.

The project problem statement required that the Roadway Design System of the Texas Highway Department (THD) be one of the systems considered. This was accomplished by visits to and discussions with the Texas Highway Department. In addition, special system documentation prepared for Project 20–8 (standard manuals and documentation were just getting under way at the start of this project) was carefully studied. On completion of this study, it was apparent that although some parts of the THD-RDS methodology would not be acceptable to all users, the methodology conformed to the three basic requirements just enumerated.

The Project Advisory Committee approved a recommendation that the Texas Highway Department Roadway Design System be used as the application system for IGRDS, thus relieving the project from extensive searching for and analyses of many such systems.

Findings

IGRDS Development Steps

The recommendations regarding the steps to prepare and install IGRDS are listed here not only to reveal a development plan, but also to provide a basis for establishing development costs.

Systems of the type of IGRDS should be developed in phases and steps. This development approach provides the opportunity to review the results of completed activities to determine whether earlier goals are still desirable and estimates of effort are realistic. The uncovering of unforeseen conditions is almost a daily occurrence, especially in the early stages of the software design work and in the later testing stages. Therefore, the development phases and steps should be as independent and as small as are reasonable. As each step is completed and reviewed, the next should be defined for system goals and effort.

To develop all of the capabilities of IGRDS that are desired, or will eventually be required to satisfy all of its various methods of use, will be a large task. It will involve solving significant problems in a number of technologies. These problems deal with: interactive graphic procedures, interfacing interactive capabilities and a large application system (RDS), long-distance data communications, and multi-terminal processing with the same application system.

The researchers recommend that IGRDS should not be developed to satisfy all needs in one effort; but, instead, it should be developed in stages. Phase I is that work that has been completed with this report. Phase II will be the work that is needed to create the first operational version of IGRDS.

Phase II should concentrate on completing a fully operational system that will provide the engineer with a production working tool and a means of directly evaluating the benefits of interactive graphics.

It is recommended that software required for long-distance data communication not be part of Phase II, but of a later phase. The research effort of Phase II should develop the system, exclusive of the data communication programs, to function as though the terminal were remote to the host computer, even if the terminal were in fact linked directly to a data channel of the host computer. This would imply selecting a terminal configuration that would operate remotely (e.g., would have a programmable computer and whatever else was necessary short of communication interface hardware) and programming the terminal modules to support the display. By developing the system in this manner, the majority, if not all, of the judgments as to the requirements for remote processing can be tested without adding to Phase II the costs or problems that would be inherent in actually making the system work under communication conditions.

It is recommended that multi-terminal processing requirement for IGRDS also be postponed later than Phase II. Many of the unknowns involved in multi-terminal processing will be resolved during Phase II and the added knowledge will ultimately lead to an efficient solution later.

It is recommended that both random scan and storage tube display devices be tested during Phase II, by selecting a random scan device as the physical display hardware, using it to its full potential, and, through programming, also using it to simulate the restricted characteristics of the storage tube. Although this approach would increase the development cost somewhat above that which would accrue

if only one device were tested, it would be less costly than if two display devices were acquired.

To achieve a functioning and useful system in highway departments, the following development steps are required in the Phase II effort:

1. Complete system design and program specification.
2. Prepare programs and perform preliminary testing.
3. Test and refine the system in a prototype highway laboratory.
4. Install and maintain the system for production use.

Each development step is expanded, as follows:

1. Step 1—The objective included in the project statement, ". . . to develop program specifications such that programming may proceed directly from this work . . .," is one that should be attained before programming begins. For the reasons previously indicated, this work has not been completed. To begin developing program systems without approved clear specifications is no more acceptable than to go to final design and build a roadway without an appropriate route location study and preliminary design. Therefore, it is recommended that the first step in the development of IGRDS, after this project, be the completion of detailed program specifications.

To complete the system and program specifications, the User Command State Diagram (UCSD) must have all commands completely described, along with all associated design engineer's actions. Charts of the entire system should be developed to describe in detail all functions to be performed, to what major program they are assigned, and in what order they will take place in the process. The listed functions and the UCSD should be compared to ensure that the functions described will actually perform all that the command structure requires. Once this verification has been made, the functions should adequately be expressed to describe program processing requirements, and should be assigned to specific, named programs. Data transfers should be specified between each program and between programs and files. Data file contents and formats should also be described. For this step to be most effective, the system hardware should be selected so that there will be a minimum of uncertainty as to system performance characteristics that affect the assignment of program functions.

2. Step 2—After completion of the system and program specifications, program development activities should commence. This step should include:

   a. The finalization of the program methods to accomplish the functions specified for each program.
   b. Preparation of program logic flow charts.
   c. Coding and testing of individual programs.
   d. Preliminary testing of the entire system.

The testing included in this step can be performed without the actual participation of a design engineer, but should take place under the direction of an engineering systems analyst. In fact, the system should not be made available to non-system-oriented users until after this step has been completed and adequate quality assurance procedures have been satisfied.

3. Step 3—When the system has passed its quality assurance tests, it should be made available, under controlled conditions, for practicing engineers to process production jobs. This should take place at a single highway department. The system should be considered as a prototype design tool being used in a laboratory environment. There should be no attempt to imply that the system has been released from the computer system group to the design group. The terminal should reside in a quiet working area of the highway department systems unit.

All design jobs that are being processed by the system should be worked in parallel with traditional methods to provide checks on the results and to protect the design operation production schedule from system failures.

During the early part of this laboratory testing stage, systems analysts should be unobtrusively in attendance as the design engineers work at the console. They should be ready to assist the engineer, and to closely observe his actions. During this stage, many of the engineer's desire assumptions concerning methods of operation will be verified or corrected. It will be the responsibility of the observing systems group to analyze the procedure and to recommend improvements.

During this step, the formal system documentation in the form of user's and maintenance manuals will be prepared, and the system flaws discovered will be corrected.

4. Step 4—On completion of testing in the prototype laboratory, the system will be ready for general release. At this time, preparations should be made to provide a capability to assist the highway department in installing the system and maintaining it in response to complaints presented by the users. Such assistance has been found to be essential, by the manufacturers of computers, if user satisfaction is to be realized. Recommendations as to how this should be achieved are not made here because this step will not be taken until some time in the future.

An appropriate schedule for system development would be:

STEP NO.	MONTHS
1	5
2	24
3	12

Host Computer

The host computer is a large computer that furnishes the main computing power of the system. It must be prepared to perform four basic functions:

1. Roadway design computations of RDS.
2. Processing for all standard batch jobs of the organization, in a multi-processing and sometimes multi-programming manner.
3. Management of all host computer processing, including that of the interactive graphic operation.
4. Central communication management of the multi-remote interactive graphic and standard-type terminals.

For the central processing unit (CPU) to perform all

these functions at a satisfactory level of productivity, a significant amount of computer power is required of the host computer. Computer power is comprised of a number of attributes; speed, size of primary memory and processing flexibility of the CPU, the over-all strength and flexibility of operating system software, secondary storage capacities, available data channels, and peripheral equipment controllers and multiplexors.

It is reasonable to expect that, in its early stages of development, IGRDS will justify neither its own host computer nor extreme changes in the existing or planned type or capacity of computer. Therefore, rather than indicate the requirements of IGRDS for a host computer, the classes of computers that now exist in highway departments will be measured as to their acceptability for IGRDS.

It appears that the minimum host computer that can support *both* standard batch processing and IGRDS is an S 360/50, with 524K bytes of memory and secondary mass storage equal to 117×10^6 bytes. Such a configuration is now available to about one-third of the highway departments. It is expected that, in time, more organizations will reach this computing capacity, and it would not be unreasonable to expect that in two or three years 60 percent of the organizations will be able to process on an equivalent configuration.

For those highway departments that have not reached that level of computation, the way should be open to them to process on a host computer of another organization, as much as several hundred miles away, through the use of wide-band telecommunications.

The random scan device appears to be the type of display to be used for IGRDS when the system consists of a small number of terminals and full or nearly full utilization can be anticipated. It is unquestionably the device that will best satisfy the design engineer's requirements. The method of use that would most clearly justify high utilization is centralized design. When many decentralized design groups must be served, with justification based solely on IGRDS, the storage tube probably would be a more practical selection from a cost standpoint.

System Cost Versus Benefit

An objective of the project has been to determine the relationship of IGRDS benefits to cost. It is difficult to establish reliable measures of many of the features that affect such a comparison. At this stage of design, the system does not have a single set of specifications to which an accurate cost can be assigned. To establish cost, a hardware configuration and the final nature of the as yet incomplete IGRDS software specifications have to be assumed.

The measurements of benefits for traditional applications of computers, or even for basic engineering procedures, are at best partially judgmental. Direct benefits are fairly readily measured, but the greater potential benefits are often indirect, and are subject to uncertainty and doubt. The evaluation of the effects of this new technique of interactive graphics, for which highway engineering has no in-service experience, will be even more judgmental than most computer applications.

Cost of IGRDS.—All cost figures are estimates that are based largely on a complex series of assumptions. Should these assumptions be modified, in total or in part, the cost estimates could vary substantially. Should the recommendations concerning system scope or equipment create costs that cannot be funded, costs could be reduced by lessening the scope of work and/or sophistication of equipment.

The cost of IGRDS should be broken into two components:

1. The development of the working, generally applicable procedures and software that presumably will be jointly funded.
2. The acquisition of the hardware components for, and the operation of, the system; which will be paid for by the individual organization using IGRDS.

Cost to Develop IGRDS.—The cost of developing IGRDS consists of that cost required for development of Phase II, steps 1 through 3. Without a known hardware configuration and finalized specifications, which are to be the result of step 1 (i.e., the first step of development), the scope of work to be accomplished during steps 2 and 3 is not as certain as would be desired for an accurate cost estimate. It is assumed that the hardware configuration will be a medium-performance random scan configuration, and that the large majority of the software functions will be effected during the three development steps of Phase II (i.e., all functions except data communication programs and multi-terminal processing). Should it be determined later that certain of the system functions are more difficult to achieve than are now thought, and should it be required that development costs be limited, it would be possible and acceptable to selectively develop the most beneficial portions of the system and to omit others.

With these qualifications and the definitions stated, a development cost for Phase II of IGRDS, exclusive of equipment, can be expressed.

Step 1—Complete system and program specification	$ 35,000
Step 2—Develop programs and perform preliminary testing of system	200,000
Step 3—Test and refine system in prototype highway laboratory	75,000
Total development labor cost	$310,000

The cost for use of the equipment required for IGRDS development depends not only on the type selected, but also on how and where this use is acquired. The necessary equipment could be used by the development project team at a highway department, a computer service center, or some other organization. Equipment could be leased from a manufacturer for a portion of the development period, or its operation could be acquired on a use basis from a computer service center.

Much of the initial work of programming and testing individual routines will be carried out without the need of the display terminal. A reasonable estimate for the period of Phase II during which the equipment would be

required would be one year for developing step 2, followed by one year for step 3.

Estimates of terminal equipment use cost can vary as follows:

1. Purchase of system use as needed:
   24 months × 25% × $9,000 per month . . $ 54,000

(Note: 25 percent indicates the amount of time per month that the system would be used.)

2. Lease interactive graphic equipment and connection component for full period with *no charge* for *host computer:*
   24 months × $6,250 per month $150,000

3. Pay full monthly charge for all equipment for full period:
   24 months × $9,000 per month $216,000

Because the actual terminal use cost will probably be somewhere between the high and the low, estimate 2 will be used. No cost has been included for using the host computer because the method of acquiring this use is unclear at this time. Therefore, if all assumptions are correct, the total estimated development cost, exclusive of any charge for using the host computer, would be $460,000.

Because IGRDS will eventually provide benefits to most, if not all, highway departments, this cost can and should be distributed among the departments. It would seem reasonable that the individual state's development cost share in a cost-benefit evaluation would be between $10,000 and $25,000. Distributed again over four years of use, the annual cost to a department becomes $3,000 to $6,000.

Cost to Operate IGRDS.—The second cost related to the system is that which the individual organization using IGRDS must bear for the acquisition of the hardware components and for operation. This cost will be developed as a yearly expenditure that must return adequate yearly benefits for its justification. It will exclude one-time charges for software conversions to fit hardware characteristics different from those for which the system was developed, and for software changes to fit a different RDS or desired user procedure. These latter one-time customization costs will also have to be justified on their own merits over and above the yearly costs.

The using organization's yearly cost can be estimated. Assuming one medium-performance random scan device connected directly to the host computer, the costs applied to IGRDS are as follows:

IGRDS COST COMPONENTS	$/MO.
Terminal rental	$ 5,500
Connection components	760
Host computer memory use	2,000
Mass storage use	240
Host processing use	500
	9,000
	×12
Total cost/year	$108,000

This assumes full-time use of IGRDS for a single shift of operation.

In addition to the hardware, one engineering analyst and one systems analyst should be assigned to full-time support of the system for operation and training.

The total cost of an individual of either of these types could be considered to consist of:

1. Direct payroll ($13,200).
2. Plus 20 percent for direct payroll-related expenses (i.e., FICA, vacation, etc.).
3. Multiplied by a burden cost of 50 percent, for support services, materials, office space, etc. (Note: It is recognized that a factor of this type is not normally used in governmental highway accounting or budgeting practices; however, such other costs do exist and are related to the number of "production" personnel. It is believed that the inclusion of these other costs is as appropriate to these evaluations as is the inclusion of the memory, processor, mass storage and communication costs with the cost of the display terminal.)

An estimated total yearly labor cost of one man would then be $24,000. The total yearly cost applicable to the use of IGRDS would be approximately:

Full shift of hardware	$108,000
Two full-time men	48,000
Distributed development cost	6,000
Total cost/year	$162,000

Benefits from IGRDS.—The value of incremental benefits will be compared to the costs of using IGRDS to arrive at a measure of the return that can be expected from such an investment.

The benefits to be realized from using a computer in engineering design operations are both direct and indirect. The direct benefits are related to the reduction of man-hours to achieve the desired design results. These are generally relatively easy to estimate and are readily accepted. The indirect benefits are related to the engineering results of the design operation. They may be realized from a safer or improved design, or a less expensive end product. Indirect benefits are not easy to quantify, and generally do not receive broad acceptance because often the same product results could be obtained through non-computer methods, if they were to be applied.

Although it would be easier to bypass the more difficult problem of indirect benefits, they are, in most cases, of significantly greater value than the direct benefits. To establish a more acceptable basis from which to evaluate the total value of interactive graphics, the direct benefits will be estimated first; then the less quantifiable indirect benefits which should be realized will be identified.

To separate the benefits received from the IGRDS, as being different from those obtained from RDS and the computer in standard batch processing method of computation, it also is of value to discuss the escalating returns that have occurred as computer sophistication has increased in the past.

Each new computer application, effectively employed,

has brought the user an additional increment of benefit. As an example, the first geometric or earthwork programs resulted in:

1. Lower cost computation through the greater computational efficiency of the computer.
2. More productivity from each using engineer, resulting in the need for a lesser number of support personnel, and again lower costs.
3. Fewer mistakes in computations, resulting in lower costs and shorter time-to-completion due to reduced requirements to re-do work caused by errors.
4. The ability to obtain better engineering results by making more design trials with the increased computational power of the computer.

Some offsetting factors, however, had a tendency to diminish these theoretical advantages:

1. More computer trials generated more information, making it more difficult for the user to organize results.
2. The resulting output was somewhat less familiar than manual results, thus requiring more assimilation time.
3. Computer results often required drafting for proper interpretation and assimilation.
4. Often the process to get the input to and output from the computer was less convenient and more time-consuming than desired, causing the user to employ manual alternatives.
5. The alternate use of two modes of operation, both manual and computer, with long time lapses at each change in mode, broke the smooth flow of work procedures, requiring more management of the engineering process.
6. The use of two modes of operation had more potential for errors in transcribing data to and from manual and computer operations.

The next important stage in the development of computer use in roadway design was to organize the design programs into systems. The primary additional benefits were:

1. The reduction of data handling required of the user, by placing this responsibility on the computer which could handle it better from a cost and accuracy standpoint.
2. The minimization of irritation, lost time, and design management caused when the user was required to shift back and forth between manual and computer operation for the various individual programs used in the design operation.
3. The receipt of all benefits realized in the first stage of computer use to an even greater degree, because of the more efficient and substantive nature of the systems.

This stage also had accompanying drawbacks:

1. Many design decisions had to be preprogrammed to achieve continuous flow of computer operation and to minimize user-computer interaction, providing results that did not suit every user, even though the results might have been technically correct.
2. The cost and preparation of preprogrammed design decisions were high.
3. Much drafting was still required to interpret the results, although in some instances automatic plotting was successfully employed to display the general nature of the results. For many of the automated drafting applications, the cost to produce a drawing was high and the techniques used did not provide all the graphic administration necessary.
4. The user was able to look only at the output that had been preprogrammed and did not have the ability to see selected intermediate results, which often made it difficult to know why the results were what they were.
5. The preceding, along with the inconvenience of communicating between the user and the computer, made it difficult to make fine adjustments to the model.

The next step up the scale of computer use, from batch processing an integrated system of programs to interactive graphics, brings all of the previous gains, plus several additional major advantages to improve the design operation:

1. The capability to work directly with the computer, application program, and data files provides the ability to:
   a. Selectively look at and concentrate on only those data that are of interest.
   b. Immediately see the results of the change caused by the introduction of new data, and thus more clearly understand cause and effect.
   c. Direct the decision-making process to fit those desired rather than depend on preprogrammed logic.
   d. "Tune-up" a model by making several small changes with immediate review of the preceding change to help in the next.
   e. Feel that the designer, rather than the computer or programmer, is in charge of the design.
2. The immediate display of information in graphic form provides a more complete and immediate understanding, allowing for:
   a. Earlier, if not immediate, detection and correction of errors.
   b. Visualization, in advance, of conditions resulting from design, such as when using perspectives or dynamic displays.
   c. Guidance to the user through every design step.
3. The convenient and natural communication of computation direction by the user in graphical form allows for:
   a. Increased speed and efficiency in command and data input.
   b. Reduction of errors.

The foregoing are important steps in overcoming the drawbacks of all preceding stages and achieving the long-desired goal to provide the power of the computer directly to the design engineer. The sum of the three main features—direct guidance, graphic display, and speed—provides the design engineer with that total capability for problem solving that no other single computer approach has provided.

The effect of all of the foregoing improvements in technique is to provide a design capability that will increase the design engineer's productivity and capacity, and will reduce elapsed time. Benefits will be realized in several ways:

1. Lower number of personnel through shifting of persons to new responsibilities.
2. Increased design output from the same in-house personnel level.
3. More design effort applied to projects (e.g., more trial alignments to minimize detrimental environmental effects).

Although the use of an RDS in production design efforts is just being effected, it is this level of computer-aided design that is improved on by IGRDS.

An analysis of estimated savings of roadway design effort due to IGRDS assumes a theoretical roadway design staff of 158 persons, made up of in-house staff and consultants, that processes an average of 50 projects per year. The mix of the assumed projects that IGRDS can assist, in one stage or another, is:

PROJECT TYPE	% OF TOTAL
Reconstruction	45
Relocation	25
New location	15
Widening and resurfacing	15

It is estimated that the use of IGRDS will increase the productivity of the organization by 8 man-years per year, resulting in a cost benefit of $192,000 per year. (The yearly cost for a man-year of this type, $24,000, is estimated previously, in relation to the cost of operating IGRDS.) This estimated yearly direct cost saving of $192,000 is slightly greater than the estimated yearly cost of operation of $162,000.

The *indirect* benefits of IGRDS that will be obtained from the better level of design and shorter elapsed times accrue from the following:

1. Roadway user and taxpayer—The shorter elapsed design times resulting from the use of IGRDS will provide a fully developed and graphically documented roadway design at an earlier date for public hearings. In addition, these shorter times will provide the finished road at an earlier date, with two benefits: (1) the economic advantages that are implicit in the use of the new roadway would be greater, due to the earlier availability to the public; and (2) for those states that obtain road funds from interest-earning state funds, the replenishment of these funds with Federal reimbursements would occur at an earlier date, thus increasing the interest to the state fund. If design efforts are credited with increased safety in road use through the elimination of hazardous conditions, IGRDS, with its ability to allow the designer to uniquely preview the road through many different viewing methods and degrees of detail, will provide better results than would any other design technique.
2. Construction—Roadway construction costs will be reduced through improved design that will reduce payment quantities. In addition, IGRDS will, through its viewing and modifying ability, allow for a more thoroughly detailed design, causing fewer construction changes or extra work orders to repair design problems that arise because the engineer has difficulty envisioning the finished roadway in the office. Drainage, slope warping, and blending new construction into existing neighboring construction will be substantially improved. Should it be found necessary to make design changes during construction, the elapsed time to make these changes will be reduced.
3. Roadway maintenance—Ditch, slope, shoulder, culvert, and headwall maintenance problems resulting from imperfect drainage design and slope warping will be significantly reduced by IGRDS, again through the ability to construct many views and profiles. The value attached to reducing maintenance costs could be substantial, because they could be yearly repetitive costs, as well as one-time rehabilitation or repair costs.
4. Development of computer programs for all highway design problems—The cost of developing computer programs for engineering design will be reduced through the use of the interactive capability of IGRDS. The costs related to the development of multi-condition, preprogrammed, decision-making logic are in the upper range of all types of software costs. By using interactive graphic concepts, which allow the design engineer to make the design decisions and provide the program linkage capabilities, the costs of developing such programs will be significantly lower.
5. Future benefits—The ability to prepare final drawings by automated means will be significantly improved by interactive graphics. For some time, it has been possible to generate many of the final drawings in highway plans, including plan-profile sheets, by automated plotting techniques. A key obstacle in implementing this approach has been the cost of developing programmed logic to adequately arrange the graphics on the sheet for all of the various positions of lines and randomly placed notes and symbols. The ability of interactive graphics to perform graphic administration provides the means to adjust the over-all picture arrangement by human guidance—a most effective and efficient method. It is not unreasonable to expect that the cost of drafting plan-profile sheets for a 150-man design organization (i.e., including both in-house and consulting personnel) could be reduced by 20 to 50 percent. Using a 35 percent reduction and an estimate that two-thirds of the personnel are draftsmen, a saving of 30 man-years could be realized, or in excess of $400,000 per year. Such a saving would justify a greater expenditure than the cost of IGRDS, plus that of the drafting machines and software required to perform the drafting task. The use of IGRDS in route selection and preliminary design awaits only the acceptance and installation of a numerical terrain model. Other digital models, such as land use, topography, and drainage, could be added to IGRDS. The future increase in benefits in the use of interactive graphics in design will be significant.

The listing of indirect benefits that can be accrued by the interactive graphic techniques of IGRDS could be continued. Not all of these can, or will, result immediately after the installation of IGRDS. However, few of them could be fully realized by the highway designer without interactive graphics.

The assessment of the real value of the foregoing in-

direct benefits to any highway department can best be made by each individual organization, depending on its own experiences and needs in relation to the cited IGRDS benefits.

Summary of Costs and Benefits of IGRDS.—The cost of development of IGRDS software, excluding host computer use costs, is estimated at $460,000. It is expected that this cost would be jointly underwritten. The total yearly use cost for a highway department is estimated at $162,000. Direct design labor savings are estimated at $192,000 per year. Additional indirect benefits to road users, from construction costs, maintenance costs, programming costs, and drafting costs, totaling several times the direct labor savings, would not be unreasonable. The researchers believe that benefits of this magnitude are achievable and would, by generally accepted yardsticks, provide an appropriate return on investment.

During the course of the project the question was asked whether, with the public's changing emphasis on priorities and goals, the development of a comprehensive roadway design system would be justified. The implication was that problems of social and environmental nature have surpassed roadway design in importance in the public mind, thereby causing roadway design to be unimportant. The researchers believe that current public demands for greater protection of social and environmental conditions, less use of new land for roadway right-of-way, and fewer funds for highway construction and staff are going to require a higher proportion of design effort as compared to construction expenditure, with fewer funds to accomplish both. Although roadway design may have dropped in relative importance, it is still the function that provides the assurance of lowest cost roads, which is of great importance when funds are grudgingly given. The greater protection of society and environment means more engineering. More roadway engineering, with personnel levels being restricted, can be achieved only through techniques of the type of interactive graphics.

Interpretation and Appraisal

Feasibility of IGRDS

The researchers believe that the development of IGRDS is feasible, if modest enough goals are established. A first goal of a tested single random-scan prototype system is feasible in two and one-half to three years. The installation of a single-device system in ten highway departments would be feasible within the following two years. By that time, it would seem reasonable to expect the first multiterminal version of IGRDS to be operational. Similarly, the offering of IGRDS service from commercial service operations via wide-band telephone lines would also seem reasonable.

There are problems to be faced in the development of an interactive graphic roadway design system, but they do not seem nearly as large as those that have been faced, either at the initiation of computers into highway engineering or at the adjustment to a new generation of computer systems and concepts that took place in the mid 1960's. Interactive graphic techniques have been under development in laboratory-type environments for about ten years. This is a longer preparation period than was available for either of the previously cited computer events. The concentration on the problems of interactive graphics alone will keep the scope of the effort reasonable. The use of an existing and tested RDS will allow this concentration of effort and localization of problems.

The development of IGRDS seems feasible and justifiable. However, it should be accomplished with care and planning.

Key to the effectiveness of any system, and especially IGRDS, is the procedures for its use. IGRDS user commands have been developed with the goal of being practical, production oriented, and detailed to the extent that the design engineer's operational desires will be satisfied and his irritations will be minimized. It is believed that, in early stages of adjusting to the new techniques of interactive graphics, the design engineer will desire and appreciate commands that clearly define options and that provide little room to stray into frustrating situations. Although the command structure constrains the design engineer to precise processing paths, the number of paths available will be large enough to provide all desired processing capabilities.

The software specified will make the command structure work and will provide flexibility to the system. Commands may readily be added, altered, or deleted. Different RDS's may be used, with appropriate changes to programs of IGRDS that interface with RDS. Changes in display imagery may be made by modifying graphic display generating programs. By replacing the command lists, the graphic display generating programs and the interface programs, a totally different interactive graphic system, such as bridge design, can be developed.

Conclusions

The IGRDS has certain costs of development and operation as well as benefits. These aspects of the IGRDS, along with appropriate recommendations describing how the system should be created and expanded in the future, follow:

1. For a state highway department, the probable direct and indirect benefits to be derived from IGRDS compare favorably with the estimated cost of operation, plus the shared cost of development.
2. Because the projected benefit-to-cost relationship is favorable, IGRDS should be developed into a fully operational prototype system.
   a. The system should be developed for a single terminal operation.
   b. The system should initially be developed to operate on a host computer data channel and should not include the communication software modules.
3. A single interactive graphic terminal configuration of the random-scan type should be selected and made available for developing and testing the prototype system.
   a. The terminal configuration should be selected as though it were to be operated in a location remote from the host computer, so that the Interactive Application Control Program (IACP) terminal

software and procedures for remote operation, exclusive of communication, can be developed and tested.

b. The operational effects of a storage tube should be simulated on a random-scan device through software means.

4. IGRDS should be tested and refined by allowing it to be used by practicing engineers on real design projects in a highway department.

5. IGRDS should be made available to the state highway departments and other agencies as a useful tool. Installation assistance, training, and long-term maintenance should be provided from a single responsible agency.

6. IGRDS software for communication and processing with multiple interactive graphic terminals should be developed, tested, and added to the initial software set under future research work.

7. Several research efforts, beyond those specified in the report, should be undertaken.

a. Techniques should be studied for developing numerical models of terrain, land use, topography, and hydraulics.

b. Methods for using interactive graphics in the process of automated engineering drafting should be studied.

Recommended Future Research

There are many possibilities for research in the use of interactive graphics. Recommendations here should be restricted to those that deal with highways. The most promising subjects of additional research are:

1. Development of steps 1 to 3 of IGRDS.

2. The use of interactive graphics in the process of automated engineering drafting.

3. The use of interactive graphics with numerical models of terrain, land use, topography, and hydraulics.

4. The study of the techniques whereby the generalized software components of IGRDS can be used as the nucleus for other highway engineering applications.

Project 22–1 FY '70

Concepts for Improved Traffic Barrier Systems

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Introduction and Research Approach

Conventional traffic barrier systems are presently being applied widely by highway and bridge engineers. All of these existing systems have some deficiencies that make their performance somewhat less than ideal. New concepts were therefore needed for economical, standardized, longitudinal traffic barrier systems that can provide a consistent degree of protection when installed as highway shoulder guardrails, median barriers, and bridge rails. The system developed presents a consistent appearance to the motorist as he moves along the highway and over structures, although parameters (such as post spacing, sectional properties, and anchorage) vary somewhat. Emphasis was given to conceiving an integrated system that maintains continuity across bridges and avoids abrupt transitions.

The objective of the research was to produce one or more traffic barrier system designs, described with sketches and narrative to the degree necessary to convey understanding, that offered promise of: preventing penetration by a standard-size U.S. automobile weighing 4,000 to 5,000 lb and impacting at 25° and 65 mph; smoothly redirecting the errant vehicle relatively parallel to traffic flow; providing a range of controlled dynamic deflections by varying design parameters; retaining longitudinal continuity following the collision; allowing adequate visibility; being capable of quick and easy repair; performing satisfactorily in various foundation conditions; limiting decelerations at the center of gravity of the vehicle to 5 g lateral, 10 g longitudinal, and a total of 12 g when averaged over any 200-millisec period; having reasonably low first cost and pleasing appearance; and minimizing vehicle damage. With these objectives in mind, a traffic barrier design was prepared with substantiating calculations, which indicated that all the objectives would be met (Fig. 1).

Research of existing reports pertaining to similar studies was initiated early, in hopes of finding useable information and guarding against duplication of work already done. Flexible rails were investigated to determine feasibility and develop quantitative data pertaining to the rail.

Trial designs were prepared and submitted to G. H. Powell for analysis by the Barrier IV computer program.* However, the attenuators that support the rail proved to be so highly indeterminate that their structural parameters could not be assumed with reliability. To obtain reliable load-deflection data to be used as input in the Barrier IV program, testing equipment was purchased or constructed, and two full-sized attenuators were fabricated and tested by deflecting them in a manner simulating lateral loading imposed by a vehicle. The vertical location of the center of lateral resistance force throughout the deflection cycle also was determined.

The empirical force-deflection data thus obtained were submitted as computer input applied to several barrier system designs. The first trials came close to meeting the requirements stated, but lateral decelerations were slightly larger than desired. Adjustments were made to the design, and it was resubmitted for analysis. Results then met the contract objectives in all respects.

Data and photographs were prepared, and the research report was completed. Working drawings suitable for fabrication and installation of a prototype were prepared for the complete barrier system (Figs. 2 through 7).

Preliminary Literature Search

Researching of other barrier projects was continued throughout the contract period, as an insurance against the

* Developed in 1970 as the result of a FHWA-sponsored research program conducted by Powell at the University of California at Berkeley.

possible duplication of work of others. However, the proposed traffic barrier apparently represents a new approach to the attenuating barrier problem, and much original research can be done without fear of duplication.

A wealth of basic information was found in the reports reviewed. Performance data from other types of barriers have given insight into the kind of performance that might reasonably be expected from the original barrier design.

Because the object of this research was to provide a barrier having universal application, reports pertaining to research performed in all parts of the United States were investigated. *NCHRP Reports 36, 54,* and *86* and other similar reports were especially helpful as they contain data collected from various sources in many states. Other important sources of basic information included reports on crash tests performed by the states of New York and California, and the Texas Transportation Institute.

This investigation of previous research was useful in helping to decide how much lateral displacement capability to provide, and how high to make the barrier. The assumptions in the original design were found to be too conservative--the result of basing them on pure theory instead of actual practice. It was possible to reduce the lateral distance required for vehicle deceleration and to reduce the height somewhat.

Reports on crash tests emphasized the importance of dependable rail-to-post fastenings and other attachments, as well as the need to keep supports well back from the face of rail to prevent snagging.

Reports dealing with vehicle statistics throughout the U.S. indicate a surprising variation in the type and size of vehicles to be retained. This project is concerned only with a situation of near maximum severity. Obviously the barrier must also ultimately consider lighter vehicles if it is to be successful. A barrier that would yield under impact from a 4,500-lb vehicle might behave as a solid barrier when hit by a light sports car. The number of light vehicles appears to be increasing in the U.S.

It seems likely that the final design emanating from this research will be a compromise that sacrifies efficiency in the most severe situation in order to reduce deceleration rates for the occupants of small vehicles. This will mean that more stopping distance will have to be provided for the very large vehicles.

The reports on full-scale crash tests showed that a considerable space is needed to decelerate the vehicle where flexible rails are used. The cables used invariably stretched a great deal, allowing the vehicle to swing wide. It became apparent from the barrier research reports that at least on bridge decks, where the cost of added space is relatively high, a rigid rail might be more appropriate.

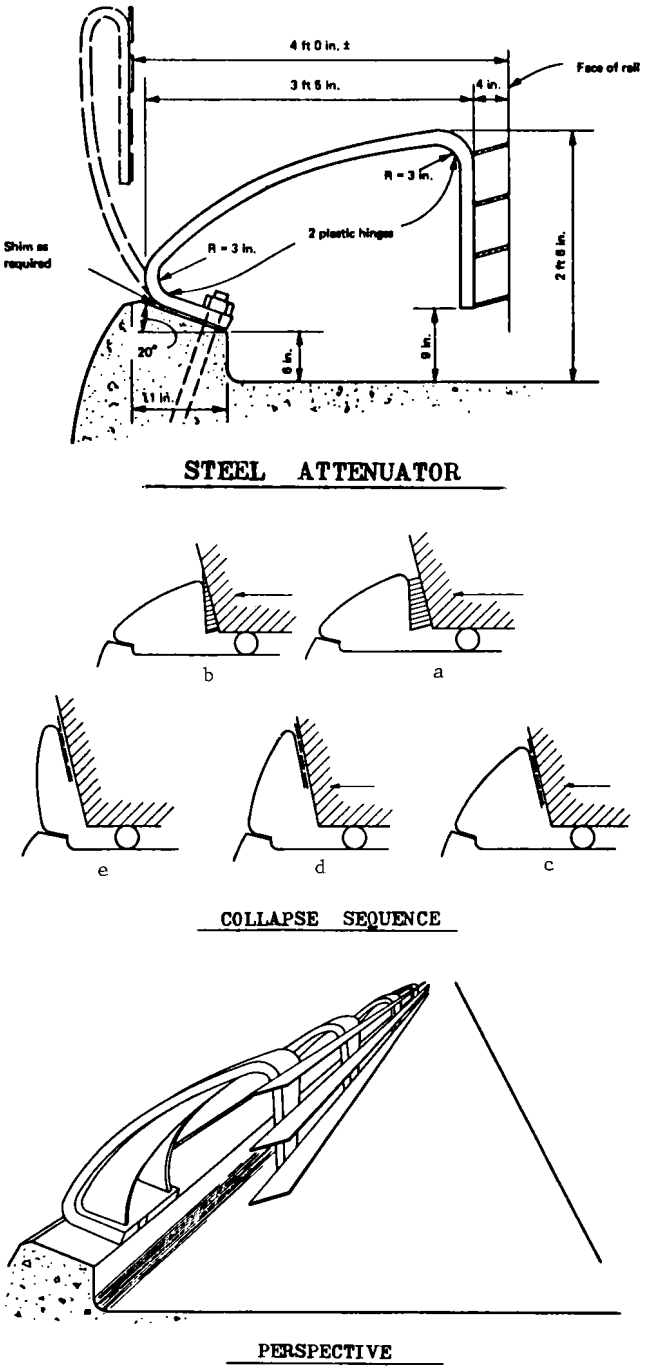


Figure 1. Original proposed attenuating traffic barrier.

Flexible and Rigid Rail Investigations

The flexible rail type of barrier promises several advantages. The rail element should have low first cost. It will also sustain much less damage than more rigid rails. The flexible rail appears to have the ability to function over a wide range of impact force. Being light and flexible, it is suited to light vehicles. On the other hand, as the flexible rail deflects, its geometry changes quickly to produce a very large lateral component of force (Fig. 8). It therefore can be made to retain easily the heavier vehicles expected also.

For example, impact from a 4,000-lb vehicle being decelerated at 5 g's would produce a stress of 18,000 psi, in flexible rails having a 6.75-sq-in. cross section, on supports spaced at 10 ft. Doubling this vehicle weight to 8,000 lb and still using 5 g deceleration, the stress does not double, but increases to only 28,900 psi.

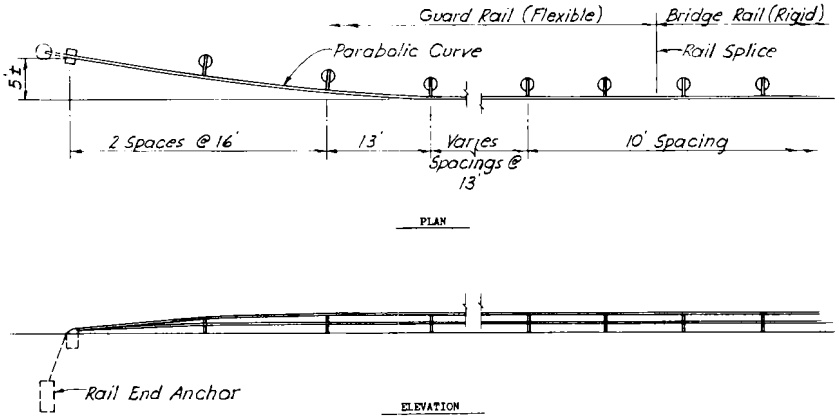


Figure 2. General plan, prototype barrier.

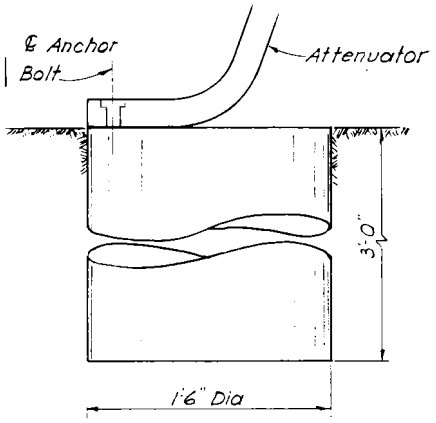


Figure 3. Guardrail foundation, prototype barrier.

By contrast, any rigid type of rail, depending as it does on bending to resist lateral force, quickly reaches a point where it fails in bending and thereafter has a reduced capacity to resist lateral force. Rigid rails are only strong enough for moderate loads, unless longitudinal anchorage is added that is sufficient to cause the rigid rails to act as true tension members after failing in bending.

Note that the weight of flexible rail elements is slightly over half the weight of some of the box beam rails being used. This saving in weight of steel, and the fact that flat plates are more economical per pound than steel tubes, represents a significant saving.

The large deflection of cables that function as rails is typical of all structures using high-strength steel. Although strengths may be considerably greater, high-strength steels have the same modulus of elasticity as ordinary A 36 steel.

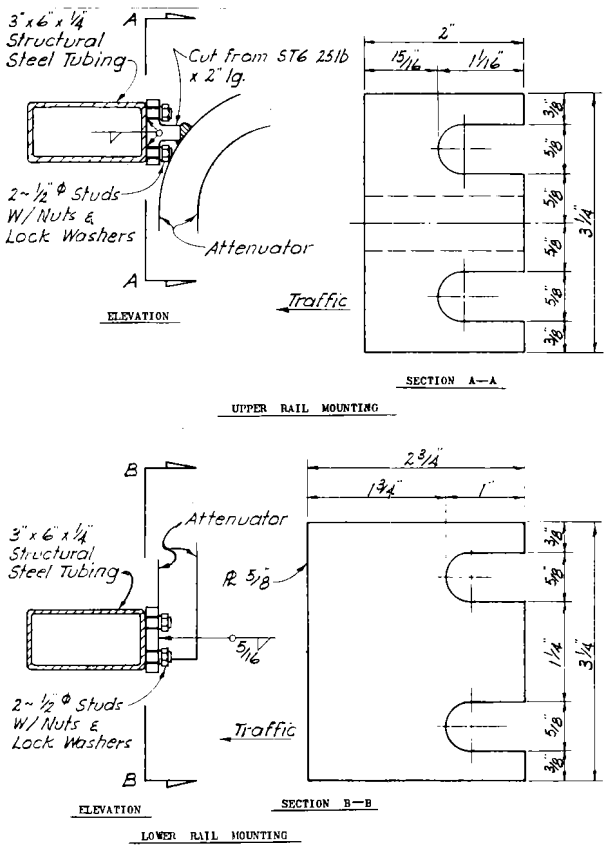


Figure 4. Rigid rail attachments, prototype barrier.

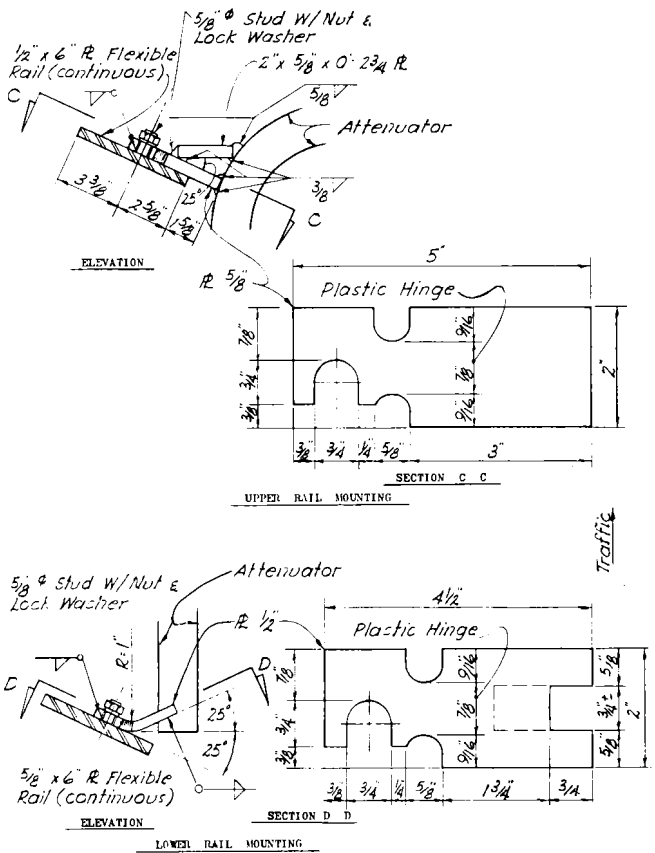


Figure 5. Flexible rail attachments, prototype barrier.

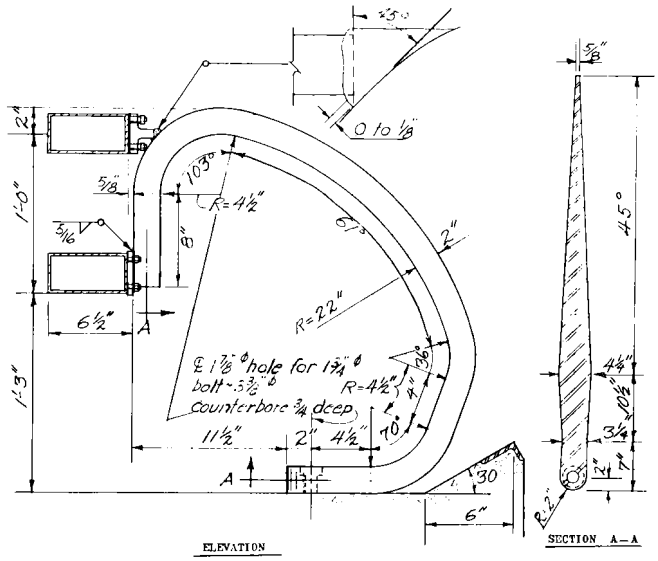


Figure 6. Attenuator details, prototype barrier.

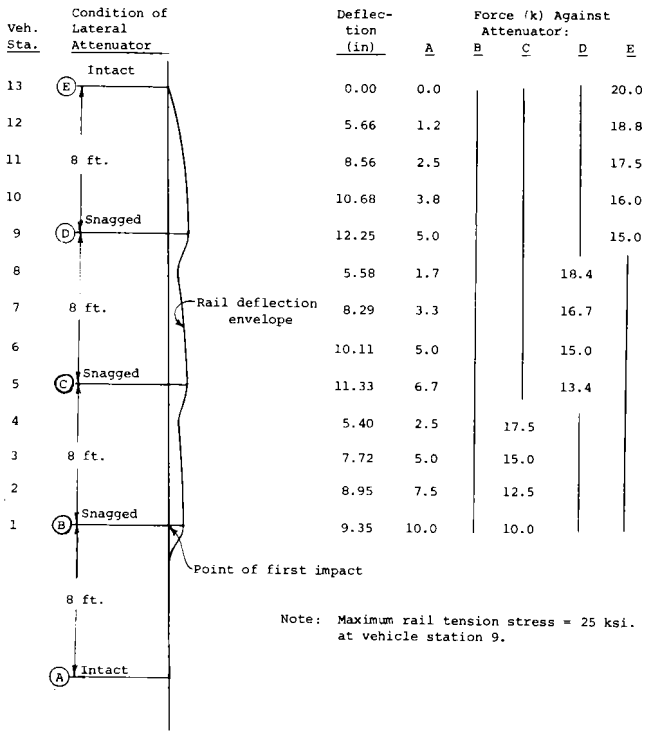


Figure 8. Flexible rail deflection due to stretch (20-kip lateral force at any station). Rail $A_s = 4.69$ in.

But, because of superior strength, member cross sections are usually much smaller in area and unit stresses are proportionately higher. This means that the strain (stretching, in this case) is very large, for strain is proportional to unit stress, the modulus of elasticity being constant.

The undesirable stretch caused by using small cross sections and relatively high unit stress was greatly reduced in the original design by simply employing rails having much greater cross-sectional area, thereby reducing the unit stress. Consequently, steels lower in strength (and in cost per pound) are also used.

The three ¾-in. cables used in most of the tests reported in the literature had a combined cross section of 0.72 sq in. By using two ⅝-in. × 6-in. flexible rails of A 441 steel the cross section was increased by a factor of 10, and stretch was reduced to less than one-tenth the amount shown by the cable rails (Fig. 15).

Stretching of flexible rails appears to be by far the greatest cause of pocketing. By reducing it drastically, as was done, it seems reasonable to believe that pocketing can be minimized to an acceptable degree.

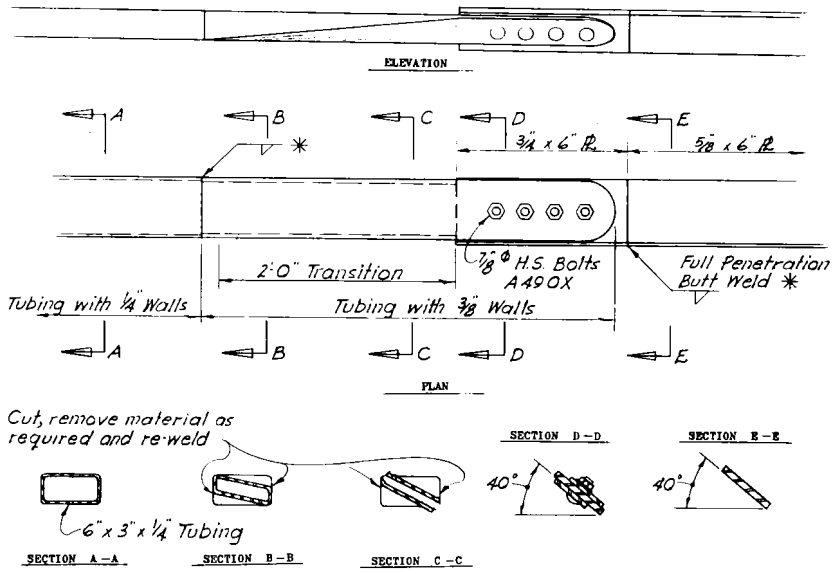


Figure 7. Rail splice details, prototype barrier.

Preliminary results showed that the (assumed) three plates with a combined cross sectional area of 6.75 sq in., supported by lateral attenuators at 6-ft spacing, will limit lateral deflection of the rail itself to 6.47 in. maximum, where no attenuators are considered snagged and removed by the vehicle, or 7.83 in. maximum where the first attenuator only is assumed to be snagged. If all attenuators are snagged as they are encountered, lateral deflection of the flexible rail will be 10.58 in. maximum.

This is an idealization to determine deflection due to the stretch in the rail only. It assumes infinitely rigid anchors at 100-ft centers and (temporarily) attenuators that do not yield.

Although some attenuation of force takes place during the initial deflection of the rail (and it is good to have some deflection without permanent deformation to resist light impacts without damage to the rail), it is considered desirable to keep deflection of the rail to a minimum to avoid pocketing. Most of the energy is to be absorbed by the supports.

Deflections of the flexible rail, as measured from a theoretical line connecting attenuator faces, and also rail reactions against attenuators, have been given detailed attention. Because of this attention it is possible not only to estimate pocketing tendencies, but also to predict with some accuracy the strength of the trial attenuator.

To obtain the total deflection of the barrier, the yielding of anchors and deflection of the attenuators must be added. This is discussed later.

Using an Olivetti "Programa" computer, a large number of rail deflections at the attenuators, at mid-span between attenuators, and at the quarter-span points were determined for attenuator spacings of 6, 8, 10, 12, 14, and 16 ft. A lateral force of 20 kips (4,000 lb × 5 g's) was applied at each of these locations, and the deflections were calculated. Three 7/16-in. × 5-in. rails were first used, having a total cross-section area of 4.69 sq in. Reactions of rail against attenuators and also tension stresses in the rail element were obtained at the same time. The same data were then calculated for three 3/8-in × 6-in. rails, having a total cross-section area of 6.75 sq in. The same attenuator spacings were used. The same 20-kip lateral force was applied at the attenuators' mid-span and quarter-span points.

Two loading cases were considered. In Case I it is assumed all lateral attenuators were snagged and taken out by the vehicle as it moved along the barrier. In Case II it is assumed that only the attenuator at the point of initial contact is taken out, the other attenuators remaining intact.

Graphs showing these data were prepared: 12 graphs for the data based on three 7/16-in. × 5-in. rails, and 12 for the data based on three 3/8-in. × 6-in. rails. Figures 9 through 14 show 12 graphs for the three 3/8-in. × 6-in. rails.

Preparation of like data for two different rails, as described previously, brought to light a definite relationship that exists between any station and each of the other stations in any given case being examined. This means that deflection at each of the other stations may be expressed as a percentage of the deflection at Station 1. The percentage relationship remains the same even though values such as area of rail cross section or lateral force are varied.

A second relationship also was found: If the station interval selected is a certain specific fraction of the attenuator spacing, in all cases the relationship between any station and each of the other stations remains the same no matter what attenuator spacing is selected. This second relationship is evident in Tables 1 and 2, in which deflection is expressed as a percentage of the deflection at Station 1, for various attenuator spacings.

All the values in Tables 1 and 2 were calculated independently. It can be seen that the deflections at Station 5, for example, are approximately 121 percent times the deflection at Station 1, for all attenuator spacings.

The foregoing two relationships are combined in Table 2 by multiplying their ratios together. The table expresses deflection at all stations in terms of the deflection at Station 1, assuming 10-ft attenuator spacing.

Figure 15 shows rail lateral deflection at Station 1, as affected by a range of lateral forces and various rail cross-sectional areas. A 10-ft attenuator spacing is assumed.

The rail deflection for any station can be obtained by multiplying the deflection found in Figure 15 times the multiplier obtained from Table 2, depending on whether Case I or Case II applies. The deflection thus obtained is the deflection due to rail stretch only.

Rail stretch is observed to be the greatest cause of excessive pocketing. A knowledge of the rail deflection due to stretch would assist in predicting the success or failure of a given flexible railing being considered. Of course it must ultimately be added to the attenuator deflection, and to the various other movements of the barrier and the vehicle to find the total deflection of the complete barrier system.

The flexible rail is assumed to be anchored at 100-ft intervals. Several devices exist to compensate for temperature expansion and contraction. They include loosely fitted piston working in a very heavy matrix, such as asphalt or a silicone plastic, or a simple lever anchor arranged so that adjacent rails expand in opposite directions to compensate each other, but act in opposition to give a positive anchor when both are pulled in the same direction. A strong spring device may be used. Other devices now in use are available. Any loss of force due to take-up can be compensated by preloading the rail, as required.

It should be pointed out that anchors to resist longitudinal force on the rails will be required, whether the rails are flexible or rigid. If the attenuators (or any other supports) are not to be a hazard to vehicles, they must be so arranged that they are not able to resist substantial longitudinal force. Therefore, the rail must be able to resist the longitudinal force components by means of anchors.

Rails can be simply anchored with fixed anchors at any convenient interval, allowing temperature stresses to occur. Under the most extreme temperature conditions a maximum temperature stress of 11.5 ksi would occur. If advantage is taken of the 25 percent temperature overstress, a residual tensile stress of 13.5 ksi is available for resisting

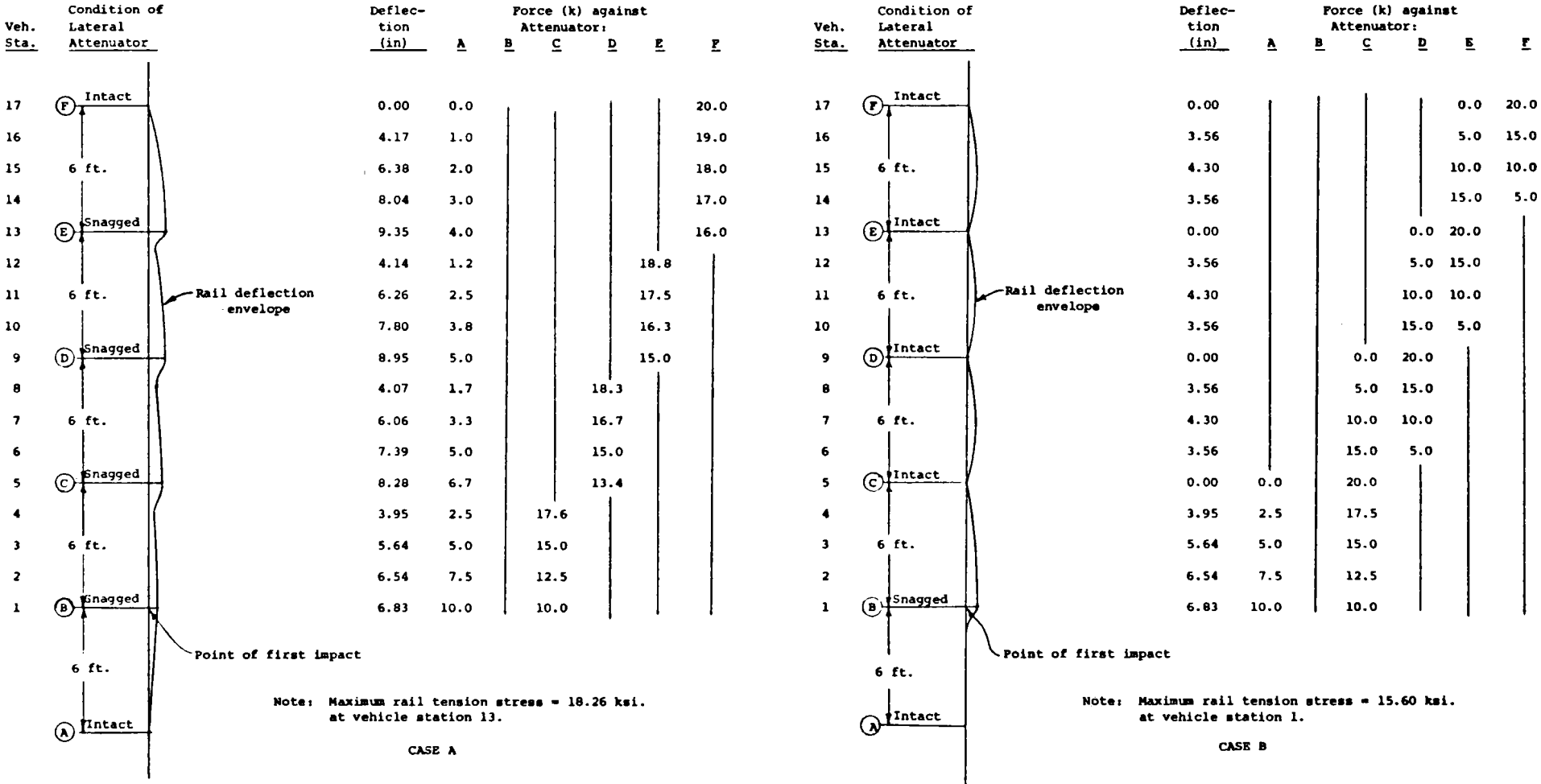
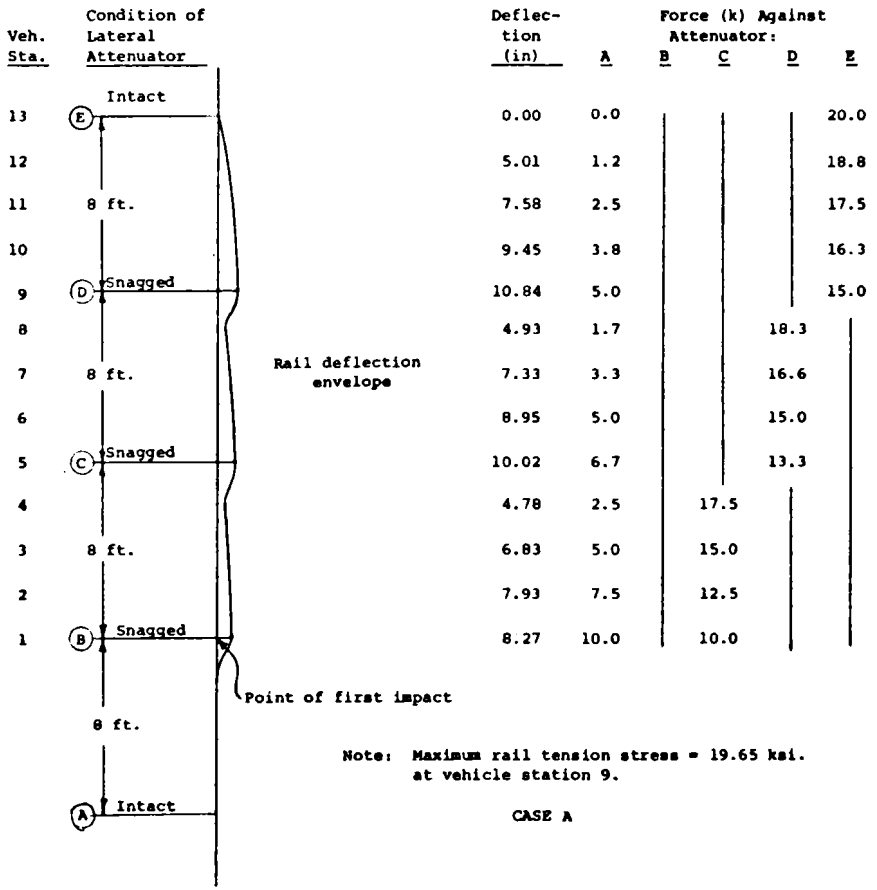


Figure 9. Flexible rail deflection due to stretch (20-kip lateral force at any station). Rail $A_s=6.75$ *in. Six-ft spacing.*



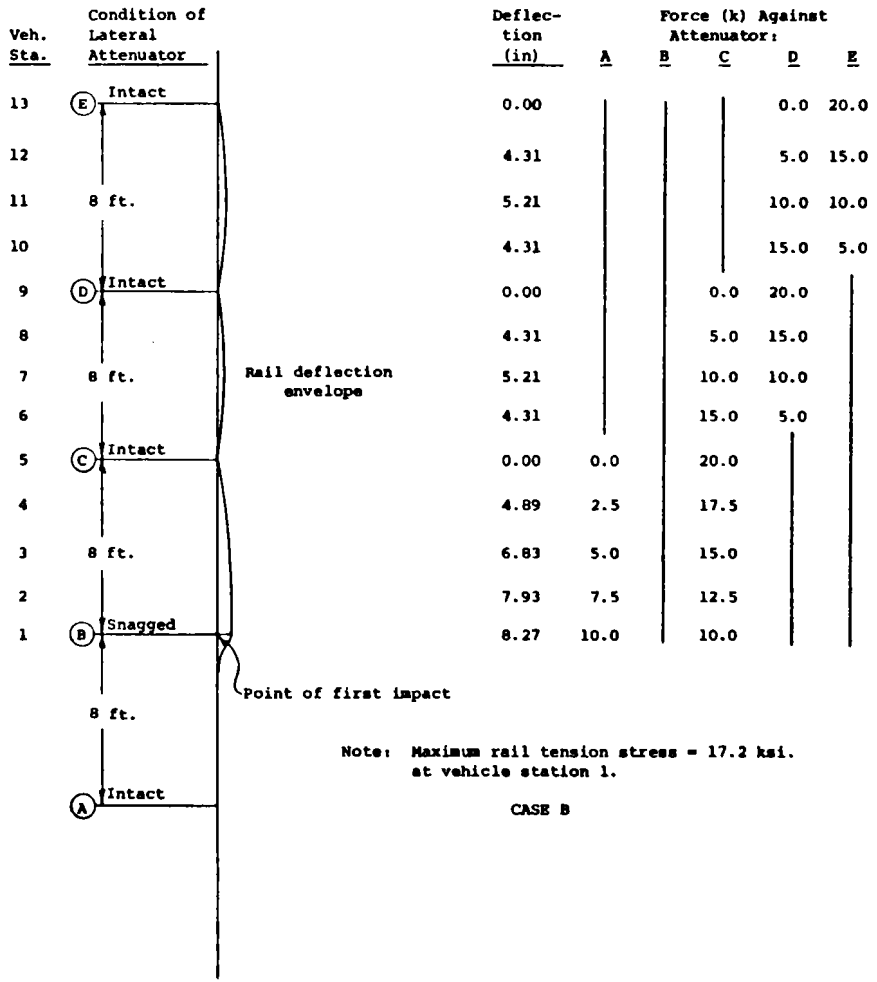


Figure 10. Flexible rail deflection due to stretch (20-kip lateral force at any station). Rail A_s=6.75 in. Eight-ft spacing.

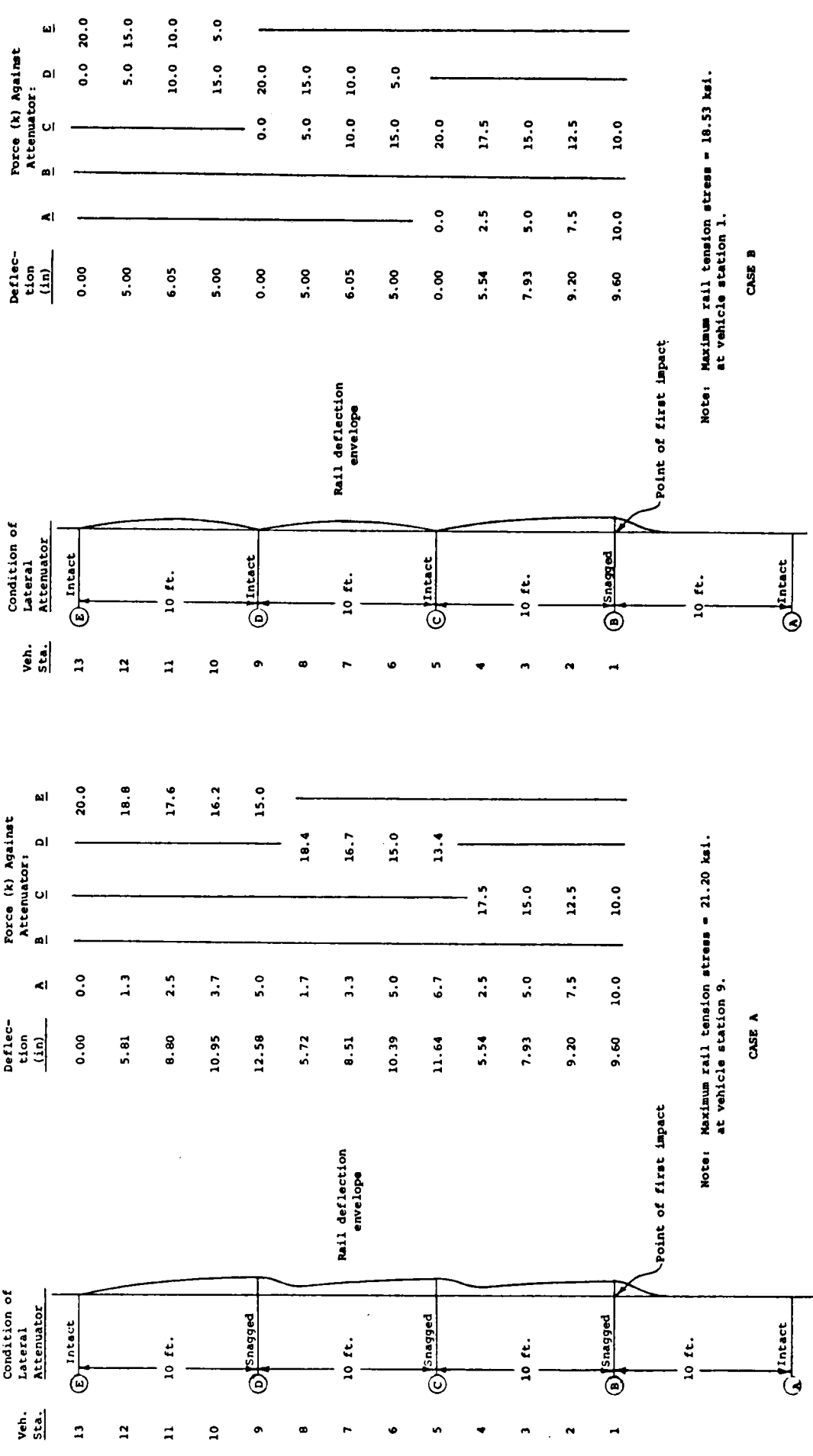


Figure 11. Flexible rail deflection due to stretch (20-kip lateral force at any station). Rail A_s=6.75 in. Ten-ft spacing.

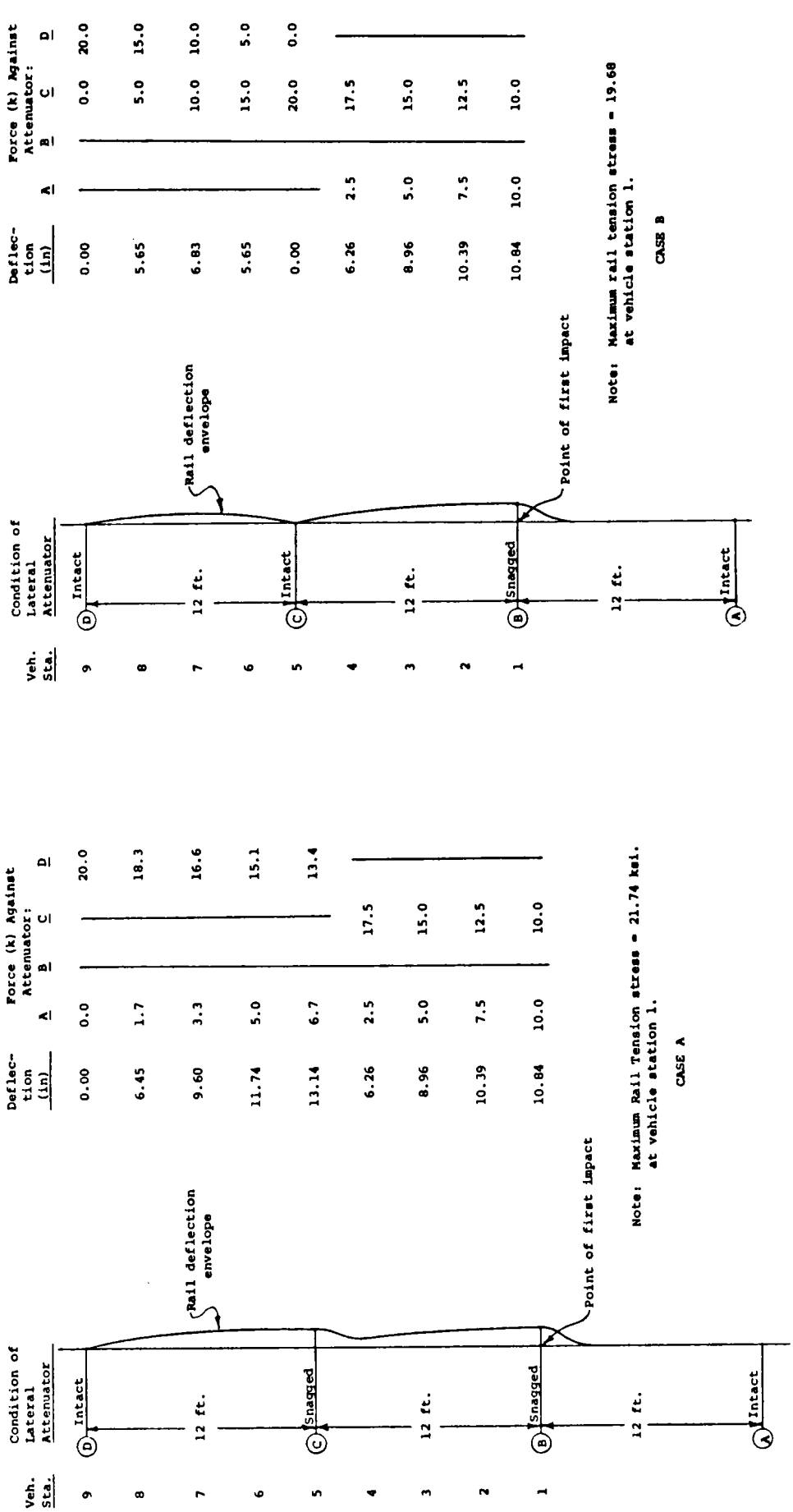
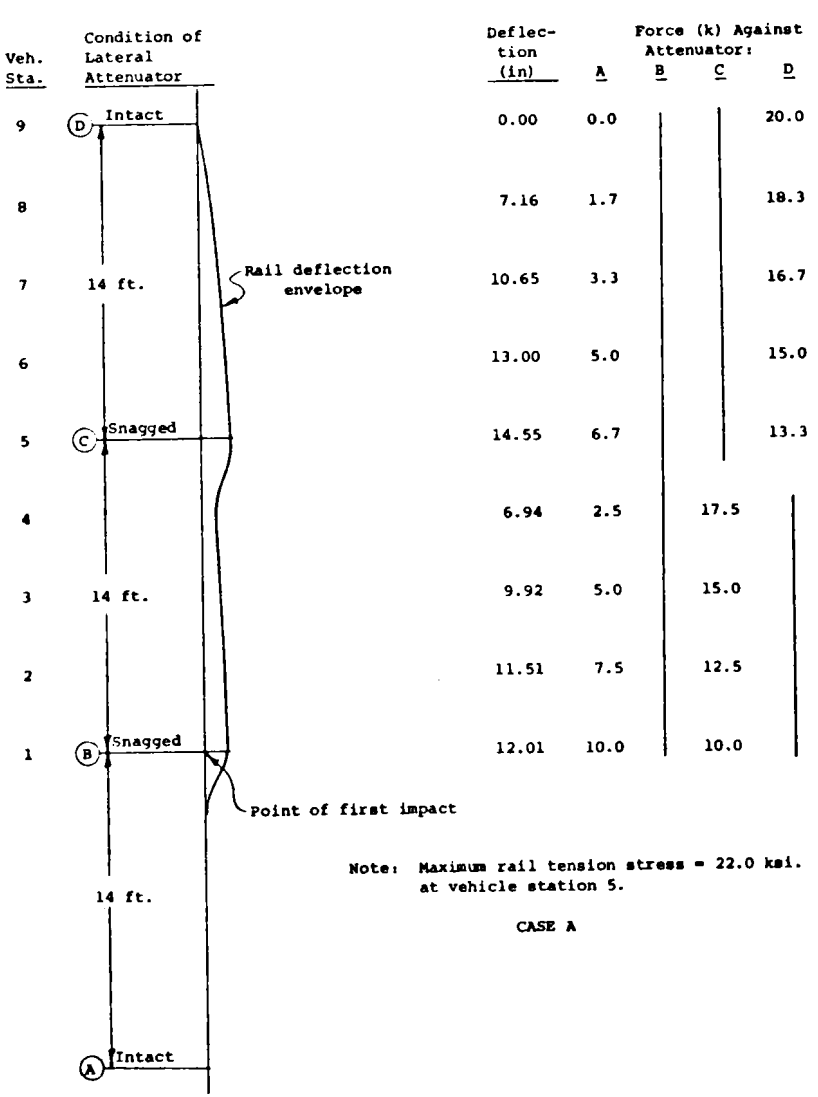


Figure 12. Flexible rail deflection due to stretch (20-kip lateral force at any station). Rail A_s=6.75 in. Twelve-ft spacing.



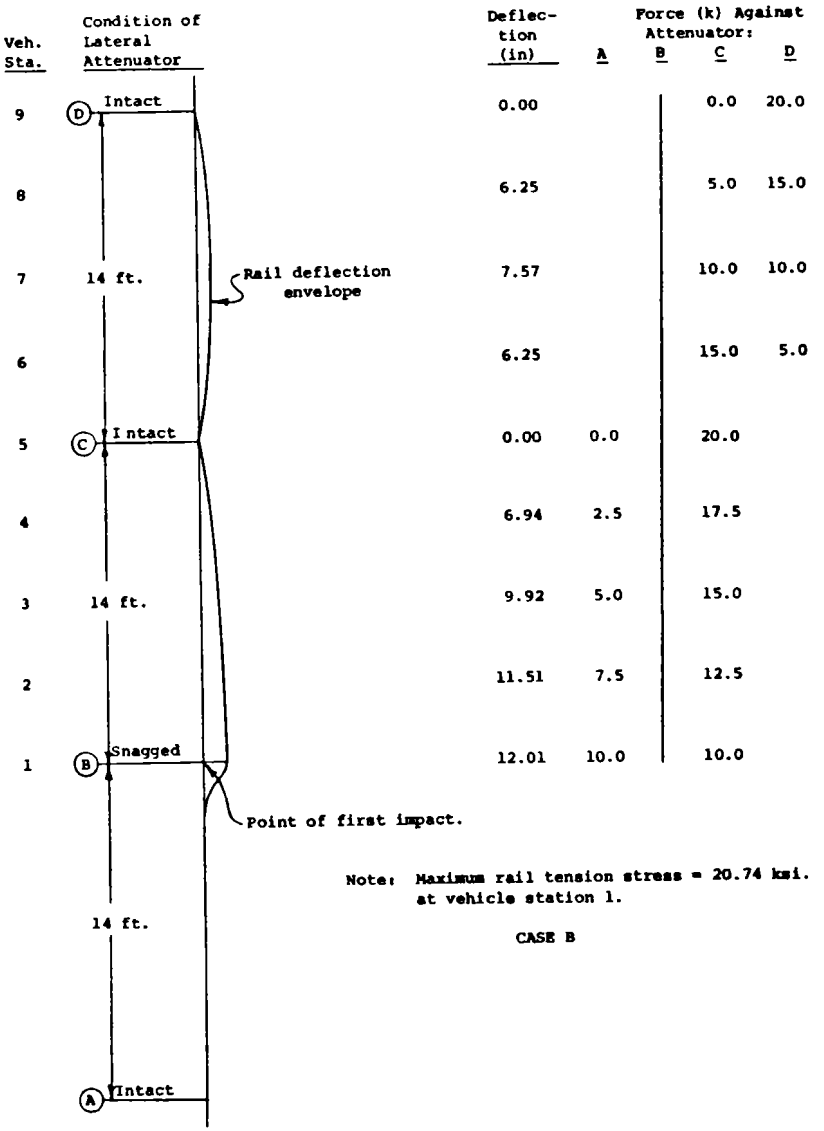


Figure 13. Flexible rail deflection due to stretch (20-kip lateral force at any station). Rail A_s=6.75 in. Fourteen-ft spacing.

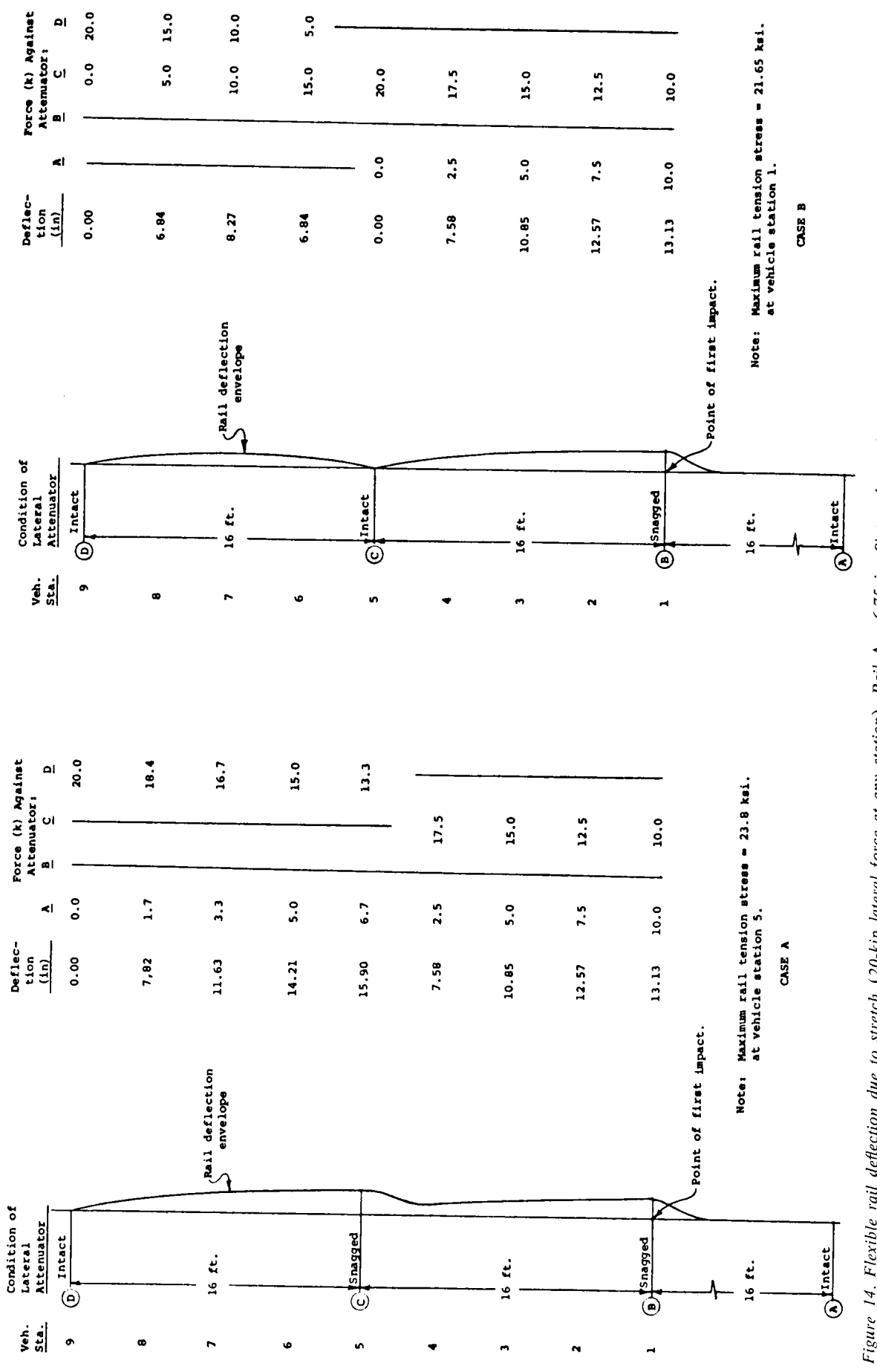


Figure 14. Flexible rail deflection due to stretch (20-kip lateral force at any station). Rail A_s=6.75 in. Sixteen-ft spacing.

TABLE 1

RAIL DEFLECTION AS A PERCENTAGE OF DEFLECTION AT STATION 1

VEH. AT STATION	RAIL DEFLECTION (%) WITH LATERAL ATTENUATOR SPACING OF: 6 FT	8 FT	10 FT	12 FT	14 FT	16 FT
(*a*) Case I: All attenuators encountered assumed taken out						
1	100.0	100.0	100.0	100.0	100.0	100.0
2	94.4	95.7	95.8	95.8	95.8	95.7
3	81.6	82.5	82.8	82.6	82.7	82.8
4	56.9	57.8	57.8	57.7	57.7	57.8
5	119.3	121.3	121.1	121.1	121.2	121.1
6	106.7	108.2	108.2	108.2	108.3	108.2
7	87.2	88.7	88.5	88.7	88.9	88.8
8	58.7	59.7	59.7	59.5	59.7	59.6
9	129.3	131.1	130.9	0	0	0
10	112.7	114.3	114.0			
11	90.4	91.6	91.3			
12	59.8	60.6	60.3			
13	134.8	0	0			
14	116.0					
15	92.0					
16	60.3					
17	0					
(*b*) Case II: Attenuators assumed intact except at Station 1						
1			100.0			
2			95.7			
3			82.6			
4			57.7			
5			0			
6			52.1			
7	←		63.1		→	
8			52.1			
9			0			
10			52.1			
11			63.1			
12			52.1			
13			0			

TABLE 2

MULTIPLIERS TO DETERMINE RAIL DEFLECTION DUE TO RAIL STRETCH IN TERMS OF DEFLECTION AT STATION 1, WITH 10-FT ATTENUATOR SPACING

VEH. AT STATION	MULTIPLIER (%) FOR ATTENUATOR SPACING OF: 6 FT	8 FT	10 FT	12 FT	14 FT	16 FT
(*a*) Case I: All attenuators encountered assumed taken out						
1	66.1	86.2	100.0	112.9	125.0	136.8
2	68.3	82.6	95.8	108.2	119.8	131.1
3	59.0	71.4	82.8	93.5	103.5	113.3
4	41.2	49.8	57.8	65.3	72.3	79.1
5	86.3	104.4	121.1	136.7	151.4	165.7
6	77.1	93.3	108.2	122.2	135.3	148.0
7	63.1	76.3	88.5	99.9	110.6	121.1
8	42.6	51.5	59.7	67.4	74.6	81.7
9	93.3	112.8	130.9	147.8	163.6	179.1
10	81.3	98.3	114.0	128.7	142.5	156.0
11	65.1	78.7	91.3	103.1	114.1	124.9
12	43.0	52.0	60.3	68.1	75.4	82.5
13	96.1	116.2	134.8	152.2	168.5	184.4
14	82.7	100.0	116.0	131.0	145.0	158.7
15	65.7	79.3	92.0	103.9	115.0	125.9
16	43.0	52.0	60.3	68.0	75.4	82.5
17	0	0	0	0	0	0
(*b*) Case II: Attenuators assumed intact except at Station 1						
1	71.3	86.2	100.0	112.9	125.0	136.8
2	68.3	82.6	95.8	108.2	119.8	131.1
3	59.0	71.4	82.8	93.5	103.5	113.3
4	41.2	49.8	57.8	65.8	72.3	79.1
5	0	0	0	0	0	0
6	37.1	44.9	52.1	58.8	65.1	71.3
7	45.0	54.4	63.1	71.2	78.9	86.3
8	37.1	44.9	52.1	58.8	65.1	71.3
9	0	0	0	0	0	0
10	37.1	44.9	52.1	58.8	65.1	71.3
11	45.0	54.4	63.1	71.2	78.9	86.3
12	37.1	44.9	52.1	58.8	65.1	71.3
13	0	0	0	0	0	0

impact if A 36 steel is used; more, if higher strengths are used.

For the rigid rail, a box beam similar to that used by the State of California is to be used. This type of rail has been thoroughly tested and widely used, and additional investigation of it is believed to be unfruitful.

It is planned to vary attenuator spacing from about 16 ft at the beginning of the guardrail portion, or where wide shoulders are available, to 10 ft on bridge decks, or where other restrictions of space exist. If necessary, strength of the attenuators will be graduated, so that the barrier will be more yielding at the ends than it is on the bridge. This, of course, is to compensate for the fact that less space is available for vehicle deceleration on the bridge deck than is available on the roadway shoulder.

The original design (Fig. 1) used three and four rails. These were reduced to two as a result of the literature search. Construction will thus be simplified. Two rails are necessary where an upper and lower plastic hinge form in the attenuator, so that both hinges are made to yield. Two rails are desirable to better retain the wide variety of vehicles encountered.

On curved alignment, centrifugal force on the vehicle makes it possible to encounter the maximum condition of

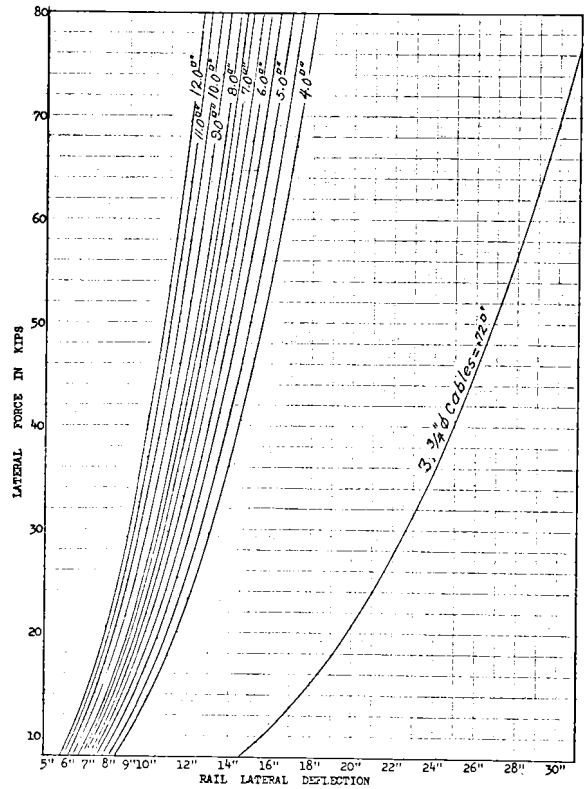


Figure 15. Flexible rail deflection at Station 1. Attenuators at 10-ft spacing.

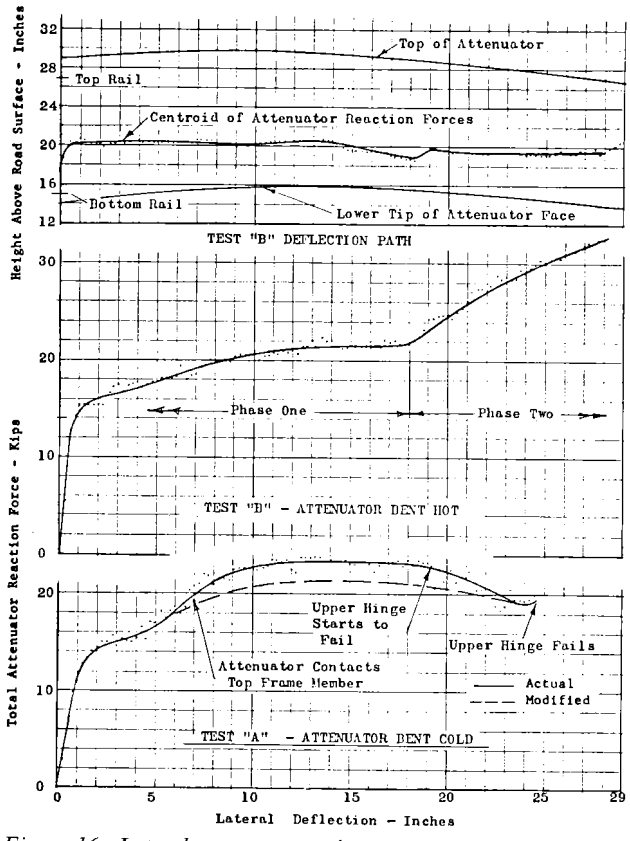


Figure 16. Lateral attenuator performance curves.

loading only on the outside railing. Curvature, therefore, will tend to resist lateral rail deflection.

It should also be noted that a preloading force in the rail, which appears to aid flexible rail performance, can still be used. For example, a 50-ft radius horizontal curve would place the rail on chords having a slope angle of 1:12 with the tangent to the curve. A 50-kip rail prestress force would impose a lateral force of only 8 to 10 kips on each of the attenuators. This would deflect the attenuators only about 1½ in.—still within the elastic range and also within the normal working stress. Obviously, highway curves have a much greater radius of curvature than 50 ft, and the actual lateral force on attenuators would be much less.

Attenuator Studies

The rail support structures are called attenuators rather than posts. Traditionally, posts have been stiff supports made to be as unyielding as possible. By contrast, the proposed attenuator is a moving structural mechanism, designed to yield.

The attenuator design uses plastic steel design concepts, but is principally concerned with the energy absorbed as the steel yields. It is expected to reach yield stress in the first ±2 in. of the deflection process, then to progress through the plastic and into the strain-hardening regions.

Only the energy absorbed in the elastic phase of the deflection cycle will be returned to the vehicle. The energy required to cause strain in the plastic and strain-hardening phases is absorbed. Consequently, the elastic phase was deliberately made as small as feasible by designing the attenuator to be initially rigid. As a result all but approximately 3 percent of the total energy of a vehicle impact is absorbed by the attenuator, and not returned to the vehicle (Fig. 16).

The high-energy-absorbing potential of steel is well known. The relatively high yield stress of steel results in a large resisting force. Its ductility allows yielding over a long distance. The product of a large force acting through a relatively long distance represents a large amount of energy.

The use of steel to absorb the energy of vehicle impacts is not new. Steel barrels and vehicle bodies have served this function. However, the subject device arranges design parameters so they can be determined and controlled with accuracy, allowing more efficient designs. This is the main premise on which the researchers' proposal is based.

The original proposal described a single-phase attenuator, called Type A, and a two-phase attenuator, called Type B. The second phase of the Type B attenuator resulted from the inclusion of a third hinge, which operated only after the attenuator had deflected to the point where its vertical link became horizontal and contacted the bridge deck, or mounting base. In this manner an extension of the deck was created, providing additional space for vehicle attenuation.

A third type was later conceived in response to expressed fears that the barrier might be penetrated unless some type of positive back-up were provided. It, too, had two operating phases, but the second phase was the result of an

additional member positioned in a manner similar to that of a vehicle overload spring.

The attenuator that has evolved incorporates all three of these types in one design. In appearance it resembles the Type A attenuator. The operation of Phase 1 is also similar to that of the Type A attenuator. However, like the Type B attenuator it forms a third plastic hinge, and geometry is such that it operates in two phases.

The second phase provides a positive barrier instead of additional space for attenuation as planned in the original Type B attenuator. The third hinge was widened to increase its strength in place of the separate back-up member of the Type B attenuator. As the attenuator reaches the end of Phase 1 its base contacts a raised portion of the deck. In effect this shortens the attenuator and further strengthens it, through the second phase.

Phase 2 is a barrier, not an attenuator, although it does have energy-absorbing characteristics. All the conditions of the research problem are met during the Phase 1 attenuating cycle. Phase 2 is merely an added back-up device. It will not in any way alter the action of Phase 1.

The fundamental laws of motion specify that a certain distance is required for slowing down the vehicle, if the rate of deceleration is limited. This required distance has been held to an absolute minimum, as described in the following.

Full deflection of the attenuator will bring the vehicle to the edge of the bridge deck or roadway. The barrier will be entirely off the deck at this time. Consequently, all of the bridge deck and roadway are available for use in slowing down the vehicle. No additional deck width is required on which to mount a solid barrier, for the barrier is incorporated in the attenuator. This fact is expected to have an important influence on the over-all cost of providing an attenuating barrier system, for the greatest cost is expected to be in providing additional bridge deck or roadway. Initially, attenuators are designed that will start to yield when the vehicle has reached a point one-quarter the attenuator spacing ahead of them.

The cost of cutting the attenuators from steel plate and bending them, as estimated by a local fabricator, would be:

Steel—114.3 lb @ $0.115	$13.20
Labor—3.3 hr @ $15	50.00
Fifty units—Total cost, each	$63.20
Less 15 percent for mass production, Total	$54.50

If the attenuators were cast from ASTM A 148 steel having good ductility and yield stress of 50 ksi, a local foundry estimates a cost of $0.45 per pound, or approximately $52 each in lots of 1,000 or more. The costs are quoted to show that the proposed barrier can be fabricated at competitive prices. No attempt was made to conduct an exhaustive economic study of the various alternatives available.

To fabricate the attenuators a bending jig had to be constructed. It has a capacity of 620,000 in.-lb, and is capable of cold-bending 2½-in.-thick × 12 in. maximum A 36 steel plate. No such bending equipment is commercially available.

A special frame was constructed to be used in performing static load tests on full-scale attenuators (Fig. 17). The test loads to be used, designed to simulate vehicle impact, place heavy shear loads on the test attenuator; consequently, a heavy shear reaction must be provided by the frame. A frame with very rigid corners is therefore necessary. Existing test frames generally are designed to resist large direct loads, but not large shear loads. None could be found that was equipped to resist the 25- to 30-kip shear loads to be used.

Steel plate 2½ in. thick was purchased, and two attenuators were fabricated. However, in bending them it was discovered that the steel was apparently A 441 steel instead of A 36, as ordered. This necessitated revision of the design, and refabrication of the attenuator to give the required attenuator strength.

Two tensile test specimens were prepared and tested. One of the load-test jacks (which are of the push-pull type) was used for the testing. Tensile test results are given in Table 3. They indicate that the steel is A 441, or the equivalent.

Two 20-ton jacks were obtained, each with its own gauge and hand pump. Special adaptors were machined to screw onto the jack cylinders. These form collars that bear against the testing frame members, or the bending jig. The jacks were mounted on the test frame. Both jacks exert forces simultaneously against the face of the attenuator being tested. By this means the attenuator face is always held in a vertical position as it is moved by the jacks in ¼-in. increments.

It was also possible to calculate the vertical position of the resultant of the two forces exerted by the jacks by simple statics. From mechanics, equilibrium demands that the resultant of all resisting forces in the attenuator must be equal and opposite to the resultant of the two forces exerted by the jacks, and must act at the same point.

The static tests on full-scale attenuators, then, give both the magnitude and the vertical location of the center of resistance of the attenuator at each increment of deflection. If one has this information, the locations and strengths of the three plastic hinges can be adjusted, if necessary, until the resisting force remains fairly constant, and its resultant location remains near the center of gravity of the model vehicle.

The geometry of the attenuator is, in fact, such that its center of resistance is forced to remain between the upper plastic hinge and the lower one, at a fairly constant distance above the roadway surface, in the following way: If the upper rail should be contacted first, the lower hinge would yield because of the long moment arm to the lower hinge and short moment arm to the upper hinge. The face of rail would then rotate clockwise until the lower rail came to bear on the vehicle. If the lower rail should be contacted first, this procedure would be reversed.

Computer analyses were run on the isolated attenuator. Results were encouraging, but seemed to present some unexplained phenomena. The resisting force climbed to 22½ kips in the first 1½ in. of deflection as expected, but then began to decline at a constant rate to 16 kips at 20 in. of deflection. At this point an unexplained drop occurred,

TABLE 3

TENSION SPECIMEN TEST RESULTS

GAUGE (KSI)	FORCE (KIPS)	f_s (KSI)	PIN SPACING (IN.)	STRAIN (IN.)	ELONGATION (%)
		(*a*) Specimen No. 1 [a]			
0.00	0.00	0.00	3.280	0.000	0.00
2.00	8.44	40.00	3.295	0.015	0.47
2.25	9.30	44.20	3.310	0.030	0.94
2.50	10.20	48.30	3.326	0.046	1.43
2.75	11.20	53.00	3.344	0.074	2.31
3.00	12.10	57.30	3.375	0.095	2.97
3.25	13.10	62.00	3.414	0.134	4.18
3.50	13.95	66.10	3.507	0.227	7.08
3.60	14.40	68.40	3.823	0.543	16.95
		(*b*) Specimen No. 2 [b]			
1.00	4.50	14.86	3.280	0.000	0.00
1.25	5.30	17.50	3.281	0.001	0.03
1.50	6.45	21.30	3.283	0.003	0.09
1.75	7.40	24.42	3.286	0.006	0.18
2.00	8.35	27.58	3.288	0.008	0.24
2.25	9.30	30.70	3.289	0.009	0.25
2.50	10.30	34.00	3.292	0.012	0.36
2.75	11.15	36.82	3.293	0.013	0.39
3.00	12.20	40.30	3.295	0.015	0.46
3.25	13.00	42.90	3.298	0.018	0.55
3.50	14.95	49.40	3.302	0.022	0.67
3.75	15.20	50.20	3.311	0.031	0.95
4.00	15.86	52.40	3.323	0.043	1.30
4.25	17.00	56.10	3.336	0.056	1.70
4.50	17.60	58.20	3.368	0.088	2.68
4.75	18.90	62.40	3.401	0.121	3.69
5.00	19.85	65.50	3.445	0.165	5.03
5.25	20.65	68.30	3.558	0.278	8.47
5.40	21.00	69.40	3.628	0.348	10.61
5.40	21.20	70.00	3.698	0.418	12.73
5.40	21.20	70.00	3.768	0.432	14.90
5.40	21.20	70.00	3.838	0.588	17.00

[a] Diameter = 0.519 in.; cross-sectional area = 0.2116 sq in.
[b] Diameter = 0.621 in.; cross-sectional area = 0.3029 sq in.

which may have been due to theoretical yielding of the attenuator portion next to the anchor bolt, or of the anchor bolt itself.

After consultation with G. H. Powell it was concluded that analysis of the complete barrier system should not be attempted until attenuator performance had been verified by physical testing. The attenuator appears to have a number of variables and some unknowns that combine to make it indeterminate.

Bending is in a region rather than at a specific point. This bending region also varies in width and, therefore, in strength as a result of taper. As the attenuator deforms, its shape and the relative positions of the plastic hinges change constantly.

Elastic behavior of the connecting links between plastic hinges cannot be predicted accurately. Lengths are not known with certainty because of the uncertainty of hinge locations. The links are tapered in width and so vary in stiffness.

The location of the neutral plane in the region of the plastic hinges is known to be strongly influenced by the tight curvature of the attenuator at that location. Because the attenuator is thick in relation to its over-all size, variation in the location of the neutral plane has a significant effect.

Dimensions of the attenuator were simplified for ease of fabrication and it does not necessarily lend itself to straightforward analysis.

The need for full-scale physical testing had not been anticipated. It soon became evident that the physical testing was to become a major portion of the research. Considerably more effort and a longer period of time were required than were expected.

The physical testing of two attenuators was done with the test frame and jacks described earlier. One attenuator had been fabricated by cold-bending in the bending jig that had been built for the purpose. Its mode of deflection is shown in Figures 17 through 19, designated Test A.

The cold-bent attenuator test was made to determine whether fabrication by cold-bending is feasible, and to find out the extent to which cold-bent joints could be strained. It is believed that attenuators can be formed while cold more economically than if heating is used. If large quantities are manufactured, bending machines can be developed for the purpose, and their cost can be justified.

The cold-bent attenuator, Test A (Fig. 20), performed very well through Phase 1 and therefore has satisfactorily accomplished the objectives outlined in the problem statement. The performance curve climbs rapidly to a resisting force of 15 kips in the first 2 in. of deflection, then climbs slowly through the next 22 in. of deflection to a value of approximately 21 kips. Note that the deflection curve shape is similar to that of a tension specimen stress-strain curve.

About 4 in. beyond Phase 1, at a total deflection of 24 in., the strain in the upper hinge proved too great, and failure occurred (Fig. 19). Strain in the upper hinge during lateral deflection of the attenuator is of the same sign as that occurring when this hinge region was cold-bent, and is therefore additive. Total strain has exceeded the ability of the material to elongate. In the two lower hinge regions, where bending during deflection is opposite to the cold-bending during fabrication, and where bending is not as severe, no suggestion of distress could be found.

Test A established the fact that cold-bending can be successfully used in fabricating attenuators. But, if it is used, it is recommended that the upper hinge region be annealed after fabrication. Heating of the upper hinge should be relatively easy, for it is only approximately 2 in. × 1½ in. in cross section.

Straightening deflected attenuators for re-use probably should be accomplished with the aid of heating, also.

Figure 17. Cold-bent attenuator mounted for Test A. $\Delta = 0$ in.

Figure 18. End of Phase 1. $\Delta = 20$ in.

It can be seen that the top of the Test A attenuator contacted the test frame through much of the deflection cycle. This, of course, introduces friction of an unknown magnitude. Two deflection curves are shown in Figure 16 for Test A: the locus of the actual test values, and a modified curve in which the maximum resisting force is arbitrarily made to be 2 kips less than the measured force. The modified curve is believed to represent the approximate true deflection curve of the Test A attenuator, had it not contacted the top of the test frame.

The cold-bent attenuator Test A curve shows slightly greater strain-hardening than does the hot-bent attenuator tested subsequently in Test B, as evidenced by the increase in force required to deform it (Fig. 16 and Table 4).

The failure of the upper hinge probably could have been delayed by a slight amount of grinding to remove case-hardened steel from the flame-cut sides, in the areas in tension. Cracks were observed forming in these flame-cut areas early in the deflection process, but did not appear to progress any deeper than ⅛ in. beneath the outer surface, at least until deflection had progressed well past the end of Phase 1, when the upper hinge began to yield disproportionately preliminary to failing.

The Test B attenuator was fabricated by hot-bending (Fig. 21 and Table 5). By making tests on both cold-bent and hot-bent attenuators it has been possible to compare performance of the two under static loading. From these

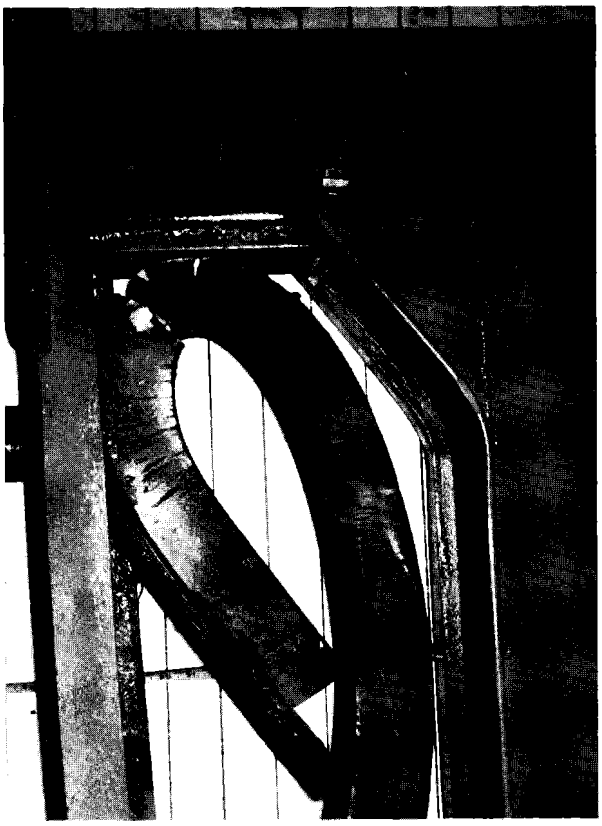


Figure 19. Cold-bent attenuator, Test A. Upper plastic hinge fails suddenly at 4 in. past Phase 1. $\Delta = 24$ in.

TABLE 4

FORCE REQUIRED TO DEFLECT COLD-FORMED ATTENUATOR, TEST A

DEFL. (IN.)	FORCE APPLIED (KIPS) UPPER JACK	LOWER JACK	TOTAL	DEFL. (IN.)	FORCE APPLIED (KIPS) UPPER JACK	LOWER JACK	TOTAL
0	0.0	0.0	0.0	13	11.8	12.0	23.8
1	1.8	9.3	11.1	14	13.1	10.3	23.4
2	2.2	12.0	14.2	15	12.7	10.3	23.1
3	1.8	12.5	14.3	16	13.1	10.1	23.1
4	3.2	12.4	15.6	17	13.1	10.1	23.2
5	5.0	12.0	17.0	18	13.1	10.4	23.5
6	6.7	11.9	18.6	19	13.1	10.1	23.3
7	9.7	11.0	20.7	20	13.7	9.7	23.4
8	11.2	9.7	20.9	21	12.1	9.7	21.8
9	10.9	11.3	22.2	22	14.5	5.9	20.4
10	10.6	12.0	22.6	23	15.4	3.4	18.8
11	12.9	10.7	23.6	24	17.6	1.8	19.4
12	10.9	11.5	22.4				

static tests an insight has been acquired into the kind of performance that probably can be expected from each type in actual use.

The deflection modes of Test B attenuator are shown in Figures 22 through 24. The attenuator exhibited great ductility (Fig. 25). No cracks or any other indication of possible trouble could be found. It is believed that the total strain in the hot-formed upper hinge region is about half that of the Test A cold-formed upper hinge.

As was done during Test A, gauge readings were made for both the upper and lower jacks at each ¼-in. increment of displacement. In this way the total resisting force (the sum of the jack forces) was obtained at each interval and the location of the resultant of these two forces was calculated (Fig. 16).

Through the whole deflection cycle the location of the resultant reaction force was observed to remain close to a height of 20 in. above the roadway (Fig. 26). This agrees reasonably well with the findings during Test A. However, because the Test A attenuator had contacted the top of the test frame, the Test A findings are not considered reliable as far as location of the resultant above the roadway is concerned.

Barrier Performance Predictions

The data resulting from the attenuator force-deflection tests were submitted to G. H. Powell, who idealized the proposed traffic barrier and analyzed it according to the Barrier IV computer program. Results of this analysis are discussed herein. The mathematical model used operates

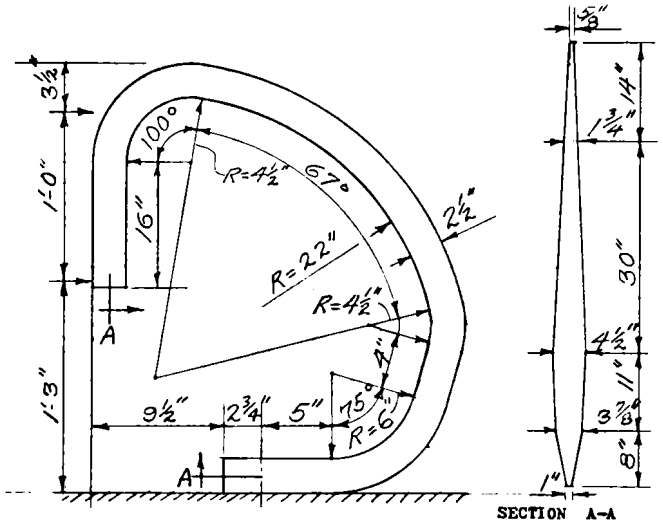


Figure 20. Cold-bent attenuator, Test A.

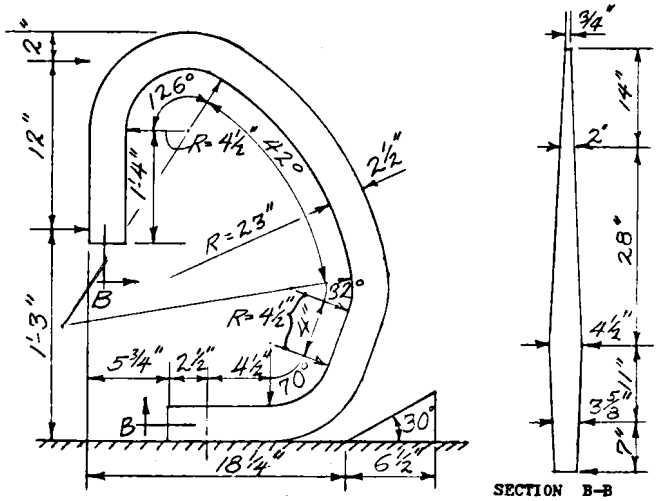


Figure 21. Hot-bent attenuator, Test B.

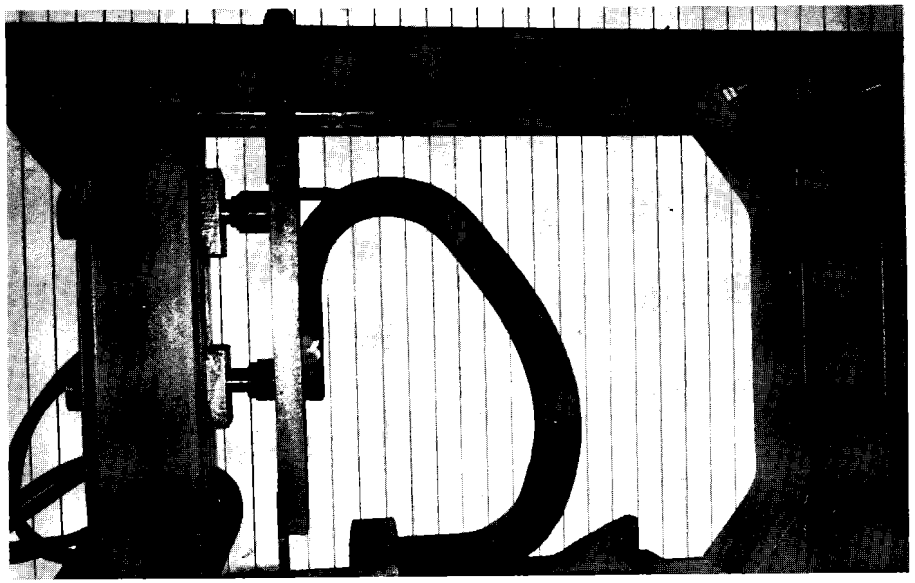


Figure 22. Hot-bent attenuator mounted for Test B. $\Delta = 0$ in.

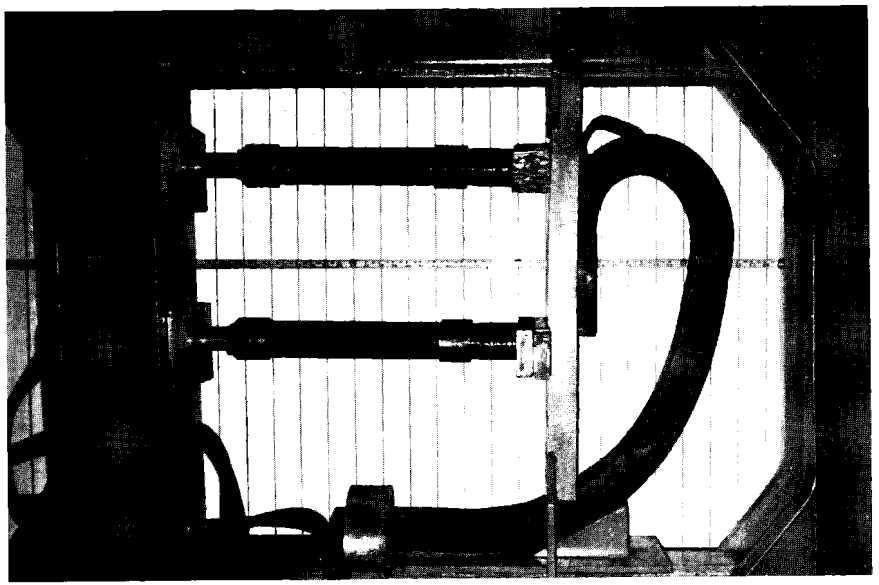


Figure 23. End of Phase 1. $\Delta = 20$ in.

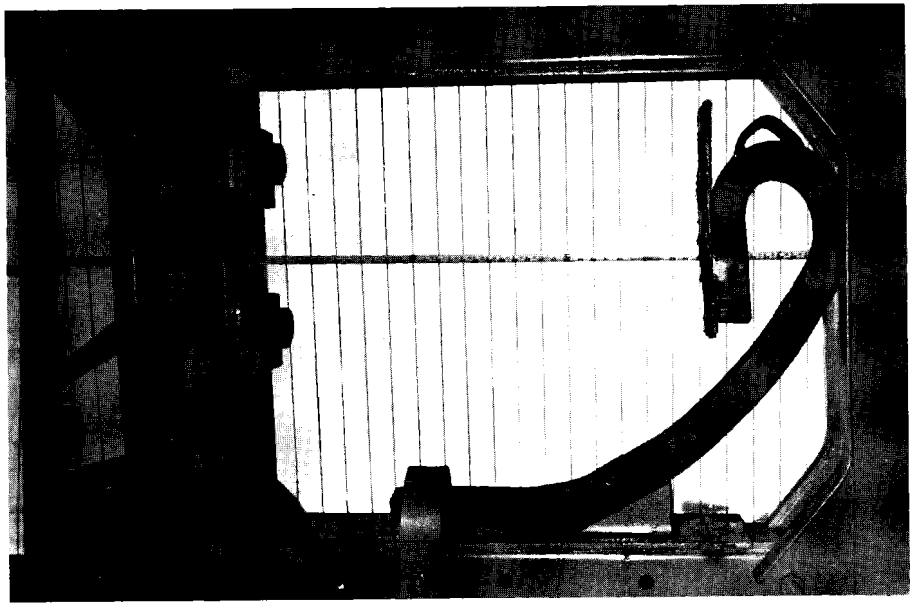


Figure 24. Attenuator at end of Test B. Note that rail face will be three lines (6 in.) inside of guide plate shown.

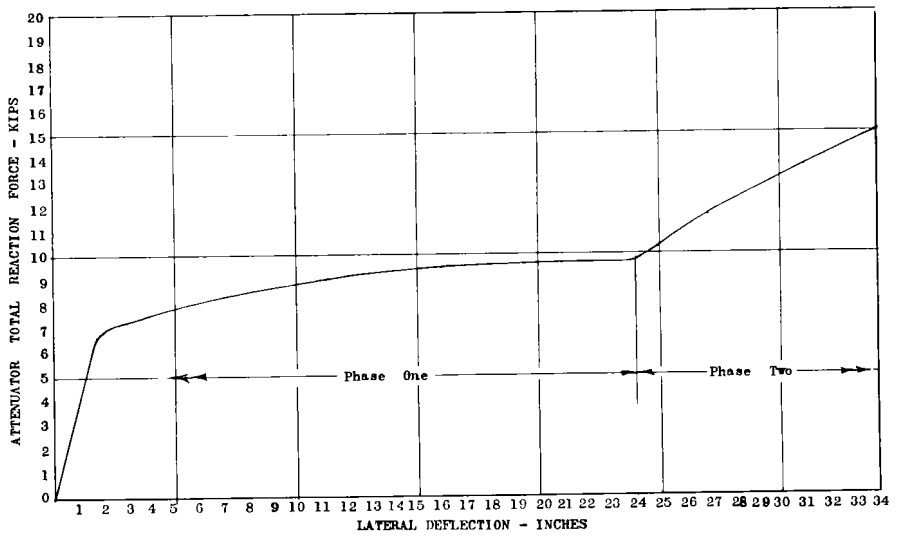


Figure 25. Prototype attenuator performance curve calculated from Test B data.

TABLE 5

FORCE REQUIRED TO DEFLECT HOT-FORMED ATTENUATOR, TEST B

DEFL. (IN.)	FORCE APPLIED (KIPS) UPPER JACK	LOWER JACK	TOTAL	DEFL. (IN.)	FORCE APPLIED (KIPS) UPPER JACK	LOWER JACK	TOTAL
0	0.0	0.0	0.0	15	7.0	14.5	21.5
1	6.2	9.2	15.4	16	6.4	15.0	21.4
2	5.7	9.7	15.4	17	6.4	15.5	21.9
3	7.0	10.7	17.7	18	5.4	16.4	21.8
4	7.4	10.4	17.8	19	8.3	16.0	24.3
5	6.8	11.0	17.8	20	8.3	16.4	24.7
6	6.8	11.4	18.2	21	8.3	17.9	26.2
7	7.4	11.3	18.7	22	8.5	18.8	27.3
8	8.3	11.8	20.1	23	8.8	19.9	28.7
9	7.4	13.0	20.4	24	8.5	20.4	28.9
10	7.9	12.7	20.6	25	9.0	21.0	30.0
11	8.8	12.0	20.8	26	9.7	21.3	31.0
12	8.8	12.2	21.0	27	10.8	21.0	31.8
13	9.4	12.7	22.1	28	10.6	22.0	32.6
14	9.4	12.7	22.1	29	15.4		

in a horizontal plane, using a structural mechanism of many parts, appropriate to the case being analyzed.

Seven different types of structural member may be specified, in any combination. These are: beams, springs, ideal columns, viscous damping links, friction damping links, and posts. Two- and three-dimensional elements are not available, but can be simulated by equivalent lattices of bars.

Complex non-linear modes of behavior can be assigned to the structural members, and hysteresis effects in yielding members are taken into account. Bilinear elastic-plastic behavior is assumed for all members.

The vehicle is idealized as a rigid body of arbitrary shape surrounded by a cushion of discrete inelastic springs.

The barrier must possess a clearly defined interface, or series of interfaces, along which interaction with the vehicle takes place.

Although they have limitations, the programs are believed to be as sophisticated as is justifiable at the present time.

The attenuators were found to exert a dominant influence on the performance of the barrier system as a whole. Therefore, actual physical testing was performed on the attenuator to determine its deflection characteristics. These tests have produced data much more accurate than any assumptions that could have been made. The resulting computed barrier performance predictions should be reliable.

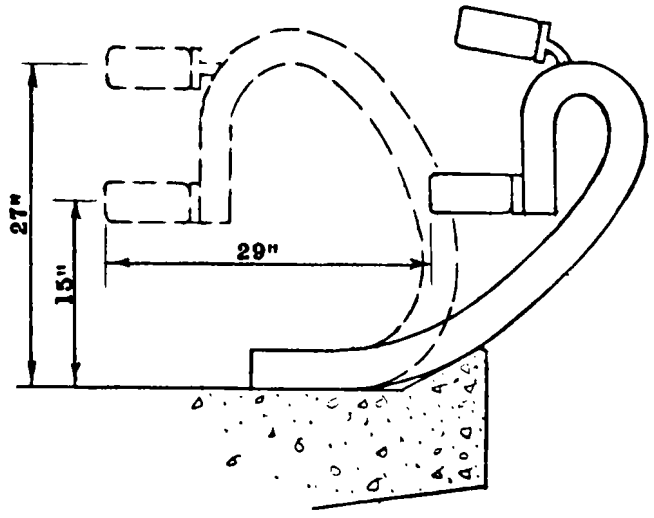


Figure 26. Test B attenuator, initial and deflected.

Cases 1 through 5

Barrier Idealization.—Five cases were analyzed. In each case an 80-ft length of barrier was considered, with attenuators at either 16-ft centers (Cases 1, 2) or 10-ft centers (Cases 3, 4, and 5). For Cases 1 through 3, a flexible rail of two 6-in. × ½-in. flat bars was assumed; for Cases 4 and 5 a flexurally stiff rail of two 3-in. × ¼-in. rectangular tubes was assumed.

Figure 27A is a plan showing a typical idealization. The attenuators were represented by inelastic links joining the rail to rigid posts. The rail was assumed to be rigidly connected to the attenuator. The force-deflection relationship assumed for each attenuator is shown in Figure 27B. A member with this relationship was obtained by placing three coulomb damping links in parallel, as shown in Figure 27C. Longitudinal anchors, represented by posts, were assumed at each end of the 80-ft length of rail.

The properties assigned to the rails were as follows:

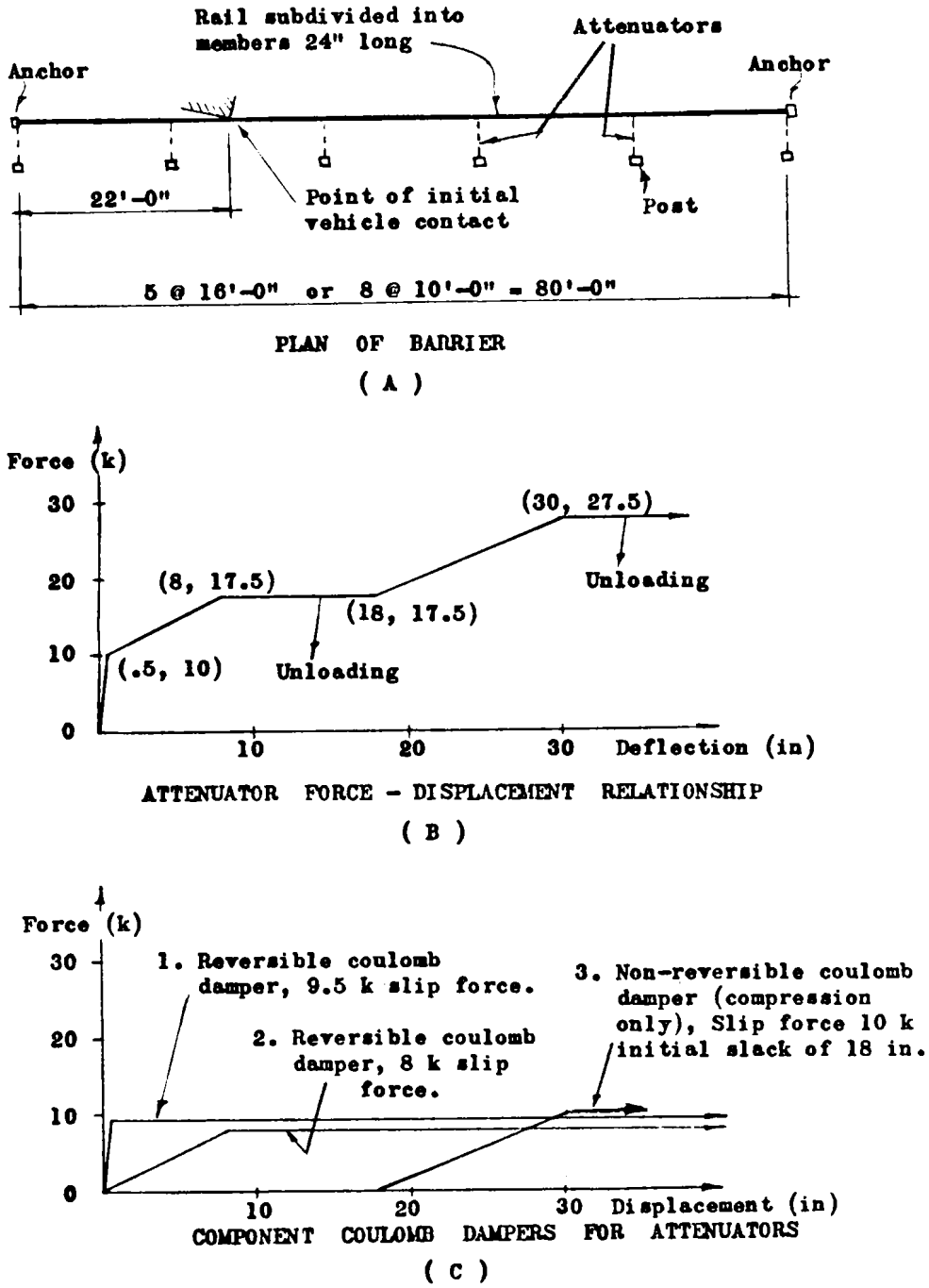


Figure 27. Barrier idealization for computer analysis.

1. Flexible rail: $I = 0.125$ in.^{4}; $A = 6$ in; $E = 30{,}000$ ksi; yield moment = 20 kip-in. The axial force to cause yield was assumed to be very high (1,000 k), so that the required strength to avoid yield could be determined. It is assumed that axial yield in a flexible rail should be avoided.

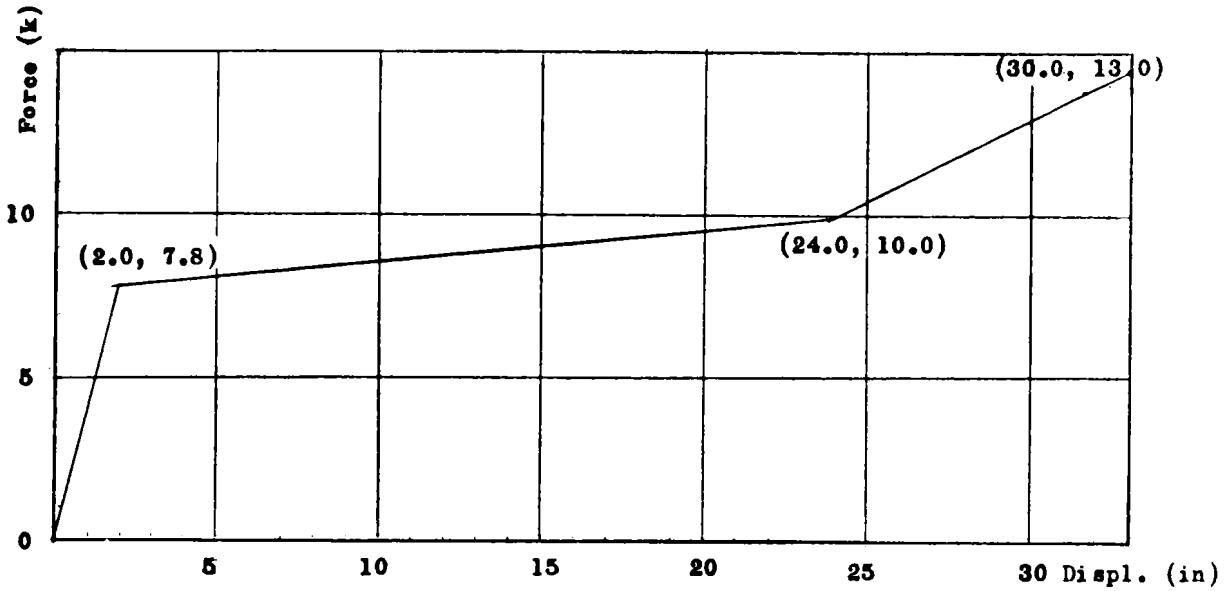
2. Stiff rail: $I = 34.8$ in.^{4}; $A = 8.08$ sq in.; $E = 30{,}000$ ksi; yield moment = 513 kip-in.; yield force = very high.

The automobile was assumed to weigh 4,500 lb, with a moment of inertia of 43,000 lb in. sec^2. The automobile size and the stiffnesses assumed for the springs around its boundary were similar to those assumed in the report, "Computer Evaluation of Automobile Barrier Systems." * A coefficient of friction of 0.6 was assumed between the automobile and the barrier rail. The initial automobile velocity was 65 mph at 25° to the barrier. The point of initial impact was 22 ft from one end of the barrier in all cases (Fig. 28).

The following parameters were selected for the five cases:

1. *Case 1.* Flexible rail. 16-ft centers. Anchor stiffness, 50 k/in.

* By G. H. Powell, Dept. of Civil Engineering, Univ. of California, Berkeley (Aug. 1970).



FORCE-DISPLACEMENT CURVE

Case 6: Flexible rails, 2 @ 6" x 5/8"; Cross-sectional area = 7.5 "
Anchor stiffness = 75 k/in. Rail prestress = 50 k.
Attenuator spacing = 10 ft.

Case 7: The same as for case 6, except that attenuator spacing = 16 ft.

Case 8: Stiff rail: $I = 34.8$ in^4, $A = 8.08$ in^2, yield moment = 513 k. in, yield force = very high. Attenuator spacing = 10 ft.

Figure 28. Assumptions for prototype attenuator analysis.

2. *Case 2.* Flexible rail. 16-ft centers. Anchor stiffness, 1,000 k/in.

3. *Case 3.* Flexible rail. 10-ft centers. Anchor stiffness, 50 k/in.

4. *Case 4.* Stiff rail. 10-ft centers. Anchor stiffness, 50 k/in.

5. *Case 5.* As for Case 4, but attenuator strengths reduced to two-thirds of the values in Figures 9 and 10.

An anchor stiffness of 50 kips per inch is believed to be reasonable. It is unlikely that a stiffness of 1,000 kips per inch can be achieved in practice. Longitudinal anchors are essential to the action of flexible rails, as they depend on suspension cable effects to span between attenuators. Anchors are not essential to the basic actions of a stiff rail but are necessary to resist the large longitudinal forces that are transmitted to the rail by friction.

Results.—Case 1. The results for sideways (relative to the automobile axis), longitudinal, and resultant deceleration of the automobile at its centroid are shown in Figure 29. The most noticeable feature of the computed response is that the longitudinal deceleration reaches a high peak of 12.2 g at 0.90 sec. At about this time the computer output indicated that the automobile was approaching an attenuator. The barrier rail had deflected by 17 in. at a distance 4 ft back from the attenuator, but the attenuator displacement was only 4 in. That is, the computer analysis predicted a tendency for the automobile to pocket into the flexible rail. The analysis did not predict actual pocketing, and the automobile moved past the attenuator, but the deceleration level appears to be excessively high, and pocketing *might* occur in a prototype test. The decrease in deceleration following the peak is believed to result from the fact that the barrier velocities exceed those of the automobile temporarily, because of the shock load imposed on the barrier, and hence the barrier moves away from the automobile for a short period of time. Typical results from the analysis are given in Table 6.

Case 2. The decelerations for Case 2 are shown in Figure 30. The anchor for this case is much stiffer than for Case 1, and the predicted behavior is improved. The computer analysis still predicts a pocketing tendency, and the computed peak decelerations are still high. Typical results are given in Table 6.

Case 3. The decelerations for Case 3, with a closer attenuator spacing, are shown in Figure 31. The results differ in form from those for Cases 1 and 2, but the conclusions are essentially the same—namely, that there is a *tendency* to pocket, and that the peak decelerations are high. Typical results are given in Table 6.

Case 4. The decelerations for Case 4 are shown in Figure 32. The sideways decelerations are similar in magnitude to those with the flexible rail, but the pocketing tendency is greatly reduced, and hence the longitudinal and total decelerations are less severe. Typical results are given in Table 6.

Case 5. The decelerations for the case with the reduced attenuator strength are shown in Figure 33. It is interesting that although the computed decelerations are reduced, the reductions are proportionately less than the reduction in attenuator strength. Typical results are given in Table 6.

Discussion of Results.—The analyses predict consistently larger barrier deflections for the cases with a flexible rail than those with a stiff rail, as is to be expected. The attenuator displacements are also larger for the flexible rail, and in all of Cases 1, 2, and 3 the most heavily loaded attenuator is deformed beyond 18 in., into the Phase Two region. In Case 4, with the stiff rail, the attenuator does not enter Phase Two. However, the deformation again exceeds 18 in. for the weakened attenuator in Case 5. The attenuator deformations are smaller with the stiff rail because of its greater ability to distribute load over a number of attenuators.

Although the peak deceleration values for the cases with flexible and stiff rails are not greatly different, the cases with flexible rails exhibit high peaks in longitudinal deceleration, indicating that pocketing may occur in prototype tests. Flexible rails must also be fixed at their ends by stiff anchors which are able to resist substantial forces.

Conclusion.—The analyses indicate that it should be possible to construct an effective barrier with the attenuators. Before testing, however, further analyses should be carried out to determine the most suitable combination of attenuator strength, attenuator spacing, and rail strength and stiffness.

It should be emphasized that the analysis does not attempt to determine the suitability of the connections of the rail to the attenuator, or of the attenuator to the bridge deck or roadway. The design of such details can be checked only by prototype testing.

(Adjustments were made to the proposed design, and further analyses were made. Results follow, for Cases 6, 7, and 8.)

Cases 6, 7, and 8

Barrier Idealization.—A different attenuator characteristic was noted. It is assumed that a physical attenuator with these characteristics can be produced. Anchors for the flexible rail are assumed to have a stiffness of 75 kips per inch. The rail is to be prestressed with a 50-kip force, and rail area is increased to 7½ sq in. Otherwise, parameters are unchanged.

1. *Case 6.* Flexible rails, 2 at 6 in. × ⅝ in. Anchor stiffness, 75 k/in. 50-kip rail prestress. Attenuator spacing, 10 ft.
2. *Case 7.* Same as for Case 6, except that attenuator spacing is 16 ft.
3. *Case 8.* Attenuator spacing, 10 ft. Rail is stiff. All parameters are the same as for Cases 4 and 5, but attenuator characteristics have been changed to provide less lateral resistance, and more lateral displacement.

Discussion of Results.—Deceleration levels and other behavior were similar in all cases. Deceleration rates were maintained at a more constant rate than for the first five

TABLE 6

COMPUTED PREDICTIONS OF BARRIER PERFORMANCE

CASE	ATTEN-UATOR	MAX. DISPL. (IN.)			MAX. FORCE (KIPS)		CONTACT	DEPARTURE		PEAK DECEL. (G)			MAX. DECEL. (G) [b]		
NO.	SP. (FT)	BARRIER	ATTEN-UATOR	RESIDUAL BARRIER	ATTEN-UATOR	ANCHOR-AGE	TIME (SEC)	VELOC. (MPH)	ANGLE [a] (°)	LATERAL	LONGI-TUD.	RESULTANT	LATERAL	LONGI-TUD.	RESULT-ANT
1	16	31	27	22	24.4	92	0.39	35.7	1.8	6.3	12.1	13.4	5.0	6.3	8.0
2	16	22	21	16	19.2	200	0.30	37.4	2.5	7.1	11.2	13.1	5.5	6.0	8.5
3	10	30	22	21	20.2	80	0.34	35.0	2.8	8.1	11.6	12.6	4.8	6.9	8.2
4	10	19	18	16	17.5	34	0.28	36.6	3.9	8.0	9.5	11.4	6.0	6.4	8.7
5	10	24	24	21	14.6	39	0.32	36.1	4.1	7.3	8.6	10.3	5.4	6.2	8.4
6	16	27	23	15	9.9	129	0.31	37.5	12.7	6.7	7.9	9.7	5.4	5.8	8.0
7	10	32	29	18	12.3	132	0.37	37.6	11.6	6.4	7.8	9.1	5.1	5.4	7.4
8	10	28	27	26	11.1	41	0.33	35.6	13.5	7.9	7.8	9.4	5.1	5.8	7.7

[a] Angle at loss of contact. Vehicle had rotational velocity in all cases, such that angle increased with time after departure in Cases 1 through 5, but decreased with time in Cases 6 through 8.
[b] Averaged over a 200-millisec period; allowable = 5 g lateral, 10 g longitudinal, 12 g total.

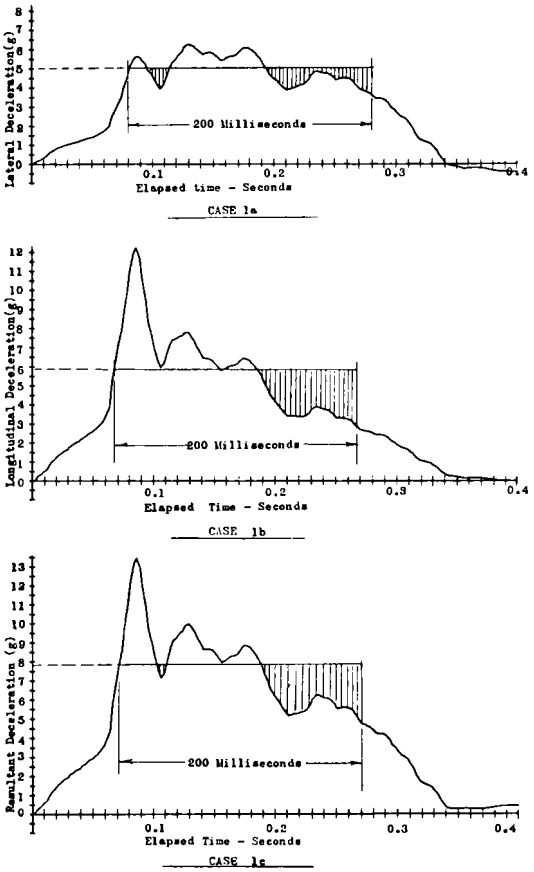


Figure 29. Completed deceleration curves, Case 1.

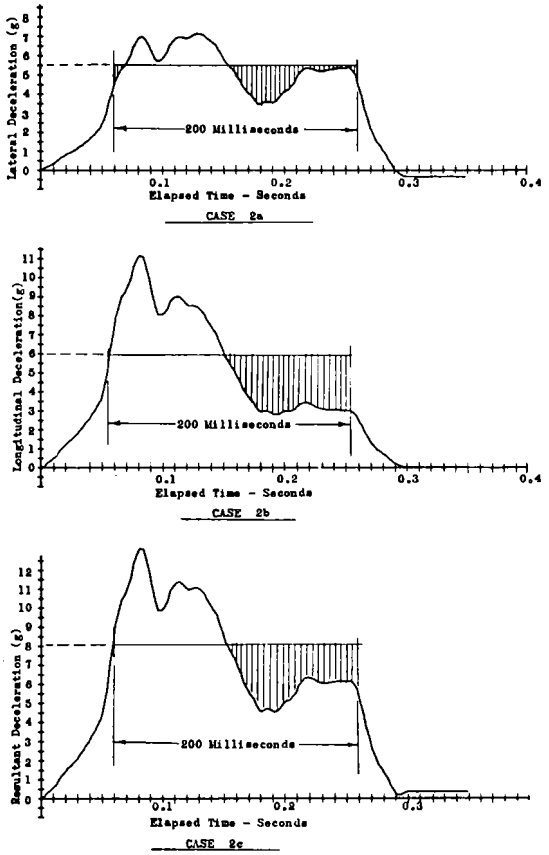


Figure 30. Completed deceleration curves, Case 2.

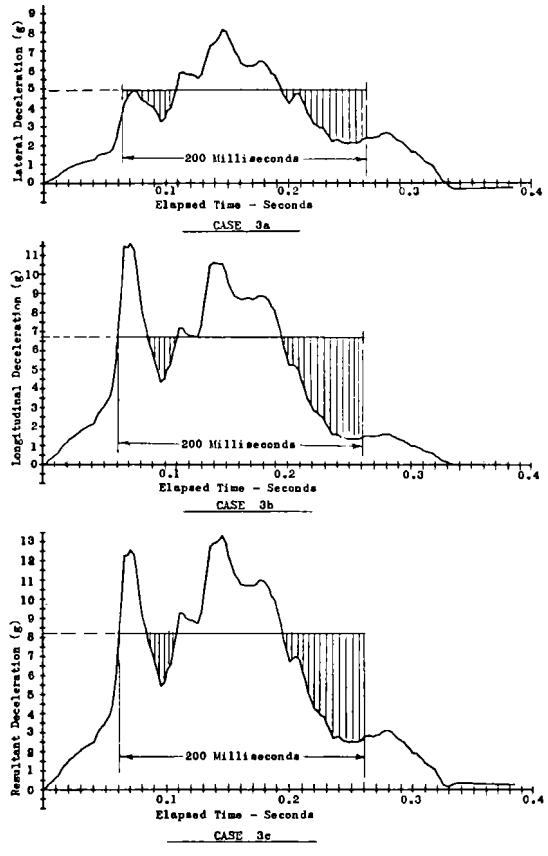


Figure 31. Completed deceleration curves, Case 3.

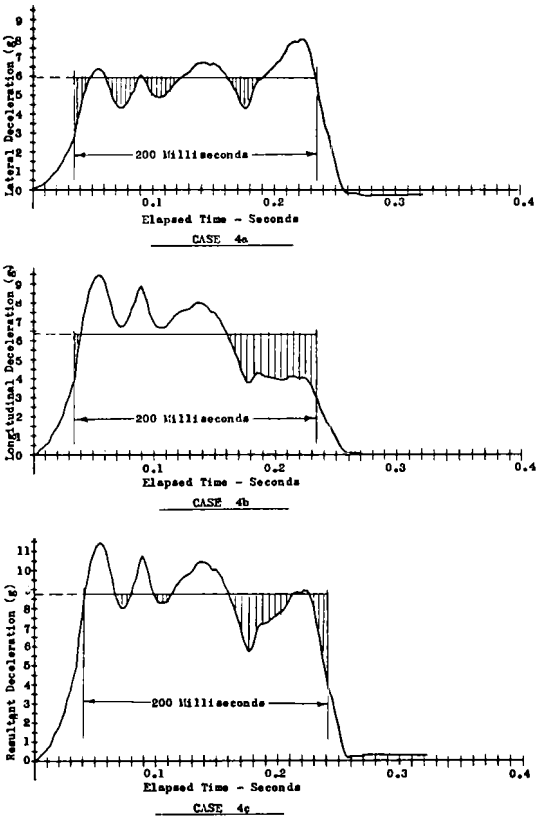


Figure 32. Completed deceleration curves, Case 4.

cases, and this is probably desirable. Attenuators deformed into stage 2 in Cases 7 and 8; most in Case 7, as is to be expected. Analysis indicates the pretensioned flexible rail in Case 6 is somewhat superior to the stiff rail in Case 8, having smaller displacement. The residual displacements are smaller for the flexible rail because the prestress force tends to return the rail to a straight configuration (Figs. 34, 35, and 36 and Table 6).

Departure angles are substantially larger than for Cases 1 through 5. Factors that cause departure angles to change are complex, involving the normal and frictional force magnitudes and their lever arms with respect to the vehicle centroid. Time variation of these forces in Cases 6 to 8 were different from Cases 1 to 5; hence, it was not unreasonable that different departure angles were computed.

Analysis cannot predict reliably what happens to the vehicle after departure from the rail, because this depends on damage to the suspension as much as to the departure angle. It warrants noting that angles were predicted to increase (i.e., angular velocity was counterclockwise) after departure in Cases 1 to 5, and to decrease (angular velocity was clockwise) in Cases 6 to 8. This implies the auto will swerve away from the barrier in Cases 1 to 5, and swerve toward it in Cases 6 to 8. Note such predictions are not reliable, as stated previously.

Conclusion.—Cases 6 to 8 exhibit superior characteristics. Prototypes with parameters in this range should be studied.

Conclusions and Suggested Research

Investigations indicate that the proposed attenuating traffic barrier successfully meets all the objectives in the problem statement.

Lateral deceleration is held to the specified 5 g, and longitudinal and resultant decelerations are about five-eighths their prescribed maximum value. The center of resistance of the barrier remains the same distance above the roadway as the center of mass of the average vehicle throughout the attenuation cycle. These factors indicate successful vehicle attenuation.

Unusually smooth deceleration curves are obtained, indicating high efficiency and consequent space saving. The barrier does not require space, for it deflects out of the way. It is believed the proposed design accomplishes the desired attenuation in the minimum space possible, thereby effecting economy. The barrier first cost appears to be competitive, and maintenance should be minimal. Where the flexible rail is used, rail damage would be slight, and repair would consist of unbolting the deflected attenuator and bolting a new one in. Deflected attenuators can be reformed and used again. Stiff rails can be straightened in place.

By greatly increasing rail area cross section, predicted pocketing has been decreased to an acceptable amount. When a preload force was added to the flexible rail, performance even better than that of stiff rails was predicted.

The departure angle is influenced by the interaction of a number of forces and the instant at which each acts, and therefore varies somewhat. Computer predictions showed that angles as flat as 2° can be obtained, given the correct parameters, although increasing the first-phase displacement seemed to increase the departure angle to as much as 13°. Some experimentation appears to be indicated.

Approximately 95 percent of the impact energy is absorbed by the attenuator, and is not returned to the vehicle. This indicates that lateral acceleration due to the barrier reaction should be minimal, and the true path of the vehicle mass center should be at a relatively flat angle. The fact that the smallest departure angles were increasing and the largest angles were decreasing indicates that the vehicle probably would follow a departure course between 2° and 13°—say around 8°.

A "soft" barrier such as this will inflict minimal damage to the front suspension, allowing good post-impact control.

It is recommended that prototype barriers be constructed and subjected to full-scale vehicle impacts. Both the rigid-rail barrier and the flexible-rail barrier should be tested, as each shows promise. A flexible-rail barrier having fixed anchors at 80- to 100-ft centers, designed to resist the temperature stress build-up, appears to be the most promising. It is believed that prestress force in the rail is not necessary. However, should it prove to be required, prestress force can be employed to assure satisfactory performance.

Prestressed flexible-rail barriers were shown by computer analysis to perform as well as or better than rigid-rail barriers. This introduces the possibility of using prestressed flexible rails on the bridges as well as on shoulders. The flexible rail having a prestress force should be tested, even though the flexible rail without prestress proves adequate.

The proposed barrier is a functional design, and the requirements for vehicle attenuation appear to be compatible with good architectural shapes and proportions.

Attenuators can be successfully fabricated by flame cutting and either hot-bending or cold-bending, although the upper hinge should be annealed if cold-formed. Casting attenuators using maleable steel would prove economical, and would allow considerable variation in shape, for greater efficiency.

Several alternative types of traffic barriers show promise for future research. To keep costs at a bare minimum, the single-round-rail alternative, such as Proposal No. 1, Figure 37, seems to be worth investigating. If it should prove to be thoroughly effective, cost would be minimal. It appears likely, however, that a slightly more sophisticated system using two rails, such as the system selected for the prototype, will be required because of the great variation in vehicles to be encountered.

An opportunity exists to combine the advantages of the New Jersey type of barrier with the attenuating capability of the proposed barrier. A method of doing this is shown in Proposal No. 2, Figure 37. For flat angles of incidence, this barrier should deflect vehicles in much the same manner as the solid New Jersey barrier. It would have the added function, however, of cushioning vehicles coming in at angles between 7° and 25°.

Many locations exist where a guardrail mounted on a retaining wall would be desirable. Proposal No. 3, Figure 37, shows how this could be done using the same structural mechanism that was used in the prototype barrier.

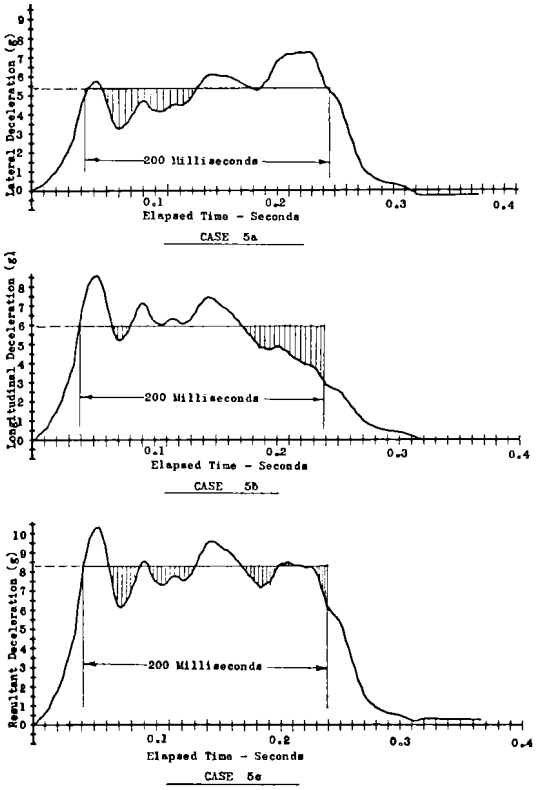


Figure 33. Completed deceleration curves, Case 5.

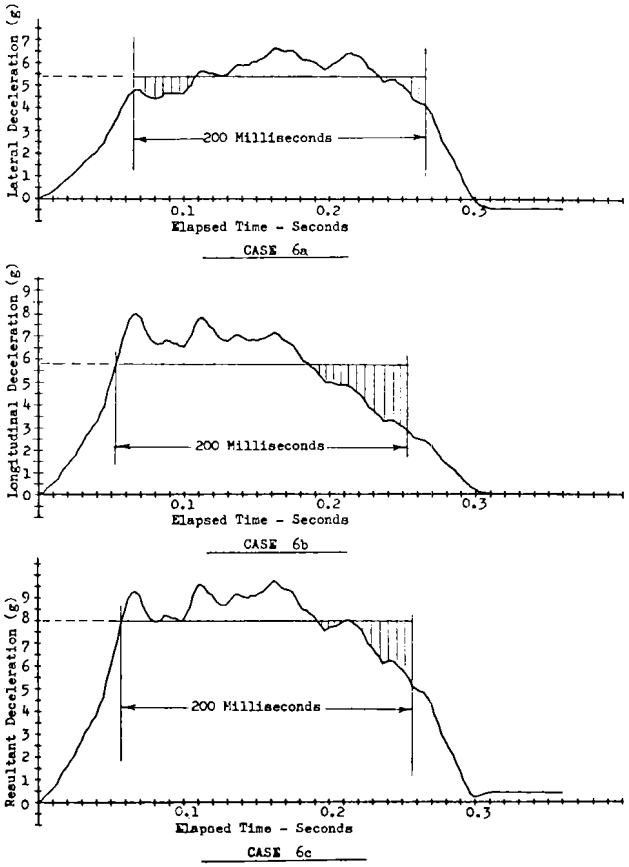


Figure 34. Completed deceleration curves, Case 6.

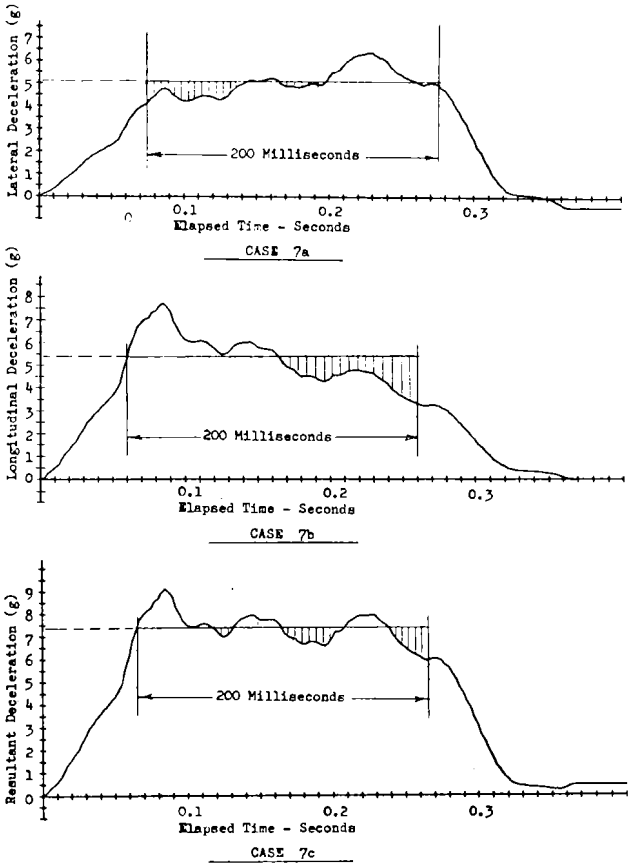


Figure 35. Completed deceleration curves, Case 7.

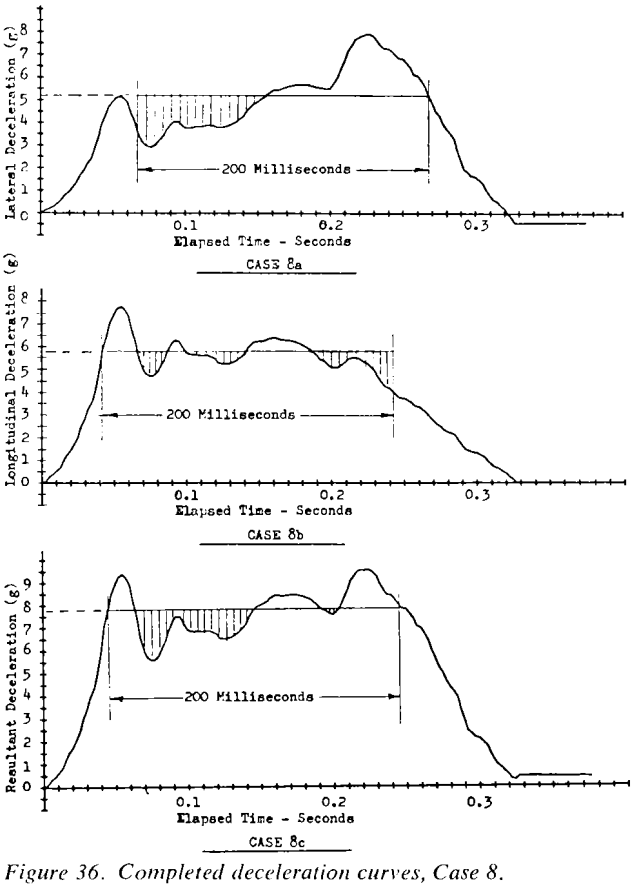


Figure 36. Completed deceleration curves, Case 8.

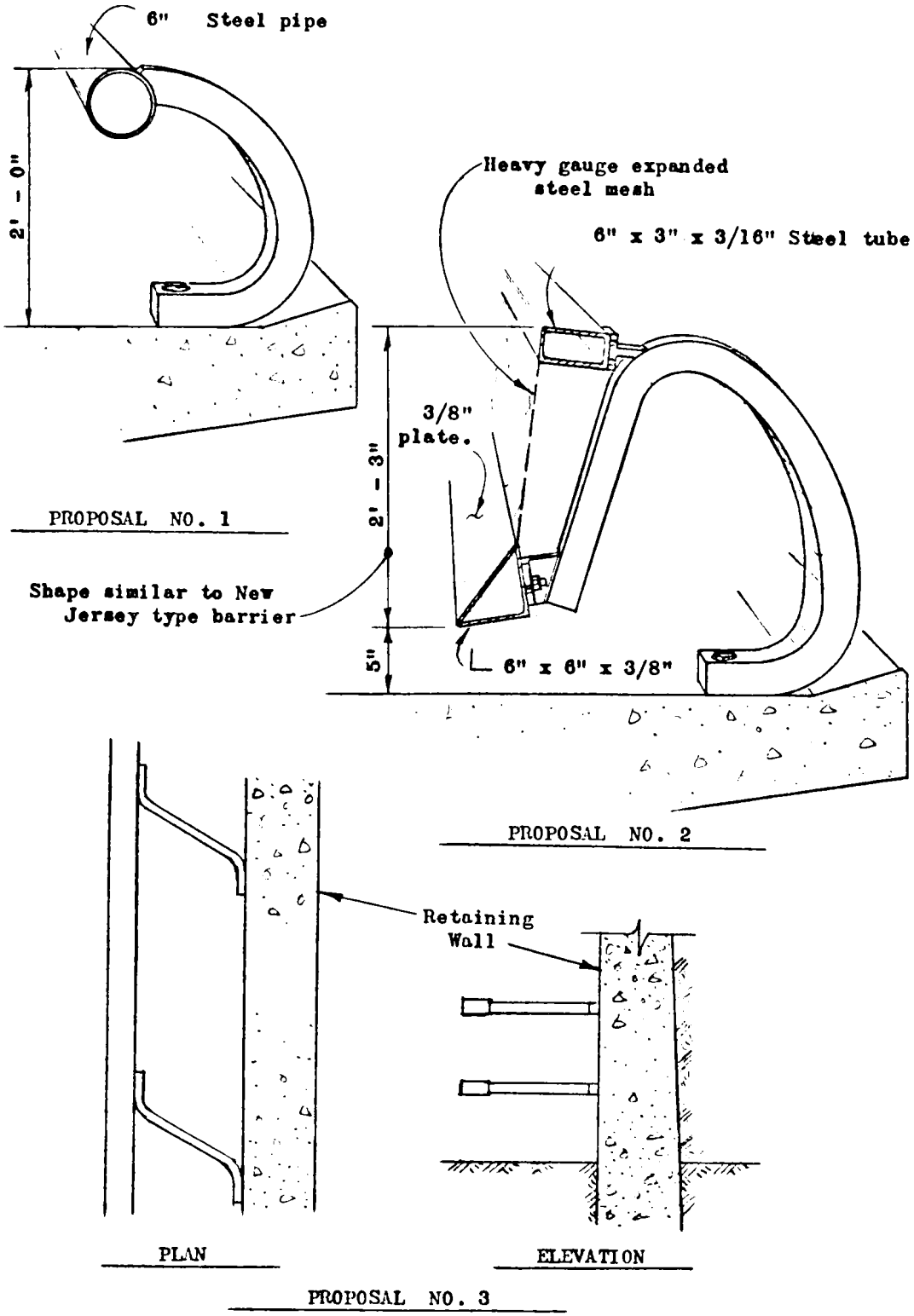


Figure 37. Traffic barrier types recommended for further investigation.

Fabricating methods should be investigated further to determine the most economical, effective attenuator and the most successful rail mountings. The casting of attenuators of relatively high yield stress, ductile steel, such as ASTM A 148 class 80–50 steel, shows great promise. Not only are per pound prices competitive, but greater latitude in shapes is possible and structural efficiency should be improved.

Strong horizontal curvature should affect barrier performance in this, as in all other types of barrier. After the proposed barrier has been proven for straight rails, the investigation of curvature influence seems appropriate.

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