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Summary of
Progress thru
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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

SUMMARY OF PROGRESS THROUGH DECEMBER 31, 1969

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

**SUMMARY OF PROGRESS
THROUGH DECEMBER 31, 1969**

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HIGHWAY RESEARCH BOARD
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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 Bureau of Public Roads, 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 objectivity; 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 DECEMBER 31, 1969

INTRODUCTION

The National Cooperative Highway Research Program (NCHRP) was established in June 1962 to provide a continuing program of highway research. The NCHRP is sponsored by participating member departments of the American Association of State Highway Officials (AASHO), in cooperation with the Bureau of Public Roads (BPR), U. S. Department of Transportation. 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 these research problems and agree to their support before they can be brought into the program.

Chairmen of NCHRP advisory panels and members of the NCHRP Advisory Committee then review the yearly program to see if it is acceptable for administration by the National Academy of Sciences (Academy) through the Highway Research Board (HRB) of its National Research Council.

Once accepted, the problems making up the program are divided among appropriate advisory panels, each having a number of sections that advise on the technical aspects of specific subject areas of research. Members of these sections 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. The advisory panels 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 agency's research plan.

The research findings are published in a special NCHRP report series. Each highway administrator receives a copy immediately upon publication, and some 4,000 copies are normally distributed through the Highway Research Board's selective distribution system.

Quarterly reports of progress are furnished to the Program sponsors on a calendar-quarter basis. The first three were published in *Highway Research News*; the fourth was not published; but all subsequent to the fourth have been. Altogether, 27 reports have been presented to the NCHRP sponsors. In all of these, the project descriptions are ar-

ranged within each major subject area of research. The fiscal year in which a project first received approval is shown by the "FY" date following the project number. If a project began under one fiscal year program and was continued under another fiscal year program, both FY dates are shown.

Although the quarterly reports constitute the primary means for keeping the sponsor informed of all administrative and technical progress, the Program in 1966 began publishing an annual summary of progress for the fiscal year through each June. Beginning with the 1969 issue, however, each document pertains to the preceding calendar year in order to present more up-to-date information that will remain current for a longer period of time. This fourth issue covers the Program from its inception through December 31, 1969, and illustrates just how the AASHO has placed projects in the Program.

In 1969 the Program received its eighth group of research problems. Approximately 160 research projects have resulted from these eight groups, and their broad areas of concern range from administration to maintenance as evidence of the sponsor's immediate interest in acquiring answers at an early date to the many acute problems facing highway administrators and engineers. The ninth group of research problems (FY '71 program) will be received early in 1970.

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 description 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 Administration.
- The chairmen of operating committees under AASHO's Standing Committee on Standards.
- The Executive Committee of AASHO.
- The Federal Highway Administrator.

The many problems received from these sources each year are then forwarded to AASHO's Research Activities Committee for consideration during the Association's fall

meeting. This committee *screens each problem* to determine:

- If the 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.
- The scope, extent, estimated cost, and time schedule for completion of research into proposed problems.

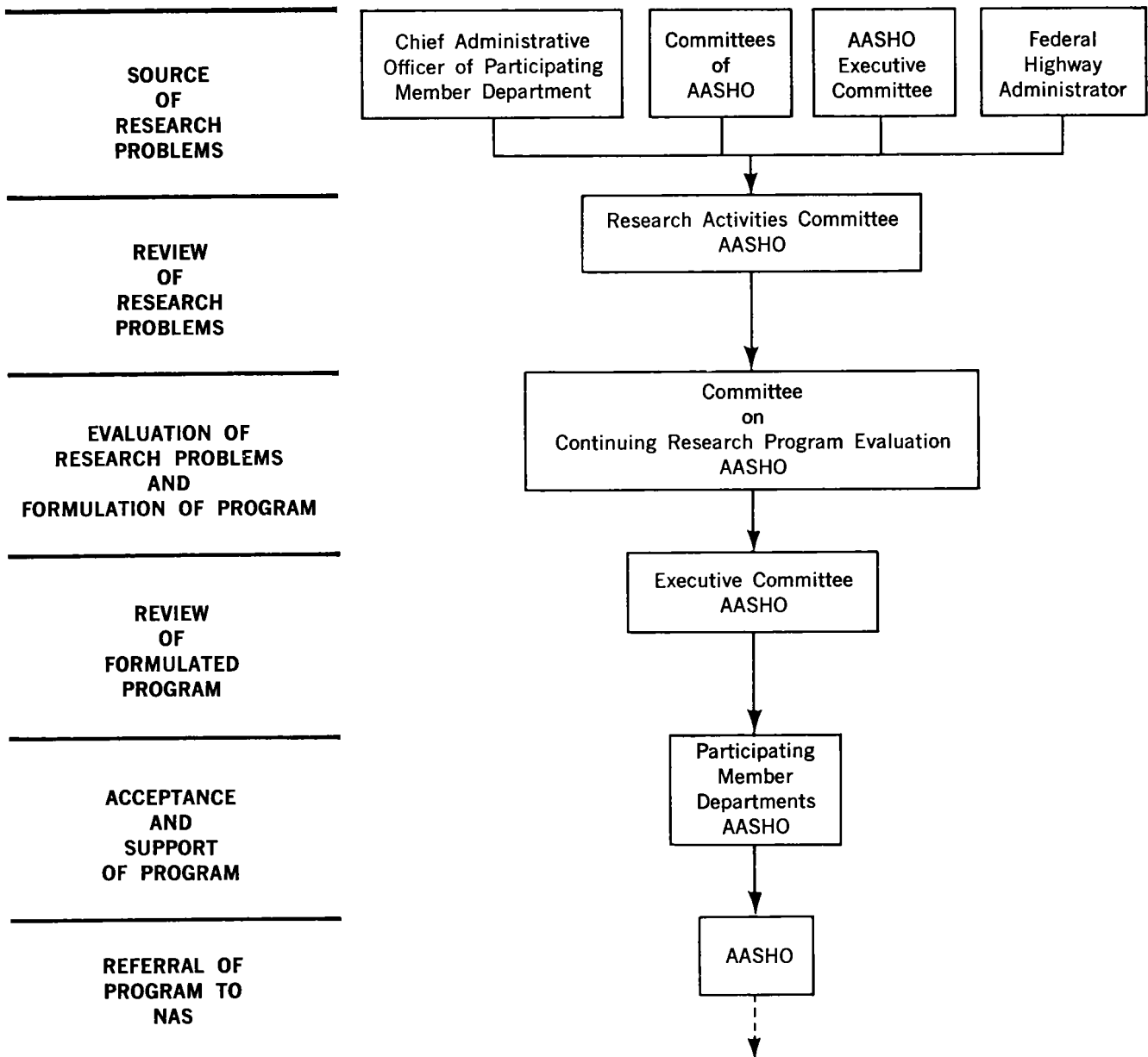


FIGURE 1

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

After this screening process, the problems that remain are sent to AASHO's Committee on Continuing Research Program Evaluation for *program development*. This committee meets each spring to:

- Screen the research problems to see if similar efforts are already under way or if satisfactory answers are already available.
- Develop a research program each year consisting of new problems and, when appropriate, continuations of research started in earlier programs.
- Provide estimates of cost for both new and continued research.
- Make certain that the proposed program cost does not exceed available funds.

During this program development, the committee receives status reports from NCHRP that offer comments and recommendations on each active project. This information includes, among other things, a statement as to the anticipated project status after the currently allotted funds have been spent, as well as the anticipated status after funds for project continuation have been used. The Committee review is also aided materially by reports from the Bureau of Public Roads, NCHRP, and HRB research staffs dealing with appropriateness of the proposed research in light of other research that is under way in this and other research programs.

The Research Evaluation Committee, after review of these reports, determines which old projects will be continued and which new problems from AASHO's Research Activities Committee will be added to make up a recommended program within the available funds.

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 summer 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 which 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 Bureau of Public Roads for its review. Within the Academy structure, the NCHRP staff reviews each item to again insure 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.

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

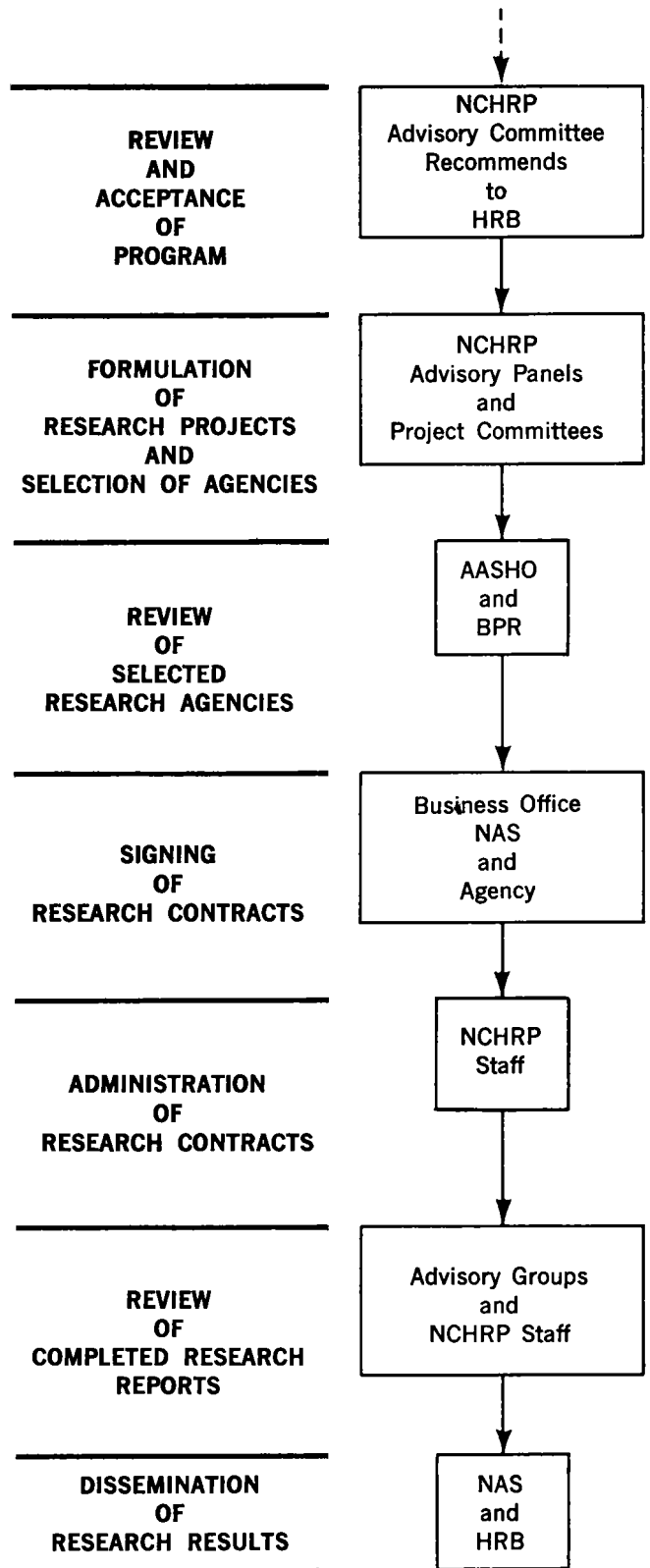


FIGURE 2
Flow Diagram for Each Program After Referral to the National Academy of Sciences

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM
Organizational Structure

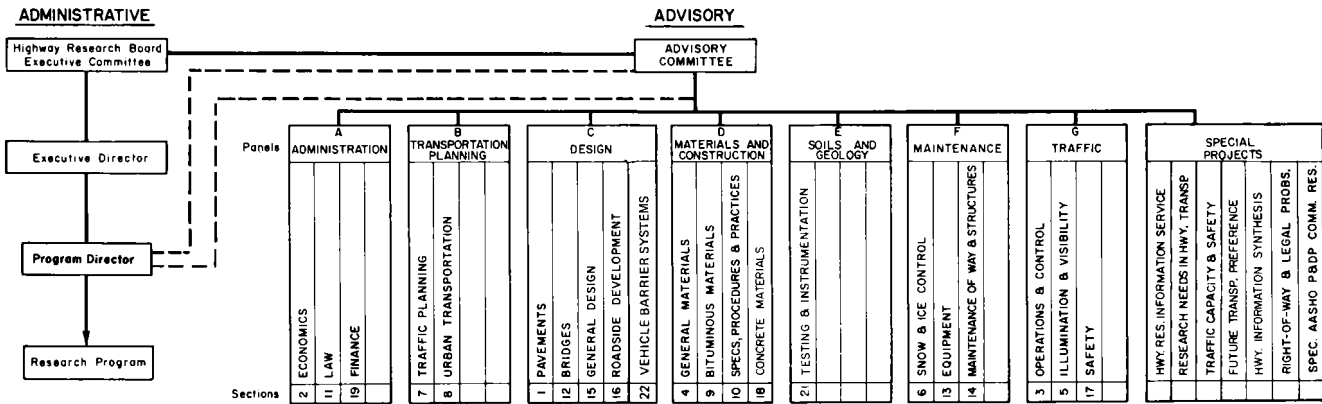


FIGURE 3
Organizational Structure of NCHRP

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.

TABLE 1
DISTRIBUTION OF PANEL, SECTION, AND SPECIAL PROJECT ADVISORY COMMITTEE MEMBERSHIP WITH RESPECT TO AFFILIATION

AFFILIATION	NUMBER OF MEMBERS	POSITIONS INVOLVED
State highway departments	113	177
Bureau of Public Roads	42	87
Special transportation and other government agencies	44	55
Colleges and universities	62	102
Institutions, associations, foundations, etc.	24	39
Industry and consultants	56	59
Highway Research Board	11	26
Total	352	545

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 made up of the officers and ex officio members of the Highway Research Board Executive Committee.

In addition, the Board has also established seven advisory panels (refer to Figure 3) that are concerned with general subject areas and that, in turn, contain advisory sections that deal with specific types of research within the general areas. For example, Panel C is concerned with the general area of Design, whereas Section 12 is concerned more specifically with Bridge Design. From time to time, special project advisory committees are appointed to advise on research work that does not conveniently fit under one of the seven advisory panels.

Committee and panel members are only advisory to the Board; they 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 350 individuals serve without compensation on these panels and committees, and their total yearly contribution to the Program is estimated to be some 2,500 man-days. Members of these committees and panels are outstanding men drawn from the agencies given in Table 1, and they come from 41 states, the District of Columbia, and Canada. Each panel has at least one state highway department employee, 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 sent to the chairmen of the appropriate advisory panels for their recommendations as to the critical need for the research and the availability of other suitable sponsors.

These recommendations are then referred to the NCHRP advisory committee for comments as to 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.

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 panels 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 2,500 interested individuals and research agencies.

Research may be and has been conducted by state highway departments, colleges, universities, research institutes and foundations, consulting engineering firms, industry, or others who possess extensive, demonstrated capability and experience in the problem areas in question. In certain instances, the Board conducts NCHRP research directly in its Special Projects Division.

The response to these announcements and the subsequent proposal return has ranged over the years from an average of 5 per project to 12 per project (refer to Table 2). The highest number of proposals received for any one project has been 28, 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).

Proposals must be submitted according to fixed deadlines

and extensions are simply not granted. Because the projects are seeking remedies for pressing operational problems, proposals are desired only from agencies or individuals already having extensive, demonstrated capability and experience in the subject problem areas. Further, 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. The types of agencies responding with proposals for the eight 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).
- 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 a panel meeting is held to select an agency. The panelists review all known aspects of agency performance on other research projects under NCHRP or elsewhere. The successful proposals are retained by the panel 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 HRB 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 Bureau of Public Roads 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 eight fiscal year programs conducted to date are listed in Table 5. As mentioned earlier, the projects are divided for administrative convenience into three general groups. There are 77 projects in traffic planning research, 75 in physical research, and 8 in the "special projects" area. The 160 projects are distributed among 26 States and the District of Columbia. To date, 117 of the projects have been completed. The distribution of research agencies for the several projects is given in Table 6.

TABLE 2
NUMBER OF PROPOSALS SUBMITTED

FISCAL YEAR PROGRAM	NUMBER OF PROJECTS	PROPOSALS SUBMITTED	PROPOSALS RECEIVED PER PROJECT (AVG.)
'63	34	186	5
'64	27	263	10
'65	14	166	12
'66	16	184	12
'67	13	151	12
'68	16	183	11
'69	19	189	10
'70	9	107	12

TABLE 3
NUMBER OF AGENCIES SUBMITTING ONE OR MORE
RESEARCH PROPOSALS

NO. OF PROPOSALS SUBMITTED	NUMBER OF AGENCIES SUBMITTING RESEARCH PROPOSALS							
	FY '63	FY '64	FY '65	FY '66	FY '67	FY '68	FY '69	FY '70
1	28	40	56	61	76	83	71	55
2	17	24	29	24	16	20	23	8
3	7	11	10	11	5	3	7	5
4	5	11	2	6	3	1	2	4
5	4	4	1	1	2	4	1	1
6	3	2	0	1	1	1	0	0
7	1	3	0	2	0	1	0	0
8	1	2	0	0	0	0	2	0
9	1	1	0	0	0	0	0	0
10	2	0	1	0	0	0	0	0
11	0	1	0	0	0	0	2	0
Total	69	99	99	106	103	118	108	73

TABLE 4
TYPES OF AGENCIES SUBMITTING PROPOSALS

TYPE OF AGENCY	NO. OF PROPOSALS SUBMITTED							
	FY '63	FY '64	FY '65	FY '66	FY '67	FY '68	FY '69	FY '70
Universities	37	36	36	35	39	41	47	38
Research institutes	19	16	13	17	21	16	11	11
Consulting firms, research firms, and industry	13	47	50	54	43	61	122	21
Individuals	—	—	—	—	—	—	7	0
State highway departments	—	—	—	—	—	—	2	1
Federal agencies	—	—	—	—	—	—	—	2
All	69	99	99	106	103	118	189	73
No. of referred projects	34	27	14	16	13	16	19	10

The Academy's research contract is either:

- Cost Reimbursement, or
- Cost-Plus-Fixed-Fee.

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 an inordinately long period. However, the time span is somewhat misleading in that the two-year period actually involves *advance* planning. The referral to the National Academy of Sciences of an AASHO-developed program for any given year meshes appropriately with the announcement of 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 July 1966 (the beginning of fiscal year 1967) to develop the 1969 fiscal-year program. Federal apportionment and States' balloting occurred in the first half of fiscal year 1968; and contracts were signed as fiscal year 1969 began at the time when FY '69 funds were first available. In July 1967 the cycle began again for the 1970 fiscal-year 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 throughout all of these activities, NCHRP takes advantage of all opportunities for

devising a systematic process that will not only increase the odds for acquiring useful research results but will also increase the probability that useful results will find their way into practice more quickly. Going beyond the sponsor's first step of having set the goals for a program of applied research dedicated to solving pressing operational problems, the NCHRP tries to 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 panel 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 panel 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

TABLE 5

PROJECTS FOR FY '63 THROUGH FY '70, SUMMARY OF STATUS THROUGH DECEMBER 31, 1969

PROJECT NO.	TITLE	RESEARCH AGENCY	CONTRACT AMOUNT
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	46,000
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	48,050
1-6	Standard Measurements for Satellite Program—Measurement Team	Texas A & M	75,000
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	24,869
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
			95,645
1-11	Evaluation of AASHO Interim Guides for Design of Pavement Structures	Materials R & D	63,720
1-12	Determination of Pavement Friction Coefficients Required for Driving Tasks	Franklin Inst	299,990
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
			33,719
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	99,848
2-11	Summary and Evaluation of Economic Consequences of Highway Improvements	HRB	100,000
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*
			49,951
			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	146,910
			69,930
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	25,000
3-10	Application of Vehicle Operating Characteristics to Geometric Design and Traffic Operations	Cornell Aero Lab	41,520*
3-11	Optimizing Street Operations Through Traffic Regulations and Control	Peat, Marwick	229,090
3-12	Development of Information Requirements and Transmission Techniques for Highway Users	Airborne Instr	200,000
			100,500
3-13	Guidelines for Medial and Marginal Access Control of Major Roadways	Texas A & M	149,916
3-14	Optimizing Flow on Existing Street Networks	Edwards & Kelcey	990,000
3-15	Weaving Area Operations Study	Poly of Brooklyn	100,000
3-16	Freeway Lane Drops	System Dev Corp	99,789

START- ING DATE	COMPLE- TION 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	Report not received	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	Report in editorial and publication process	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	8/31/70	Research in progress	1-10
10/23/67	12/23/68	Report being modified	1-11
8/25/69	2/24/72	Research in progress	1-12
6/1/63	11/30/67	Report not to be published; summarized in Summary of Progress Through 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 to be covered by Project 2-5A	2-5
7/1/67	12/31/68	Completed—Report to be included in final publication	2-5A
8/11/69	8/10/70	Research in progress	2-5A
6/1/63	9/30/66	Completed—Published as NCHRP Report 63	2-6
2/1/64	5/31/66	Completed—Report being combined with Project 2-5A report	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	10/31/69	Report in editorial and publication process	2-11
2/15/63	2/29/64	Completed—Report not to be published; summarized in Summary of Progress to June 30, 1967	3-1
7/2/64	2/28/66		
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	11/30/69	Report in review stage	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	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	Report in editorial and publication process	3-9
1/1/66	3/10/67	Completed—Published as NCHRP Report 68	3-10
9/1/66	9/30/68	Report in review stage	3-11
10/1/66	12/31/67	Completed—Report being included in final report	3-12
4/1/68	12/1/69	Report in editorial and publication process	3-12
9/1/67	11/30/69	Report in editorial and publication process	3-13
10/1/67	10/31/69	Report in editorial and publication process	3-14
10/1/69	3/31/71	Research in progress	3-15
11/1/69	4/30/71	Research in progress	3-16

TABLE 5 (continued)

PROJECT		RESEARCH AGENCY	CONTRACT AMOUNT
NO.	TITLE		
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*
4-3(2)	Development of Methods to Identify Aggregate Particles Which Undergo Destructive Volume Changes When Frozen in Concrete	Penn State U	23,337*
4-4	Synthetic Aggregates for Highway Uses	Battelle Mem Inst	56,457*
4-5	A Study of the Mechanism Whereby the Strength of Bases and Subbases is Affected by Frost and Moisture	Michigan Tech U	49,756*
4-6	Protective Coatings for Highway Structural Steel	Steel Str Paint	14,790*
4-7	Fatigue Strength of High-Yield Reinforcing Bars	P C A	64,105*
4-8	Research Needs Relating to Performance of Aggregates in Highway Construction	V P I	25,000*
4-9	Evaluation of Preformed Elastomeric Pavement Joint Sealing Systems and Practices	Utah St Hy Dept	100,000
4-10	Promising Replacements for Conventional Aggregates for Highway Use	U of Illinois	59,493
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	93,494
5-2(2)	Effects of Illumination on Operating Characteristics of Freeways—Driver Response, Visibility, and Visual Discomfort	Ohio State U	50,000
5-2(3)	Effects of Illumination On Operating Characteristics of Freeways—Driver Discomfort	Inst for Research	100,000
5-3	Visual Information Needed by the Driver at Night	Ohio State U	37,460*
5-4	Economic Study of Roadway Lighting	Franklin Inst	100,940*
5-5	Nighttime Use of Highway Pavement Delineation Materials	Sw Research Inst	19,412*
5-6	Highway Fog	Cornell Aero Lab	50,000
5-7	Roadway Delineation Systems	Penn State U	100,000
5-8	Warrants for Highway Lighting	—	99,955
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	471,250
6-2	Nonchemical Methods for Preventing or Removing Snow and Ice Accumulations on Highway Structures	Jorgensen & Assoc	199,626
6-3	Development and Evaluation of Protective Coatings to Prevent Deterioration of Concrete Structures by Deicing Agents	Battelle Mem Inst	40,000*
6-4	Evaluation and Development of Methods for Reducing Corrosion of Reinforcing Steel	Battelle Mem Inst	25,000*
6-5	Study of Physical Factors Influencing Resistance of Concrete to Deicing Agents	U of Illinois	58,557*
6-6	To Evaluate Existing Methods and/or Develop Improved Methods for the Measurement of Certain Properties of Concrete	Ohio State U	39,330*
6-7	Estimation of Disintegration in Concrete Structures	Geotechnics	72,500*
6-7A	Estimation of Disintegration in Concrete Structures	IIT Research Inst	69,393*
6-8	Evaluation of Methods of Replacement of Deteriorated Concrete in Structures	Tallamy Assoc	8,547*
6-9	Potential Accelerating Effects of Chemical Deicing Damage by Traffic and Other Environmental-Induced Stresses in Concrete Bridge Decks	U of Illinois	44,614*
6-10	Develop Improved Snow Removal and Ice Control Techniques at Interchanges	Tallamy Assoc	25,000*
AREA SEVEN: TRANSPORTATION PLANNING—TRAFFIC PLANNING			
7-1	The Influence of Land Use on Urban Travel Patterns	Louis E. Keefer	200,000*
7-2	Traffic Attraction of Rural Outdoor Recreational Areas	IIT Research Inst	95,000
7-3	Weighing Vehicles in Motion	Franklin Inst	62,674*
7-4	Factors and Trends in Trip Lengths	Voorhees & Assoc	66,894*
7-5	Predicted Traffic Usage of a Major Highway Facility Versus Actual Usage	Yale University	24,652*
7-6	Multiple Use of Lands Within Highway Rights-of-Way	Barton-Aschman	24,844*
7-7	Motorists' Needs and Services on Interstate Highways	Airborne Instr	73,391*
			88,927*
			61,730
			99,906
			24,220*
			100,000

START- ING DATE	COMPLE- TION DATE	PROJECT STATUS	PROJECT NO.
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	Report in editorial and publication process	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 Report 74	4-6
10/1/67	2/28/70	Research in progress	4-7
1/1/68	12/31/68	Report in editorial and publication process	4-8
10/1/68	12/31/70	Research in progress	4-9
10/15/69	1/14/71	Research in progress	4-10
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	Report in editorial and publication process	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	Report in review stage	5-5
10/2/67	4/30/69	Report in review stage	5-6
10/1/68	12/31/70	Research in progress	5-7
—	—	Contract pending	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—Report not to be published; summarized in Summary of Progress to June 30, 1967	6-7A
2/15/63	2/29/64	Completed—Published as NCHRP Report 1	6-8
1/1/65	6/15/68	Report in editorial and publication process	6-9
9/1/67	8/31/70	Research in progress	6-10
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	Report in editorial and publication process	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

TABLE 5 (continued)

PROJECT		RESEARCH AGENCY	CONTRACT AMOUNT
NO.	TITLE		
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*
8-6	Individual Preferences for Alternative Dwelling Types and Environments	U of N Carolina	100,000
8-7	Evaluation of Data Requirements and Collection Techniques for Transportation Planning	Creighton, Hamburg	99,897*
8-8(1)	The Impact of Highways Upon Environmental Values (Study Design)	M I T	190,000
8-8(2)	The Impact of Highways Upon Environmental Values (Study Design)	Daniel, Mann et al	30,000
8-8(3)	The Impact of Highways Upon Environmental Values	M I T	28,950*
			220,000
AREA NINE: MATERIALS AND CONSTRUCTION—BITUMINOUS MATERIALS			
9-1	Asphalt Durability and Its Relation to Pavement Performance	American Oil	50,000*
9-2	Asphalt Durability and Its Relation to Pavement Performance—Adhesion	Montana College	50,000*
9-3	Evaluation of Pavement Joint and Crack Sealing Materials and Practices	Rensselaer	107,670
			24,996*
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	47,486
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 Hwys	149,835
10-9	Criteria for Need of Seal Coats for Bituminous Pavements	U of Minnesota	36,814
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, Mikkelsen	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
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	25,000
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	200,000
12-8	Bridge Rail Service Requirements as a Basis for Design Criteria	Texas A & M	30,000
12-9	Elastomeric Bearing Research	Battelle Mem Inst	84,800
12-10	Analysis and Design of Bridge Bents	PCA	250,000

START- ING DATE	COMPLE- TION DATE	PROJECT STATUS	PROJECT NO.
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	Report being modified for publication under Project 8-4A	8-4
10/14/68	1/10/69	Report in editorial and publication process	8-4A
4/1/65	5/31/66	Completed—Published as NCHRP Report 31	8-5
8/7/67	1/15/70	Research in progress	8-5
2/14/66	3/13/68	Completed—Published as NCHRP Report 81	8-6
9/13/68	3/15/70	Research in progress	8-7
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	6/15/71	Research in progress	8-8(3)
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	Report not received	9-2
6/1/65	6/30/66	Completed—Published as NCHRP Report 38	9-3
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 final report	10-4
5/1/65	2/28/67	Report in editorial and publication process	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	Research in progress	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
		Contract pending	10-8
11/1/69	7/31/71	Research in progress	10-9
1/1/65	4/30/67	Report in editorial and publication process	11-1
9/2/68	2/28/69	Report in editorial and publication process	11-1(1)
10/1/68	3/31/69	Report in editorial and publication process	11-1(2)
9/16/68	4/30/69	Report in review stage	11-1(3)
12/1/68	5/31/69	Report in review stage	11-1(4)
9/15/68	4/14/69	Report in editorial and publication process	11-1(5)
9/2/68	11/28/69	Report in editorial and publication process	11-1(6)
10/1/68	3/31/69	Report in editorial and publication process	11-1(7)
10/15/68	1/15/70	Research in progress	11-1(8)
3/15/69	12/1/69	Report in review stage	11-1(9)
3/15/69	9/15/69	Report in review stage	11-1(10)
2/24/69	8/25/69	Report in review stage	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	Report in review stage	11-3(1)
9/2/68	2/28/70	Research in progress	11-3(2)
7/1/69	9/30/70	Research in progress	11-4
2/1/65	6/30/67	Report not received	12-1
6/1/66	12/31/68	Report in editorial and publication process	12-2
12/15/65	3/14/69	Report in editorial and publication process	12-3
12/15/65	3/31/68	Completed—Rep. not to be publ; summarized in Summary of Progress Through Dec. 31, 1969	12-4
9/15/66	11/15/68	Report in editorial and publication process	12-5
2/1/67	1/31/69	Report not received	12-6
10/1/66	1/31/70	Report in review stage	12-7
3/1/68	2/28/69	Report in editorial and publication process	12-8
9/1/67	1/31/70	Research in progress	12-9
1/1/70	12/31/72	Research to begin January 1, 1970	12-10

TABLE 5 (continued)

PROJECT		RESEARCH	CONTRACT
NO.	TITLE	AGENCY	AMOUNT
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*
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
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	200,000
16-2	Evaluation of Research on Roadside Development	Western States	100,000
AREA SEVENTEEN: TRAFFIC—SAFETY			
17-1	Development of Improved Methods for Reduction of Traffic Accidents	Cornell Aero Lab	250,000
AREA EIGHTEEN: MATERIALS AND CONSTRUCTION—CONCRETE MATERIALS			
18-1	Revibration of Retarded Concrete for Continuous Bridge Decks	U of Illinois	106,300
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
AREA TWENTY: SPECIAL PROJECTS			
20-1	Highway Research Information Service	HRB	455,000*
20-2	Research Needs in Highway Transportation	Tallamy—Smith	100,000
20-3	Optimizing Freeway Corridor Operation Through Traffic Surveillance, Communication, and Control	Texas A & M	419,000
20-3A	Optimizing Freeway Corridor Operation Through Traffic Surveillance, Communication, and Control	U of Michigan	248,730
20-4	Public Preference for Future Individual Transportation		20,000††
		Chilton Research	195,260
		National Analysts	82,000
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	200,000
20-7	Special AASHO Planning and Design Policies Committee Research	Texas A & M	100,000
AREA TWENTY-ONE: SOILS AND GEOLOGY—TESTING AND INSTRUMENTATION			
21-1	Instrumentation for Measurement of Moisture	Res Triangle Inst	34,470

* Final total amount subject to equipment disposition and adjustments in fiscal year programs.

† 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.

START- ING DATE	COMPLE- TION DATE	PROJECT STATUS	PROJECT NO.
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
12/15/65	6/14/66	Completed—Published as NCHRP Report 36	15-1
7/1/67	3/31/70	Interim findings published as NCHRP Report 54; research in progress	15-1(2)
7/1/66	6/30/73	Initial phase report in editorial and publication process; Phase II research in progress	15-2
10/1/67	12/31/68	Report in editorial and publication process	15-3
9/1/67	11/30/69	Report not received	15-4
8/15/67	1/10/69	Report in editorial and publication process	15-5
9/1/67	8/31/68	Completed—Published as NCHRP Report 77	15-6
3/1/66	2/28/71	Initial phase report in edit. and publ. process; Phase II research in progress	16-1
10/1/67	3/31/69	Report not received	16-2
2/1/66	5/31/68	Completed—Published as NCHRP Report 79	17-1
9/1/67	12/1/69	Report in review stage	18-1
9/5/67	9/4/68	Report in editorial and publication process	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	6/30/71	Research in progress	19-2(4)
3/16/64	10/31/67	Report being modified	20-1
4/1/66	12/31/67	Completed—Published as NCHRP Report 55	20-2
12/15/66	1/31/69	Reports in review stage	20-3
1/1/67	12/31/68		20-3
11/20/68	12/31/69	Research in progress	20-3A
1/1/69	12/31/69		20-3A
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	12/15/69	Research in progress: Topic reports published as NCHRP Syntheses 1, 2, 3	20-5
11/1/68	10/31/71	Research in progress: Refer to Table 9 for publications	20-6
12/2/68	3/1/70	Research in progress	20-7
8/25/69	11/24/70	Research in progress	21-1

TABLE 6
AGENCY DISTRIBUTION OF FY '63 THROUGH
'70 PROJECTS

TYPE OF AGENCY	PROJECTS AND CONTINUATIONS	
	NO.	%
Universities	66	41
Research institutes	39	24
Consulting firms	37	23
Commercial research firms	11	7
Industrial firms	2	1
Individuals	4	3
State highway departments	2	1
All	161	100

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 a concise and readily usable working document.

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 by provision of 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 uncorrected drafts of the agency reports are retained until formal publication in the regular NCHRP series 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 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 publica-

tions 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, quarterly 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.

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 new series of flyers that are 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 being designated in most 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 the 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.

Recently, 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 falls solely to the discretion of the sponsor as to whether or not attempts are made 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 BPR have taken steps to develop a system that should lead ultimately to the sponsor's adequate consideration of all research results.

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. Because there has been steady improvement as regards the usefulness of NCHRP products and because this situation is optimistically anticipated to maintain its trend as a result of the increased Program stability resulting from the heavy concentration on the aforementioned critical factors, it is hoped that there will be a corresponding rise of user interest that will be reflected by an increased utilization of NCHRP research results.

EXAMPLES OF UTILIZATION OF NCHRP RESEARCH RESULTS

Previously Reported

Many instances have come to light as regards the use of research results from NCHRP projects. There are undoubtedly many other uses of results which 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.

Project 3-5, "Improved Criteria for Traffic Signals at Individual Intersections," as conducted by the Planning Research Corporation, contained the development and utilization of incremental travel costs as an objective, composite measure of effectiveness of operation at a signalized intersection. The incremental travel costs technique was applied to a comprehensive determination of the existing effectiveness of operation in the traffic signal system in the District of Columbia. Annual incremental travel costs for the District of Columbia system were estimated and utilized in a benefit/cost analysis of traffic signal system improvement alternatives.

Civil Engineering (Feb. 19, 1966) carried a half-page advertisement by the National Flaxseed Processors Association which presented the results of NCHRP Project 6-3 on "Protective Coatings to Prevent Deterioration of Concrete by Deicing Chemicals," as conducted by the Battelle Memorial Research Institute. The advertisement highlights

the 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."

The research reported on Project 6-8, "Evaluation of Methods of Replacement of Deteriorated Concrete Structures," as conducted by Bertram D. Tallamy Associates, was used by a consulting engineering firm in its work with the U. S. Park Service on the deck repair of Memorial Bridge, Washington, D. C. The repair techniques depended quite heavily on the report.

The results of NCHRP Project 2-5, "Running Costs of Motor Vehicles as Affected by Highway Design," influenced one state to replace outdated material in the AASHO book on *Urban Freeway Design*.

At least two state highway departments are now utilizing the results of Project 5-4, "Economic Study of Highway Lighting," as conducted at Franklin Institute. This report is useful in arriving at a decision as to the type of lighting to be used.

The Highway Research Information Service (HRIS) was developed as NCHRP Project 20-1 and 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.

The results from NCHRP Project 15-1 as conducted by the Cornell Aeronautical Laboratory and reported in *NCHRP Report 36*, "Highway Guardrails—A Review of Current Practice," have been used by one company in formulating a design for a new fiberglass guardrail system.

One very notable instance concerned the University of Minnesota work on NCHRP Project 15-2, "Design to Control Erosion in Roadside Drainage Channels," from which results were put into practice months in advance of the completion date of the research. On a trial basis, the Connecticut State Highway Department made use of a design technique that the research agency developed for channels lined with riprap. The technique was applied under Project 76-85 for a section of Relocated U.S. 6A in the town of Manchester. Major relocation of Hop Brook, having a design flood discharge of 3,900 cfs from a drainage area of 7.3 square miles, and its tributaries was involved. An estimated saving of better than \$90,000 resulted from the use of riprap instead of paving. The channel is currently under observation as regards its behavior during and after any significant storms, and evaluations are being made of the effectiveness of the treatment.

It has been reported from Minnesota that steps have been taken toward implementation of the Project 3-5 delay difference offset technique in an existing signal network. The conclusions from the project's evaluation had a direct bearing on the decision to select this technique for trial.

One consulting firm has applied the knowledge gained from Projects 1-8, 1-10, and work for the U.S. Navy to the development of a new approach to pavement design for heavy aircraft loadings and has employed this approach for the redesign of the Salt Lake City runway to accommodate B747 aircraft. Similar use is being made 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 configuration of the B2707 (SST).

Indications are that considerable Federal and State use will be made of *NCHRP Report 54*, "Location, Design, and Maintenance of Highway Guardrails and Median Barriers," prepared under Project 15-1(2) at the Southwest Research Institute and recently released. The researchers have been informed by the Armco Steel Corporation that the recommendations of the Highway Task Force of the American Iron and Steel Institute's Sheet Committee include the use of the flat washer illustrated on page 29 of the report, and that these recommendations are ready for release by the Bureau of Public Roads.

Heavy reliance has been placed by the National Highway Safety Bureau on *NCHRP Report 37*, "Tentative Skid-Resistance Requirements for Main Rural Highways," in the preparation of a Highway Safety Program Manual that will be issued to the States. This report emanated from Project 1-7, "Development of Interim Skid-Resistance Requirements for Highway Pavement Surfaces."

It has been learned that Iowa has built a bridge with galvanized reinforcing bars in one-half of the deck. This follows the recommendations of the Battelle Memorial Institute study reported in *NCHRP Report 23*, "Methods for Reducing Corrosion of Reinforcing Steel," to the effect that more field evaluation is required of zinc, nickel, and asphalt-epoxy coatings.

The Ford Motor Company has claimed a saving of countless hours of search and survey as a result of the current state of knowledge of highway joint and crack sealing materials and methods compiled under NCHRP Project 9-3 by Rensselaer Polytechnic Institute and published in *NCHRP Report 40*. Chapters One and Three are seen as potentially being very useful to the company in further understanding their various design, construction, and maintenance problems, in analyzing specific failures, and in adapting future developments in highways to their industrial and other roadway problems.

A study is in progress for the Ohio Department of Highways to develop a forecast of maintenance needs for the decade 1970 through 1980 and will compare it with the trends in highway maintenance needs for the United States as a whole and for the northeast region in particular. The concepts developed by Bertram D. Tallamy Associates under NCHRP Project 14-1 and reported in *NCHRP Report 42*, "Interstate Highway Maintenance Requirements and Unit Maintenance Expenditure Index," are being employed in making these new, comprehensive forecasts of future needs.

North Dakota State University reports the use of *NCHRP Report 17*, "Development of Guidelines for Practical and Realistic Construction Specifications," as a basic text for a course in statistical quality control that has been taught to both undergraduates and a sizeable number of engineers, the majority of the latter category being highway department employees.

The Orange County Traffic Engineers Council of Cali-

fornia reports extensive use of *NCHRP Report 50*, "Factors Influencing Safety at Highway-Rail Grade Crossings," as the best available source of information for preparation of warrants for the installation of protective devices at rail-grade crossings.

Although yet unpublished, the results from the second year of research under NCHRP Project 20-3, "Optimizing Freeway Corridor Operation Through Surveillance, Communication, and Control," have been acquired by the California Division of Highways and are being used as background for installing freeway surveillance and control systems and in planning alternative methods of improving freeway operations on the Los Angeles Area freeway system.

The Land Acquisition Division of the Indiana State Highway Commission rated *NCHRP Report 56*, "Scenic Easements—Legal, Administrative, and Valuation Problems and Procedures," as excellent and requested extra copies for use in the development of new work in its area of responsibility.

NCHRP Report 42, "Interstate Highway Maintenance Requirements and Unit Maintenance Expenditure Index," has been of considerable assistance to the investigators in the Minnesota 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. Further, this same report has been utilized by the Washington State Highway Commission in attempting to develop a unit maintenance expenditure index for that State.

It is particularly noteworthy that the Illinois Division of Highways has instituted a process wherein the various Bureaus extensively review *NCHRP Reports* and rate them according to a broad usefulness scale. Although the ratings of *Reports 1* through *47* were most encouraging, those for *Reports 48* through *57* are even more so, for they exhibit a very noticeable upswing into the upper levels of the usefulness scale. This would be expected in view of the fact that 34 projects were programmed in the first year alone to get the NCHRP in operation, and 27 more were added in the second year. Some of the more notable examples of Illinois' application of results from all studies are as follows:

- The Bureau of Research and Development has reported frequent use of *NCHRP Report 2*, "An Introduction to Guidelines for Satellite Studies of Pavement Performance," and *Report 2A*, "Guidelines for Satellite Studies of Pavement Performance," in its studies of existing pavements and of the rehabilitated Road Test project at Ottawa. Particular use has been made of recommendations for experimental designs, measurement programs, and data processing analysis.

- The Bureau of Materials has reported that *NCHRP Report 34*, "Evaluation of Construction Control Procedures," as developed by Miller-Warden Associates, will be used, 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.

- The Bureau of Traffic has stated its intent to employ many of the Cornell Aeronautical Laboratory findings as reported in *NCHRP Report 9*, "Traffic Surveillance and Means of Communicating with Drivers," in a FAI 80 Motorist Communication Project. The Bureau has also stated that as a result of the findings contained in Cornell's *NCHRP Report 29*, "Digital-Computer-Controlled Traffic Signal System for a Small City," 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 a good number of pedestrians.

- Further, the Bureau of Materials has stated the intent of using the information in Miller-Warden's *NCHRP Report 17*, "Development of Guidelines for Practical and Realistic Construction Specifications," in conjunction with the Bureau of Public Roads sigma bank, and data developed by the Bureau of Materials' field testing to develop special provisions covering statistical acceptance of bituminous concrete pavement.

- The Bureau of Design proposes to utilize much of *NCHRP Report 50*, "Factors Influencing Safety at Highway-Rail Grade Crossings," 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.

- In view of the potential accuracy of the nuclear pellet technique for measuring pavement thickness, the Bureau of Research and Development, at last notice, was considering a trial of the recommendation in *NCHRP Report 52*, "Measurement of Pavement Thickness by Rapid and Nondestructive Methods."

- The Bureau of Design states that the findings given in *NCHRP Report 54*, "Location, Selection, and Maintenance of Highway Guardrails and Median Barriers," are—or will be—included in their highway design policies and standards. From the Bureau of Maintenance comes the statement that the new Illinois guardrail and median barrier standards appear to have resulted from *Report 54*. Although not specifically examples of use of the findings of *Report 54*, comments of the Bureau of Traffic nonetheless deserve mention for, in terms of immediate usefulness, they highlight *Design Manual* or *Highway Standards* areas that could be improved by the reported 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.

- The Bureau of Research and Development states that a committee within the Illinois Highway Research Council, having the assignment of developing a system of establishing research priorities for the Division's program, is making use of *NCHRP Report 55*, "Research Needs in Highway Transportation," which outlines one possible method for structuring research programs.

- The Bureau of Right-of-Way reports that most of the principles set forth in *NCHRP Report 56*, "Scenic Easements—Legal, Administrative, and Valuation Problems and Procedures," have been in practice and that the Land Economic Study unit will conduct a study according to the report recommendation for one method of analysis of the value of scenic easements.

Current Reporting

NCHRP Report 7, "Comparison of Different Methods of Measuring Pavement Condition—Interim Report," emanated from Project 1-2, "Comparison of Different Methods for Evaluating Pavement Conditions," and has been utilized in research by the New York Department of Transportation to develop a flexible pavement performance equation. As of June 1968 this equation was being used to analyze New York's flexible pavements.

The results from *NCHRP Project 17-1*, "Development of Improved Methods for Reduction of Traffic Accidents," have been used in the development of a college textbook, "Economic Analysis for Highways," authored by Robley Winfrey.

In a study of highway maintenance management, Advanced Management Planning, Inc., has recommended to the Delaware State Highway Department that *NCHRP Report 26*, "Development of Uniform Procedures for Establishing Construction Equipment Rental Rates," an outgrowth of Project 13-1, "Equipment Rental Rates," be used as a guide in establishing equipment rental rates.

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,

TABLE 7

PUBLISHED REPORTS OF THE NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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

* Highway Research Board Special Report 80.

TABLE 7 (continued)

<i>Rep. No.</i>	<i>Title, Project, Pages, Price</i>
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
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 Guardrail 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. 3-5/1), 55 p., \$2.80
74	Protective Coatings for Highway Structural Steel (Proj. 4-6), 64 p., \$2.80
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)), 38 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), — p., \$—
81	Moving Behavior and Residential Choice—A National Survey (Proj. 8-6), — p., \$—
82	National Survey of Transportation Attitudes and Behavior—Phase II Analysis Report (Proj. 20-4), 89p., \$4.00

Synthesis of Highway Practice

- 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), 38p., \$2.20

TABLE 8

UNPUBLISHED REPORTS OF THE NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM ^a

PROJECT SUMMARIES MAY BE FOUND IN SUMMARY OF PROGRESS REPORT FOR PERIOD ENDING

JUNE 30 1967	JUNE 30 1968	DEC. 31 1969
1-2	2-1	12-4
2-8	4-1	
3-1	4-5	
6-6		
6-7A		
8-3		

^a See Table 5 for project titles. For information on availability of loan copies of research agency reports write to the Program Director, NCHRP, Highway Research Board, 2101 Constitution Ave., Washington, D.C. 20418.

TABLE 9
NCHRP RESEARCH RESULTS DIGESTS

DIGEST NO.	PROJ. NO. ^a	TITLE
1	15-2	Tentative Design Procedures for Riprap-Lined Channels
2	7-7	Motorists' Needs and Services on Interstate Highways
3 ^b	20-6	Relocation Assistance Under Chapter Five of the 1968 Federal-Aid Highway Act
4	1-4(1)A	Rigid Pavement Performance Influenced by Slab Strength and Thickness
5	12-5	Protection of Steel in Prestressed Concrete Bridges
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
7	17-1	Development of Improved Methods for Reduction of Traffic Accidents
8	4-6	Protective Coatings for Highway Structural Steel
9	20-4	National Survey of Transportation Attitudes and Behavior—Phase II Analysis Report
10	12-2	Distribution of Wheel Loads on Highway Bridges
11 ^b	20-6	Valuation Changes Resulting from Influence of Public Improvements
12	12-8	Tentative Service Requirements for Bridge Rail Systems
13	6-9	Effect of Stress on Freeze-Thaw Durability of Concrete Bridge Decks
14	12-3	Waterproof Expansion Joints for Bridges

^a See Table 5 for project titles. Digests are available free in limited quantity. Make request to Program Director, NCHRP, Highway Research Board, 2101 Constitution Avenue, Washington, D. C. 20418.

^b Final publication.

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.

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 problems in the realm of highway transportation. 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 have been established for the study of existing and new experimental pavements in the satellite research program. Definitions are provided for pavement units and behavior, traffic factors, and environmental factors. Recommendations are 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: \$46,000

The degree of influence of various factors commonly assumed to affect pavement performance has not been suitably evaluated to allow translation of performance test results from one area to another. The objectives of this research are to identify these factors, their order of importance, and their relative effect on design and to correlate pavement design and performance with factors common to a number of regions of the United States.

On the hypothesis that factors affecting pavement design and performance can be grouped on a regional basis and that pavements within these regions perform similarly, initial work on this contract consisted first of dividing the continental United States into 14 major regions, the boundaries of which were principally delineated by physiographic factors, and then subdividing these regions into subsections for purposes of comparing design and performance concepts in light of such factors as topography, geology, pedology, soil types, availability of construction materials, and climate.

The results reported from the initial research provide the basis for continuing work, which presently seeks to further develop and quantify the regional approach in four principal aspects—namely, (1) generalized mapping of soils, rocks, topography, and climatic factors; (2) rating in as quantitative a sense as is practicable and representing in mapped form those highway engineering problems which are considered susceptible to regionalization; (3) examination of the integrity of the various physiographic subdivisions (province, sections, subsections, etc.) as reasonably homogeneous regions relative to highway design and performance; and (4) collection, by political unit, of highway design and performance data and analysis of such data on a regional basis. It is intended that a quantified regional approach in respect to the foregoing will afford guidance in the selection of detailed case studies which might at some future date be deemed necessary for the development of predictive models.

Information has been assembled for each of the aspects of the study and prepared in map form for inclusion in the final report. The physiographic regions and subsections described in the interim report have been reviewed and some modifications have resulted. Pedological soil classification mapping is being correlated with the physiographic region boundaries. A frost severity index is being developed by combining information on soils and climate. Aggregate availability, slope instability, and soil volume change are problems that are also being analyzed on a regional basis for some indication of quantitative relationship. Organic foundations, pumping, and soil sensitivity tend to be local problems that need an individual rather than a regional approach. Highway design and performance data have been collected from practically all State highway departments and are being analyzed on the basis of physiographic regions rather than political boundaries.

Preparation of the final report is nearing completion.

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 have been examined, and observed behavioral trends have been 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 upon 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. Since available information indicated that deformations inducing fatigue

cracking under moving vehicle loads are almost fully recoverable, therefore essentially elastic, they have been termed "resilient" deflections, and the research program has involved the laboratory measurement of the resilient behavior of representative paving materials, field measurement of deflections of prototype pavements composed of the same materials as those tested in the laboratory, and the relating of the laboratory test results to observed deflections of the prototype pavements through available 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 involves 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 are being 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(1A) 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 is 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 have been developed for existing theories of mechanical behavior of rigid pavements.

Research has been completed, and the essential findings from the report published in NCHRP Research Results Digest 4. The complete report is in the NCHRP editorial and publication process.

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: \$48,050

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: \$75,000

This research relates 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 has been 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 will be 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 are 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 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: \$24,869

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.: F. N. Finn
 Dr. W. R. Hudson
 B. A. Vallerga
Effective Dates: Sept. 12, 1966 Dec. 1, 1968
Completion Dates: Mar. 11, 1968 Aug. 31, 1970
Funds: \$99,803 \$95,645

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 concentrates on improving the understanding of the significant basic properties of pavement systems and components and their relationships to design and performance, with due regard being given to locality and environment. The specific objectives of the research are (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.

Phase I of the research has been completed and progress has been made toward the project objectives. The complex problem of pavement design has been thoroughly analyzed. A system engineering approach has been developed which organizes the influencing factors, such as significant pavement materials characteristics, construction techniques, maintenance requirements, and economics, within a suitable framework for further progress toward pavement design procedures which will be applicable to all locations, environments, and traffic loadings.

A project report covering this phase has been received. It will not be published as a separate document but will be incorporated into the report for Phase II of the study.

Research is in progress on Phase II. The general objectives of the initial phase continue to be applicable, with specific emphasis being placed on the following two major subdivisions of the problem:

1. Characterization of soils and paving materials.
2. Formulation of the total pavement system.

A particularly high level of effort is currently being concentrated on the testing program intended to produce guides for the characterization of materials.

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 Date: October 23, 1967
Completion Date: December 23, 1968
Funds: \$63,720

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 are (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. The project report was prepared containing suggestions for revision of the Guides with supporting information.

For the purpose of providing state highway departments

The 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. This includes more data on variations in road gradients and curvature on the fuel consumption of passenger vehicles, together with data on the effect of rough surface on tire wear, maintenance, and oil consumption. The results of the earlier work on Project 2-5 and Project 2-7 will be combined with the additional results of this phase of the project into a single comprehensive final report.

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 is 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 are expected to be developed.

The final report has been submitted and has been re-

viewed by the advisory panel. This 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 will be combined with the results of Project 2-5A and published in a single report.

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 should 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: \$99,848

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: October 31, 1969
Funds: \$100,000

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 report is in the editorial and publication process.

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 has 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 quantifies the operational performance. A procedure has been 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 have been 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 is concerned with the development, practice, and evaluation of various methods of surveillance and means of communicating with drivers, has taken advantage of the several surveillance systems available in the United States to further its research.

The report of the first phase of research describes 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 is 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 involves establishment of the operating requirements of a communication system designed to enable better communications between vehicles on expressway-type facilities.

Evaluation and comparative examination of four inter-vehicular communication systems were completed. This 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 have been studied for the various signal systems previously tested. A prototype infrared sensing system has been developed and tested to indicate distance and relative velocities between vehicles. Field studies of traffic dynamics have been 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 is 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 is 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."

Based on the comprehensive review of the nature, extent, and characteristics of the stopped vehicle problem conducted during the first year of research, the researchers have continued to investigate the feasibility of a detector system. A roadside vehicle detector system has been developed using a silicon photo-voltaic diode as the roadside receiving unit and signalling has been performed by a vehicle-mounted relay-type interrupting device which modulates infrared-emitting diodes. A prototype system has been 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 11/30/69
Funds: \$123,030 \$49,951 \$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 overall objective of the research is to determine the most efficient method of timing traffic signals for isolated intersections, arterial highways, and grid networks of city streets. The research is being 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 is 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 contains 46 signalized intersections, and the Los Angeles

network contains 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 research is completed and the report will be published in the regular NCHRP series.

Project 3-6 FY '63, FY '64, and FY '66**Effect of Regulatory Devices on Intersection 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 have been 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, FY '65, and FY '67**Establishment of Standards for Highway Noise Levels**

Research Agency: Bolt Beranek and Newman
Principal Invest.: Dwight Bishop
Effective Dates: Feb. 1, 1964 Oct. 14, 1968
Completion Dates: Apr. 30, 1967 Jan. 15, 1970
Funds: \$146,910 \$69,930

This project is concerned with the evaluation of noise levels of the various classes of highways and the effective-

ness 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 reports 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 is to prepare a highway design noise manual for the practicing highway engineer. The design guide will be 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 has been 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 are well under way, and an analytic technique for predicting traffic noise levels to be used in the design guide is complete. Extensive studies have been undertaken to determine highway noise design criteria. The development has been 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 have been adopted as a basis for setting an upper design limit for allowable traffic noise. The accumulation of current information regarding sound propagation path effects, including barriers, elevated and depressed roadways, and reflective surfaces is complete.

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 which was tested with accident data obtained from Minnesota, Oregon, and Virginia. A warrant has been 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: \$25,000

The purpose of this study is 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 have been made on the major freeway surveillance and control facilities currently in operation. The final report has been received and is in the NCHRP editorial and publication process.

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 is directed at identifying the motor vehicle characteristics that are related to highway geometric design and traffic control operations. The objective is to determine the relationships between the vehicle and its operating environment. Vehicle characteristics will be reviewed, and where appropriate highway design criteria will be 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 are 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, Livingston & Company
Principal Invest.: James H. Kell
Effective Date: September 1, 1966
Completion Date: September 30, 1968
Funds: \$229,090

This research is 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 will be explored. The cities of Sunnyvale and Redwood, Calif., were selected as the cooperating demonstration test cities. The research emphasis is 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 theorem 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 research has been completed and the final report is in the NCHRP editorial and publication process.

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
Effective Dates: Oct. 1, 1966 April 1, 1968
Completion Dates: Dec. 31, 1967 Dec. 1, 1969
Funds: \$200,000 \$100,500

Street and highway sign standardization has progressed to a satisfactory point in many of its technical aspects, but many functional deficiencies remain. The "Interstate Sign Manual" incorporates many appropriate provisions for particulars of design and application, but with the ever-increasing demands of the driving task there is urgent need for improvement in the understanding of the driver's needs for information and the means of communicating it to him. Better performance criteria must be established for selection and transmission of the appropriate messages.

The research defines and measures, where possible, all pertinent factors and functions of the information system and identifies those variables under control of the highway designer, the traffic engineer, the traffic control officer, the driver educator, etc. With regard to the highway user, the research considers those variable parameters which motivate the driver to respond naturally and safely to the range of messages transmitted.

The objective of the overall 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 infor-

mation system requirements. In addition, current sign use was investigated, particularly the night legibility problem, to determine problem areas in sign application criteria. Mathematical analyses are 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 is outlined. The test site for the project was located in North Carolina.

The research has been completed and the final report is in the NCHRP editorial and publication process.

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 are: 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 recommends 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 research has been completed and the report is in the NCHRP editorial and publication process.

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: October 31, 1969
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 describes the variance and distribution of many elements of traffic flow. This study also describes 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 Mode 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 overall efficiency of the network. The overall 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 received and will be published in the regular NCHRP report series.

As part of the project a film, "Relief for Tired Streets," has been 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 Inst. of Brooklyn
Principal Invest.: Dr. Louis J. Pignataro
Effective Date: October 1, 1969
Completion Date: March 31, 1971
Funds: \$100,000

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 a study program which will lead to improved techniques for the analysis and design of weaving sections. Within the constraints of time and funds, a limited data collection and analysis program will be undertaken.

To date the project working plan has been developed, and the procedures in the *Highway Capacity Manual* regarding weaving have been checked for accuracy and consistency.

Project 3-16 FY '70

Freeway Lane Drops

Research Agency: System Development Corp.
Principal Invest.: Antranig V. Gafarian
Effective Date: November 1, 1969
Completion Date: April 30, 1971
Funds: \$99,789

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 this research are:

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 "con-

figurations" includes distance from the nearest upstream and downstream ramps.

To date the project working plan has been developed, and the agency is currently selecting test sites for the field phase of the research.

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 has been 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. It is expected that the results of the study will show not only the mechanism of degradation but also what properties to measure to predict degradation.

Aggregates from all basic continental types were considered and include igneous, metamorphic, and sedimentary rock types which are used as aggregates by different agencies throughout the United States. Laboratory testing has been performed on a continuing basis in respect to Los Angeles abrasion, sulfate soundness, and freeze-thaw procedures. Thin sections have been prepared for the petrographic examination of the various grain parameters. Such textural parameters as grain interlock, average grain size, and grain size distribution have been obtained by taking thin-section traverses for the purpose of more closely determining the relative importance of these properties. Statistical analyses have been made of the grain parameters measured from the thin sections and polished sections, from laboratory test data, and from previously obtained performance evaluations, and studies have been made to ascertain which grain parameters are best reflected by specific laboratory tests, and, in addition, which grain parameters or laboratory tests best reflect the performance record of the aggregate. It is intended that such information will be of value in the development of meaningful degradation tests. Problems associated with quarry sampling and the effect of plant processing have been investigated, and additional quarry samples have been obtained in order to ascertain the inherent variability of some testing procedures used earlier in the project work.

Research has been completed, and the project report is in the NCHRP editorial and publication process.

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 relates 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 is 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 involves 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 is 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 byproducts. Inquiries have been 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 involves 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."

Project 4-7 FY '68

Fatigue Strength of High-Yield Reinforcing Bars

Research Agency: Portland Cement Association
Principal Invest.: Dr. John M. Hanson
Effective Date: October 1, 1967
Completion Date: February 28, 1970
Funds: \$100,000

The AASHTO 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 is to obtain fatigue strength test data on ASTM A432 steel bars (60,000 psi yield strength) by the design and execution of a statistically valid experiment which will place 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.

The experimental phase consisted of repeated-load tests on 231 rectangular or T-shaped concrete beams reinforced with a single longitudinal bar. These specimens contain bars ranging in size from No. 5 to No. 11, and having nominal yield stresses from 40 to 75 ksi. To reduce variation caused by laboratory technique, the casting and testing of specimens was carried out in a carefully randomized order. No unexpected difficulties were encountered in testing the specimens.

The experimental work was completed in August 1969. The analyses of data were completed in October 1969.

Preliminary review copies of the final report were submitted in December 1969. The original contract comple-

tion date of November 30, 1969, was changed to February 28, 1970, as a matter of administrative convenience for NCHRP. The agency will remain under contract throughout the report review period and be available to revise the report as directed.

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: December 31, 1968
Funds: \$59,493

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.

A thorough review of past and current research on utilization of aggregates has been accomplished, and a two-day highway aggregate workshop conference was conducted at V.P.I. as part of the information gathering activity of the project. More than 50 experienced engineers and researchers participated in the conference. Personal contacts provided additional information that was useful in identifying the primary research needs in the aggregate field.

Research has been completed, and the project report is in the NCHRP editorial and publication process.

Project 4-9 FY '69

Evaluation of Preformed Elastomeric Pavement Joint Sealing Systems and Practices

Research Agency: Utah State Highway Department
Principal Invest.: George M. Jones
Effective Date: October 1, 1968
Completion Date: December 31, 1970
Funds: \$93,494

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 predictors 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.

The purpose of this project is to evaluate the performance of preformed elastomeric joint seals and develop tentative criteria for their use in generally accepted portland cement concrete joint configurations used throughout the United States.

Specific objectives are to:

1. Collect and evaluate available research and field performance information.
2. Conduct laboratory studies to:
 - (a) Determine the cross-sectional geometry (shape, internal cell configuration, wall thickness, etc.) of preformed seals to optimize performance for various joint configurations and movements.
 - (b) Determine material properties (tensile strength, elongation at break, tear resistance, hardness, heat-aging, ozone resistance, etc.) that will result in acceptable performance and durability characteristics.
 - (c) Determine the effect of cyclic strain on durability and resistance to cracking of various cross-sectional shapes for given material properties. This might be accomplished by environmental testing with laboratory fatigue testing equipment in conjunction with an environmental chamber.
 - (d) Determine the effect of interface pressure and adhesion between the seal and the pavement joint.
3. Develop realistic tentative performance criteria and guide specifications based on the results of items 1 and 2.
4. Propose a field evaluation program to verify or modify the tentative performance criteria and guide specifications developed under item 3.

These objectives are to be accomplished through consideration of factors influencing performance of preformed elastomeric pavement joint seals to include (1) material characteristics, (2) cross-sectional geometry, (3) installation practices, (4) joint movement, and (5) environment.

During the early stages of the project, the major effort was preparation, distribution, and evaluation of questionnaires designed to collect information on current highway

department practices with regard to such items as pavement joint spacing, joint opening width, and sealing materials used, plus specific research and field experience with preformed elastomeric seals. The acquisition of equipment and materials for the laboratory testing program was also accomplished during this period. This was followed by a pilot environmental chamber testing program involving two joint simulators and selected samples of seals. The full-scale testing program with 12 additional joint simulators and a wide range of seal sizes and configurations is now under way.

Project 4-10 FY '70

Promising Replacements for Conventional Aggregates for Highway Use

<i>Research Agency:</i>	University of Illinois
<i>Principal Invest.</i>	Dr. C. R. Marek
<i>Effective Date:</i>	October 15, 1969
<i>Completion Date:</i>	January 14, 1971
<i>Funds:</i>	\$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 of the fact that many of the existing sources are becoming unavailable through zoning restrictions, pollution control, and appreciating land values.

The vast amount of modern-day technical knowledge and experience in this country and other countries should provide a basis for development of substitute materials and/or new procedures for upgrading existing unsuitable materials. 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 is to study the utilization of modern technology as it might apply to production or upgrading of materials for use as aggregates in portland cement concrete, bituminous mixes, and base courses.

Specific objectives are to:

1. Plan and conduct a seminar of representatives of a variety of disciplines with the objective of exploring the possibilities that are available for the production of new aggregate materials. This is intended to include the upgrading of unsuitable aggregates and utilization of waste products, and other readily available materials, using new production techniques.
2. Evaluate the ideas evolving from the seminar and select the promising replacements for the conventional aggregates as used in highway construction and maintenance.
3. Formulate an experimental program to investigate the feasibility of production, to evaluate the performance, and to determine the practicality of the selected replacement materials.

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: \$125,000 \$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 supplement 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 complements that of Project 5-2(1). This study is 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 includes 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 project is to determine the visual information needed by motorists on freeways at night. The assessment and relative significance for the various items of needed information are to be studied to develop criteria for the freeway environment. It was expected that the type of information would vary with roadway geometrics, background topography, adjacent land uses, and lighting, if any, along with operating conditions such as speed and volumes.

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 has been 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 research has been completed, and the final report is in the NCHRP editorial and publication process.

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 is 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 knowledge of initial and annual costs for the installation of roadway lighting is needed by highway administrators for economic analyses.

The researchers have 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 have been analyzed to provide standard illumination levels on typical two-lane, four-lane, and six-lane divided highways. A literature search has been made of available lighting cost studies, specifications, design criteria for highway lighting installations, maintenance, and replacement factors. Methods for evaluating capital improvement proposals have been reviewed,

and the annual cost method appears to be most suitable for evaluating costs of different roadway lighting configurations. Questionnaires have been 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, 1969
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 are under investigation.

This program was initiated by a field study of the performance characteristics of conventional marking materials. Following this, the researchers have conducted studies of the physical nature of reflective materials with particular emphasis on their performance characteristics under various types of water films. Attention has been 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 country was completed. Experimental markers were placed on highways, for long-term observation, in California, Oregon, Washington, Wyoming, Illinois, Michigan, Pennsyl-

vania, Connecticut, North Carolina, Florida, Texas, and Missouri.

The research has been completed, and the final report is in the NCHRP editorial and publication process. In addition, a motion picture film has been produced describing the results of the research. Loan copies of the film may be obtained through the NCHRP.

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 has been 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 is 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 specific types of highway fog. These concepts are 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 final report has been received and is in the review stage.

It is anticipated that a second phase of research will begin during the early part of 1970. The additional research would provide for the testing of promising warm-fog abatement methods.

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: December 31, 1970
Funds: \$471,250

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 are: (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.

The state-of-the-art summary has been completed and loan copies may be obtained through the NCHRP.

Project 5-8 FY '70

Warrants for Highway Lighting

Research Agency: Texas A & M University Research
 Foundation

Principal Invest. Neilon J. Rowan
Effective Date: Contract pending
Completion Date:
Funds: \$199,626

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.

Specific objectives are 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.

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 this and other countries have been evaluated, as well as 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, "Method for Reducing Corrosion of Reinforcing Steel."

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 6-5 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 6-7 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 6-6 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

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 towards 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 research plan included a literature search and bridge survey, limited-scale testing, full-scale testing, and data interpretation and evaluation.

The most important conclusion from this study is that although stress appears to influence somewhat the rate of development of surface scaling, it is not a primary factor. The physical characteristics of the surface mortar compared with those of the coarse aggregate layer of the concrete appear to be the most important factor.

The essential findings from the study have been reported in NCHRP Research Results Digest 13 (Oct. 1969).

The final report has been submitted and is in the NCHRP editorial and production process.

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: August 31, 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 specific objectives of the research are:

1. Identify and evaluate the factors that influence the efficiency of snow removal and ice control operations at interchanges; e.g., circuitousness of travel, limited storage area, equipment operational difficulties, kinds of interchanges, traffic volumes, drainage, lower traffic lanes, etc.
2. Develop operation systems that will provide for efficient snow removal and ice control procedures on interchange roadways with associated structures in both rural and urban locations. Primary emphasis is to be placed on the maintenance problems attendant to existing facilities and equipment and their recommended solutions. Consideration shall also be given to design innovations that will minimize future maintenance problems.

An interim report has been submitted by the agency as evidence of completion of Objective 1. The report also contains suggestions for further research to accomplish Objective 2 of the study. An advisory panel meeting was held in Washington, D. C., September 20, 1968, with a panel consensus that additional effort should be placed on Objective 1 and a condensed version of the interim report should be submitted as accomplishment of this objective. The agency was also invited to submit a continuation proposal for the accomplishment of Objective 2 in accordance with the FY '69 continuation allotment for this project.

A condensed version of the interim report has been submitted and distributed to the AASHO Committee on Maintenance and Equipment. A continuation proposal was received and approved by the advisory panel, resulting in an amendment to the contract extending the completion date by one year to August 31, 1970, and increasing the funds by \$45,000 to \$95,000. The second objective of the project has been modified as follows: Evaluate improved operational

procedures and techniques and potential design improvements for specific snow removal and ice control problems identified under Objective 1 and prepare a procedural manual based on the evaluations.

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 seeks 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) are 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 has been 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

<i>Effective Dates:</i>	Feb. 1, 1964	Oct. 23, 1967
<i>Completion Dates:</i>	Oct. 31, 1966	Jan. 10, 1969
<i>Funds:</i>	\$88,927	\$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 were 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 have been 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 of the continuation research work is in the NCHRP editorial and publication process.

This 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-base work-trip analyses for certain hypothetical urban forms and transportation systems.

Project 7-5 FY '64 and FY '65

Predicted Traffic Usage of a Major Highway Facility Versus Actual Usage

<i>Research Agency:</i>	Yale University, Bureau of Highway Traffic
<i>Principal Invest.:</i>	M. J. Huber H. B. Boutwell
<i>Effective Date:</i>	February 1, 1964
<i>Completion Date:</i>	November 30, 1966
<i>Funds:</i>	\$99,906

This project involves the development of better methods for forecasting and assignment of traffic. Various methods in current use are investigated. Methods are 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

<i>Research Agency:</i>	Barton-Aschman Associates
<i>Principal Invest.:</i>	Harvey R. Joyner
<i>Effective Date:</i>	February 1, 1966
<i>Completion Date:</i>	February 28, 1967
<i>Funds:</i>	\$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 assembles 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 this country 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

<i>Research Agency:</i>	Airborne Instruments Laboratory
<i>Principal Invest.:</i>	Martin A. Warskow
<i>Effective Date:</i>	January 1, 1966
<i>Completion Date:</i>	December 31, 1967
<i>Funds:</i>	\$100,000

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 finan-

cial 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."

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. Over 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 metropolitan 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 will be 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 Progress 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 numerical 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 has been 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 project report has been completed. 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 panel review, some new and more recent 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 final revised report is in the NCHRP editorial and publication process.

Project 8-5 FY '65 and FY '68

Transportation Aspects of Land-Use Controls

Research Agency: Victor Gruen Associates
Principal Invest.: Harold Marks
Effective Date: April 1, 1965 Aug. 7, 1967
Completion Date: May 31, 1966 Jan. 15, 1970
Funds: \$25,967 \$100,000

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 is 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 transportation planning in areas of rapid growth and intensive development. The effects of zoning and general plans were studied, as well as 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 has been continued to establish principles or guidelines for developing land-use controls and other techniques that will be stable and effective in preserving the investment in transportation systems. The researchers propose to develop more realistic land-use controls for broader application. Intrinsic protection of the highway system will be proposed through the use of access control and geometric design.

The initial research is being reviewed to document

the causes of transportation facility breakdowns as they relate to current practices of land-use and access controls. The effects of changing land-use controls on the utility of highways are being studied, with special attention being given to large traffic generators located near freeway interchanges. Built-in protection of various highways is being analyzed to determine how a flexible design can be provided to accommodate changing functions and demands.

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: March 15, 1970
Funds: \$190,000

Urban transportation planning studies require travel, transportation facility, land-use, and various socio-economic 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 is to see what data are 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 which are developing. A very limited number of transportation studies are selected for careful and detailed data analysis to establish recommendations on guidelines for data requirements and collection techniques. The project defines data requirements for both basic and continuing urban transportation studies with regard to travel, transportation facility, land-use, and socio-economic data. Sensitivity analysis is performed to examine variations of the transportation data for assessing the impact that data errors have on the output of the transportation planning process.

A study has been completed 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 have been completed. Studies of data needs for new types of transportation-planning processes and alternate means of collecting data have been completed. The final report, a synthesis and guideline for data collection, is being prepared.

Project 8-8(1) FY '70

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: \$30,000

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 '70**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 '70**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: June 15, 1971
Funds: \$220,000

The increasing emphasis on social and esthetic values has focused attention on the need for improving integration of the highway with the community. To achieve desirable levels of such integration, research is needed to develop a practicable method for evaluating the effects of different types of highways, and of various design features, upon environmental value and to test, evaluate and refine the method through application to specific cases covering a range of community types and environmental situations. Methodology of this kind is needed to establish guidelines for use in highway planning, location, and design in reaching enlightened decisions on alternative location and design problems.

The objective of this research is to develop a practicable method of the objective evaluation of the immediate and long-term effects of highway types and design features upon environmental values. Although the scope ultimately should cover all types of highways and their design features, this study is to be limited to consideration only of highways in urban areas; i.e., expressways, freeways, parkways and major streets and highways (except local roads and streets).

Under projects 8-8(1) and 8-8(2) two agencies were selected to conduct independent study designs. As a result of the review of these alternate research approaches one agency was designated to carry on the second-phase work.

The urgent need is for a pragmatic approach which will change the way that community values are considered in highway location and design—in spite of the present lack of knowledge about how to measure and predict impacts

of highways upon community values. The evaluation method of this research is designed to maximize the probability that the 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 an evaluation method in the context of the location process.

The problems of measurement and prediction of impacts are not ignored, however. In the research, first priority is given to those research tasks devoted to the development of an evaluation method including community interaction techniques, the evaluation technique, location team strategy, and information display techniques. A portion of the research resources will also be used to attempt to advance incrementally the state of the art in measurement and prediction techniques, as a second priority area.

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 is 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 concerns the relationship between asphalt durability and pavement performance and specifically considers the contribution of asphalt adhesion to the durability of pavements and the development of suitable methods of tests for determining this property of asphalts. The initial effort is directed toward the evaluation of present techniques, or development of new techniques, for measuring the adhesion between asphalts and aggregates and toward the identification and evaluation of the factors that affect adhesion. The research approach to this problem is based on the theory of assessing interfacial activity and changes in the existing or resulting synergy of asphalt-aggregate systems from electrokinetic (streaming potential) measurements which can be related to temperature, the nature of the mineral aggregate, the characteristics of a particular asphalt, the solvent-extracted constituents thereof, and other physical and chemical factors.

Research has been divided into two phases—(1) instrumentation systems development and (2) data acquisition and correlation—and, to date, these have been pursued concurrently inasmuch as they are interrelated.

Streaming potential data (E/P vs T) have been collected for a number of AC-10 asphalt cements juxtaposed against a variety of natural and synthetic aggregates, and continuing study has been given to the selection of parameters for data presentation so that rapid analysis and interpretation can be made. The constancy of the streaming potential pressure (E/P) ratios has been examined as a measure of the accuracy of streaming potential data.

Studies of nonaqueous media systems have been initiated where it is planned to disperse solvent-extracted constituents of asphalts in media of varying dipole moments and to stream them through different aggregates. It is also planned for asphalt cements and other products to undergo the same treatment. Spectrophotometric studies have been made to ascertain procedural methods appropriate for the nonaqueous media systems and to obtain information regarding the identity and significance of factors influencing reactions between asphalts and aggregates. It is also planned to augment the knowledge on interfacial reactions by means of microcalorimetry studies.

Most recent effort has concerned (1) an assessment of the reproducibility of data obtained from the technique thus far developed for measuring asphalt-aggregate adhesion and (2) the identification and evaluation of factors which affect adhesion. Primary emphasis has been on the latter aspect, and attention has been given to instrumentation needed for the measurement of specific conductivity, dielectric constant, and viscosity for an asphalt cement and for the nonaqueous media systems. Existing equipment will be evaluated for adequacy in making these measurements.

Data collection and analysis have been completed. The major portions of the final report have been prepared, and the remainder are still being worked on by the principal investigator.

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."

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 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 have been determined; the present knowledge and state of development of various methods for meeting these needs have been investigated; and those methods with greatest promise for satisfying the needs in the areas of bituminous paving mixtures, base course construction, and soil compaction have been 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 is in the NCHRP editorial and publication process.

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 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 gages 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 gages currently in use.

Research on the continuation phase has been completed and the project report for this phase 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: \$47,486

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. The primary problems associated with these devices have been identified as sensitivity to 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 have been developed utilizing calibration model, energy discrimination, and dual-gauge principles.

The objectives of this project are:

1. The study and optimization of the dual-gauge principle for compensating gamma-ray density gauges for composition effects.
2. The study and optimization of the energy discrimination method for compensating gamma-ray density gauges for composition effects.
3. Additional study and optimization of the calibration model method for calibrating neutron moisture gauges.
4. The study of techniques for minimizing surface effects on the gamma-ray density gauges.

Individual research programs have been developed for each of the objectives. For optimization of dual-gauge principle, data have been collected for several gauge configurations, including three energy sources, various source-to-detector distances, and two types of GM tubes. A technique has been developed to evaluate the error introduced by surface heterogeneities. Early results indicate that the air-gap dual-gauge technique exhibits large surface heterogeneity errors. Some data have been collected with various energy sources at various source-to-detector distances and various collimation angles for optimization of the energy discrimination method of Objective 2. Early indications are that the high-energy component of the backscattered spectra are less sensitive to both density and composition.

For the neutron moisture gauge calibration, the Monte Carlo computer program has been completed and the re-

sults were found to agree very well with experimental data. Four neutron gauge moisture standards have been prepared covering a range of moisture contents and soil composition. These standards were prepared from polyethylene powder (to simulate water), sand, and iron powder.

Research has been completed, and the project report is being prepared by the agency.

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 non-destructive technique would be advantageous, both cost- and time-wise, in comparison to present methods. In initiating this research, four objectives were outlined. They include: (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 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 well 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 to make 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 Department of Highways
Principal Invest.: W. G. Weber
Effective Date: Contract pending
Completion Date:
Funds: \$149,835

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 non-destructive test methods for making conventional measurements. Pavement thickness should be determined non-destructively 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.

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: July 31, 1971
Funds: \$36,814

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 is to develop criteria for the need of seal coating bituminous surfaces. These criteria should 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 shall be distinguished. Also, the types of seals shall be classified. It is 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 $\frac{3}{4}$ inch or less; this will 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 is proposed that the following approaches may 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.

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 analyzes current legal rules and appraisal practices and suggest 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 researchers consisted of both legal and appraisal authorities. They analyzed the exiting law of compensability of various losses, valuation problems, and rules of evidence and procedure.

The project report is in the NCHRP editorial and publication process.

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, either to 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 are also studied.

The research includes a study of the general principles and techniques (both valuation and legal) which cause enhancement or diminution in the value of surrounding properties or those being taken by eminent domain as a resultant of the date of valuation or announcement thereof. Statutory laws of each of the 50 states were examined. Case law research was limited to five states considered in varying degrees to be representative of a broad cross-section of the country.

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 is in the NCHRP editorial and publication process.

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 explores 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 compre-

hensive, 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 is in the NCHRP editorial and publication process.

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 includes the Federal income and capital gains tax elements, but also treats these elements from a State income and ad valorem tax point of view for purposes of illustration.

The research distinguishes, for taxation purposes, between all of the different compensation elements involved (i.e., relocation payments, partial takes, etc.) It includes 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.)

The report is in the review stage.

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 report is in the review stage.

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 report is in the NCHRP editorial and publication process.

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; the present state of appraisal practice in the field involving these special use properties; and 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 is in the NCHRP editorial and publication process.

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 project report has been completed and is in the NCHRP editorial and publication process.

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 is to identify and clarify these elements. The research includes 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.

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 condemning 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 to 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, are developed as to the acquisition and valuation criteria that have been judicially prescribed. Comments are 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 is reviewed and cited, particularly law review articles, *ALR* annotations, and *The Appraisal Journal*.

The project report is in the review stage.

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.

This research utilized facts developed in a study entitled "The Highway Relocation Assistance Study," House Public Works Committee Print Number 9, July 1967. It included present legal authority; to wit, the reported appellate cases involving the principle of substituted compensation. Within this existing framework, various alternative means for assisting relocation were outlined, including public acquisition of land, movement of buildings, financial assistance for moving and construction of substitute housing, and other means. Special attention was given to possibilities for inter-agency and intergovernmental cooperation. Problems of identifying and measuring costs involved in alternative methods were analyzed, and a basis suggested for consideration of these factors in selection of alternative methods in specific illustrative situations.

The project report is in the review stage.

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 project report is in the review stage.

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.
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 careful and objective 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 is in the review stage.

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 a review of decided cases, discussing all the various elements of compensation involved.

The valuation research included a general discussion of valuation principles and concepts applicable to the junkyard use; gave careful and objective 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 other special damages; and recognized and separately treated the different types of junkyard establishments. Actual illustrations and case studies were utilized.

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: September 30, 1970
Funds: \$25,000

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 will be suggested to eliminate or diminish such divergences. The alternative solutions that are to be explored will include possible changes in the law, presentation and admissibility of valuation evidence, changes of appraisal concept or methods of administration.

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

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 this project was to develop mathematical design relationships which will define in general terms the basic behavior of welded coverplate beams under service loading conditions. In the accomplishment of this objective, the following work items were considered: (1) a review of existing fatigue data for beams with welded coverplates and any existing mathematical relationships that define this behavior; (2) the design of a statistically controlled experiment which will provide sufficient information for the development of suitable mathematical relationships relating the behavior of welded coverplated beams to applied stresses, design details, type of steels, and any other significant variables that may affect the basic behavior of such members; (3) initiation of fatigue studies under variable loadings (cumulative damage studies) which simulate service conditions for steel beam highway bridges; and (4) development of suitable mathematical design relationships to assist or aid in predicting the life expectancy of coverplated steel beam highway bridges.

Testing was carried out at Lehigh University and at Drexel Institute of Technology. Both static and fatigue tests were undertaken, and the initial fatigue failures of rolled-beam specimens agreed well with existing data.

Test results for the initial failure of coverplated beams indicate that minimum stress and grade of steel are not significant variables.

The research has been completed. The preliminary review copies of the final report were submitted in October 1969. The contract completion date was changed from September 30, 1969, to January 31, 1970, in order to keep the agency under contract throughout the report review period and have it available for work on revisions to the final report as directed. The report is in the review 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 Date: March 1, 1968
Completion Date: February 28, 1969
Funds: \$30,000

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 condi-

tions 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 research has been completed. The essential findings from the study have been reported in NCHRP Research Results Digest 12, (Oct. 1969). The final report is in the NCHRP editorial and publication process.

Negotiations are under way to arrange for continued work on bridge rail design criteria.

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 AASHTO specifications for elastomeric bearing pads.

Combined static and cyclic laboratory tests were conducted on various pad arrangements and configurations under conditions simulating, as nearly as practical, actual bridge conditions. The tests were on full-sized pads as large as 200 sq in. in area and as high as 9 in. under vertical pressures up to 2,000 psi, with horizontal movements of plus or minus one-half the pad thickness. Tests were conducted with a constant vertical load under continuous cycling at a frequency of about 30 load cycles per minute up to 100,000 cycles.

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. The final report is in the review process. The completion date was changed from October 31, 1969, to January 31, 1970, so that the agency will be available to revise the report as may become necessary.

Project 12-10 FY '70**Analysis and Design of Bridge Bents**

Research Agency: Portland Cement Association
Principal Invest.: Dr. John M. Hanson
Effective Date: January 1, 1970
Completion Date: December 31, 1972
Funds: \$250,000

The present strong emphasis on safe and aesthetic design of reinforced concrete highway bridges has resulted in substructure configurations which 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 which 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 should be based on prototypes having round or square reinforced concrete columns 5 ft thick, of 18-ft minimum length, spaced on about 40-ft centers in the bents, and with flares (where used) transverse to the longitudinal centerline of the bridge and parallel to the bent cap. Bridge spans of about 80 ft are to be assumed, and a girder depth/span ratio of about 0.055 should be used. Primary emphasis is to be given to box girders, but T or I sections are to be considered also. Grade 60 reinforcing steel is to be assumed for all cases.

The accomplishment of this research should include the following:

1. A review of the relevant technical literature to take advantage of previous work in this problem area.
2. Determination of a procedure that can be used to design a cap for single- and multiple-column bents. The configurations to be investigated should include:
 - (a) Single column of constant cross section with cap concealed and integrated into continuous superstructures;
 - (b) Multiple columns of constant cross section with caps concealed and integrated into continuous superstructures; and
 - (c) Multiple columns flared at the top with caps concealed and integrated into continuous super-

structures. Two flare conditions are to be investigated:

- (1) In the plane of the bent, flare symmetrically over a span of twice the column diameter or thickness. There is to be no flare in the plane normal to that of the bent.
- (2) In the plane of the bent, flare symmetrically over a span of three times the column diameter or thickness. There is to be no flare in the plane normal to that of the bent.

3. Determination of the design width of the cap by defining the extent of superstructure—normal to the cap—participating in supporting the cap loads. The cap will be concealed in a box girder structure, and part of the cap reinforcing steel may be carried out into the box girder slabs.

- (a) The slab will be thickened to $2t$ (t = deck thickness) near the cap, extending 10 ft out into the span.
- (b) The slab will not be thickened near the cap.

4. Proof testing of specimen designed by the recommended procedure.

5. Specifying those changes required in the AASHTO specifications to permit use of design procedures.

All models shall be designed and loaded in accordance with AASHTO specifications for bridge design. Loads will be positioned to obtain maximum cap loads and a critical load combination applied—increasing progressively to failure. The most progressive, currently used design theories should be utilized. It is anticipated that the end result of this research project will be recommended design procedures and suggested specification changes that would be necessary to implement them.

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."

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

Guardrail Performance and Design

Research Agency: Southwest Research Institute
Principal Invest.: Dr. R. L. Calcote
 J. D. Michie
Effective Date: July 1, 1967
Completion Date: March 31, 1970
Funds: \$280,000

There is a need to provide highway design engineers with a choice of effective guardrail systems. Considerable research has been conducted on the more commonly used types (W-beam, standard cable, box beam). This research needs to be compared and critically analyzed to determine what further investigations are necessary to refine structural details and obtain comparable performance. Full-scale testing is necessary to fill in the apparent gaps in previously concluded investigations. Accordingly, the objectives of this research are (1) to critically analyze existing data on guardrail performance and identify additional needed research; (2) to conduct the additional full-scale performance tests, which should include more than one value of the principal variables such as medium and high speeds, shallow and severe angles of approach, vehicle size, vehicle control, and point of impact; and (3) to evaluate the performance of the various guardrail systems considering vehicle response and damage as a measure of accident severity and rail repair.

Interim results from the research were published as:

NCHRP Report 54, "Location, Design, and Maintenance of Highway Guardrails and Median Barriers."

The research, which included a series of 23 full-scale crash tests on basic systems, end treatments, and transitions, has been completed. Preliminary review copies of the final report have been submitted.

The completion date was changed from December 31, 1969, to March 31, 1970, to keep the agency under contract throughout the report review period.

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 these two. The major emphasis of the research will be existing procedures for conditions intermediate between placed on developing a procedure for the design of armored channels, with investigations into the critical tractive force of gravel and crushed stone.

The initial phase research has been completed, and the essential findings have been published in NCHRP Research Results Digest 1. The complete report is in the NCHRP editorial and publication process.

Continuation of the research has been authorized and is under way extending the scope of the study to include channel bends and non-symmetrical shapes. A field evaluation program of the tentative design procedures developed during the initial phase is also included in the continuation work.

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.

There is a need to undertake an evaluation of current practice and research for the purpose of establishing rational design methods for both rigid and flexible pipe culverts. These design methods should permit the accurate prediction of the factor of safety against each possible mode of failure from measurable properties of the culvert system, bedding condition, and fill material. There is also a need for a better definition of the construction process and anticipated loadings. Toward meeting these needs, this research is to survey and evaluate existing information and current research in this field and develop a design procedure for both flexible and rigid culverts based on the evaluation.

Work during the first portion of the project consisted of staffing, completion of the literature review phase, visits to State highway departments to obtain information on current practices, and contact with culvert manufacturing representatives. In addition to the principal investigators, the following are serving as part-time consultants for the study: Jorj O. Osterberg, Northwestern University; George Herrmann, Northwestern University; Lester Gabriel, Sacramento State College; Gabor Karadi, University of Wisconsin; Merlin Spangler, Iowa State University; Merrill Townsend, BPR (retired); Colin Brown, Columbia University; and George Meyerhof, Nova Scotia Technical College.

Visits have been made to 13 State highway departments, as well as the Portland Cement Association, American Concrete Pipe Association, Illinois Concrete Pipe Association, National Corrugated Steel Pipe Association, Kaiser Aluminum Company, Reynolds Metals Company, and the Bureau of Reclamation. These visits have provided

considerable information on current design and construction practices with regard to the use of culverts. The visits, literature review, and information from three foreign countries have resulted in exposure to the majority of research in this field. A conference, attended by agency personnel, NCHRP staff, and representatives of both the Office of Engineering and Operations and the Office of Research and Development of the BPR, was held in Washington to provide additional information, particularly with regard to possibilities for practical application of the project findings.

A final report has been prepared that contains an extensive bibliography and synthesis of current knowledge on the design and installation of pipe culverts, plus proposed design criteria based on the synthesis. It seems apparent that information is not available at this time to develop a complete rational structural design procedure for culverts, due largely to a lack of generally accepted definition of pipe failure. However, it is anticipated that several specific factors, such as installation practices, construction techniques, soil type, and safety factor, can be given greater consideration in design criteria. This should result in significant improvement in pipe culvert design procedures.

Research has been completed, and the project report is in the NCHRP editorial and publication process.

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: November 30, 1969
Funds: \$299,902

The hydraulic phenomena involved in culvert design are fairly well understood and applied. As a necessary step, however, in the design of culverts, better hydrological procedures, productive of more reliable results, are needed for estimating runoff from small rural watersheds. Reliable procedures will permit more confident selection of the flow to be accommodated and, with recent advances in hydraulic and structural design, should help to optimize the expenditures for drainage structures.

Many State highway departments are participating with the U. S. Geological Survey in programs to collect runoff information from selected small rural watersheds. Other agencies have also gathered information related to a better understanding of the phenomena involved in the generation of runoff from small drainage areas. In addition, a number of investigations have developed methods for synthetically determining maximum discharge and hydrograph definition in relation to the parameters exerting a major influence on runoff. With this background it now appears possible, by analyzing the information and interrelating functionally the major parameters affecting runoff, to develop computer programs, or other procedures, that will, upon definition of the various parameters involved, produce an estimate of the

maximum discharges likely to occur from small rural watersheds for selected recurrence intervals.

The over-all objective of this project is to develop a better method(s) for estimating the magnitude and frequency of runoff from small rural watersheds (approximately 20 square miles or less). It is desired that the method will: (1) require only data that can be readily obtained by the designers, (2) use parameters and functional relationships which are logically justified, (3) take cognizance of differences due to geographical characteristics, and (4) present the information desired in a readily usable form.

A pilot study has been conducted using 92 Agricultural Research Service watersheds. The purposes of this phase of the overall study have been (a) to help formulate the hydrological/statistical experimental strategy, (b) to test procedures for data reduction and analysis, (c) to test the quality and quantity of available data, and (d) to provide first-cut statistical relationships between the climatic and physiographic variables and peak runoff. A detailed summary of the pilot study has been prepared and is currently being reviewed. The results of the pilot study were presented before the HRB Committee on Surface Drainage of Highways during the 1969 Annual Meeting of HRB.

A total of 493 rural watersheds with an area of 25 square miles or less and at least 12 years of surface runoff data has been selected for the main study. All available climatological data and physiographic information for these watersheds have been compiled on punch cards. These data, designated as a National Small Streams Data Inventory (NSSDI), will provide the input for the main study hydrological statistical analysis and the development of better methods for estimating the magnitude and frequency of runoff from small rural watersheds.

Of the 493 basins for which complete data have been compiled, 395 have been selected for analysis leading to the development of runoff prediction methods. The remaining 98 are being held for testing of the developed relationships. The first approach involves linear relationships between the numerous variables of the 395 watersheds. This is to be followed by eight or nine primary stratifications, several secondary stratifications, and non-linear studies. The end result should be prediction methods that are better than those available in most states.

Research has been completed, and the project report is in the review stage.

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 19, 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 per-

missible 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.

Dynamic forces were predicted from pavement roughness and vehicle characteristics and were experimentally verified. Among the factors included in the research were (1) a study and evaluation of existing information or research in progress that relates to this study; (2) development of techniques to obtain the desired information, including the design and construction of equipment and instrumentation for recording the desired information; (3) measurement of the pertinent characteristics of different types of heavy vehicles, including, but not limited to, static and dynamic axle loads, suspension effects, and sizes and dimensions of vehicles; and (4) development and experimental verification of a method to predict the dynamic loads that will appear at the tire-road interface.

The research has been completed, and the final report is in the NCHRP editorial and production process.

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 near-by 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: February 28, 1971
Funds: \$200,000

This study is being conducted in two parts. The objectives of Part I are to determine the adverse effects of deicing compounds used in winter maintenance operations in snow-belt areas on vegetation along the highway. Means will be 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 will be 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 will be made.

For Part I of the project, more than 30,000 plants of various types, as well as turf plots, have been established on soils of three distinctly different physiographic regions. These are located at Blacksburg (mountain), Warsaw (coastal), and Organ, Va., (piedmont). During the past two winters, plots have been treated with sodium chloride and calcium chloride at various rates. A number of plots received no treatment for comparison and for future treatment as more mature plants. After three winters, there is 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 have been collected for laboratory analysis. Chemical treatments, observations, and laboratory analysis will continue until the end of the study.

Part II of the study has been completed, and the report on this part of the project is in the NCHRP editorial and production process.

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

Recognizing the emphasis now being placed on roadside development, it is imperative that past and present research on this subject be interpreted and evaluated and recommendations made for additional research as needed.

The objective of this project is 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 will include, but not be 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 will be given to research under way or accomplished in legal authority, but it will not be evaluated in this project.

During the initial period of research, major emphasis has been on project organization and the listing of available information of roadside development research. In addition to the principal investigator, the agency has completed arrangements with seven persons of notable background and experience to act as associates or consultants during the study. A preliminary list of problem categories and subcategories has been compiled. Approximately 2,000 card file items have been selected from the BPR library as being related to roadside development. A manual search of HRIS has also been completed.

State highway department personnel in various parts of the country were interviewed to provide additional information on roadside development research, experience, and field problems.

Research has been completed, and the project report is in the review stage.

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: \$250,000

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 include an improved centralized accident record system in which accident data are integrated with appropriate nonaccident data. Also proposed is 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 is regarded as essential. Short-term rec-

ommendations include 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 are 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."

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: \$106,300

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 has 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.

A series of laboratory experiments was performed to demonstrate that revibration, using a surface vibrator, was a successful technique for closing surface cracks and internal voids in retarded concrete bridge deck model specimens.

Three field tests of this technique on actual highway bridges indicate that the technique is feasible in practice

and offers promise as an aid in producing more durable concrete bridge decks.

The research has been completed. The final report is in the review stage.

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.

In-depth State highway budgeting studies have been conducted in Pennsylvania, Texas, Kentucky, New York, and Nebraska. The differing concepts presented by these States will serve as a sound base for a standard budgeting system. The researchers visited ten additional States for on-site surveys and a questionnaire was mailed to the remaining States to obtain the desired budgetary information for each State.

Research has been completed, and the project report is in the NCHRP editorial and publication process.

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: June 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.

This research will first develop a proposed model highway maintenance performance budgeting system, taking into consideration simplicity and economy of installation and operation, and a pilot installation will be made to determine whether the procedures are reasonably adaptable to use by a state highway department.

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 are: (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.

A non-technical project report has been received. In addition, a report containing details documenting the system design and use is being prepared.

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: \$100,000

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 *

* 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.

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.

The technical report, "An Evaluation of Two Types of Freeway Control Systems," covering the 1967 research work has been completed and has been reviewed by the advisory committee. 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 Surveillance, Information, and Control System," has been completed. The report is in the review stage.

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.

Project 20-3A FY '69**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: Dec. 31, 1969 Dec. 31, 1969

Funds: \$248,730 \$20,000 *

* 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.

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.

Review of the incident data obtained from previous research was undertaken. An incident-detection strategy intended to minimize false alarms while still providing satisfactory reliability was developed. The effectiveness of the new strategy was compared with the model used previously. In addition, field trials to test automatic equipment were undertaken. Effectiveness of additional aids to detection were made, using primarily the television system to validate model output. Videotaping of incidents seen on television surveillance systems was also used.

Improved ramp meter-control techniques were continued. The number was removed from the signal head and special signs were erected. Different environmental conditions were evaluated in terms of freeway travel time as well as capacity.

New frontage-road, ramp-condition, information signs were installed. A comparison of the occupancy recorded with the ramp queue detectors and the length of the queue was made. Data on individual vehicles, as well as total flow and total travel, were collected for use in determining the use made of the alternate route.

As part of the experiment in traffic routing within the freeway corridor, eight information signs were installed on an alternate route from which eight of the nine ramps in the corridor are easily accessible. The new signs feature improvements in both visibility and legibility and give the motorist clear directions as to the best route to the Freeway. In the event that the three ramps named on the sign are congested, the motorist is directed to continue along the alternate route. It is possible, however, that the alternate route itself can become congested. When this occurs, another alternative route should be suggested to the motorist. To accomplish this, eighteen variable signs were installed in the corridor. These signs are of three types.

A variable-message sign gives routing information from the southern part of the corridor to the first uncongested ramp. Secondly, a blank-out sign is used to divert westbound Davison Expressway traffic attempting to enter a congested ramp of the northbound Lodge Freeway to Twelfth Street. Finally, sixteen trailblazer signs were installed at decision points in the corridor to indicate the appropriate route from each point.

Traffic-condition sampling took place in five one-lane positions on surface streets. Except for historical data, this

sampling provided little idea about travel times on routes parallel to the Freeway.

The University of Michigan submitted a continuation proposal for research work in 1970. It proposed additional work to improve the ramp-metering strategy, the operation of the Davison-Lodge Interchange, and the traffic routing in the corridor.

The continuation proposal is in the review process.

Project 20-4 FY '68

Public Preferences for Future Individual Transportation

<i>Research Agencies:</i>	Chilton Research Services (CRS) National Analysts (NA)
<i>Principal Invest.:</i>	Robert K. McMillan James M. Marshall
<i>Effective Date:</i>	May 2, 1967
<i>Completion Dates:</i>	January 21, 1969 (CRS) January 2, 1968 (NA)
<i>Funds:</i>	\$277,260

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 is 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 rela-

tion 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 FY '69

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: December 15, 1969
Funds: \$200,000

Administrators, practicing engineers, and researchers are continually faced with highway problems on which much information already exists, either in documented form or in terms of undocumented experience and practice. Unfortunately this information is often fragmented, scattered, and unevaluated. Often it is unknown to the person normally responsible for initiating changes related to the topic (changes in specifications, procedures, etc.). 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.

Another type of waste occurs if a number of people who have similar problems make independent efforts to assemble the appropriate information, especially if the assemblies are incomplete and not made available to others.

Textbooks, monographs, and state-of-the-art papers represent conventional methods for maximizing the use of existing information and for minimizing the total effort expended in bringing together useful information. All such documents involve the synthesis of information from various sources and can therefore be looked upon as *information syntheses*.

In this project particular highway problems, or sets of closely related problems, will be designated as topics for information synthesis.

For each topic the project objectives are:

1. To locate and assemble documented information on the topic.
2. To learn what engineering practice has been for solving or alleviating problems within the topic.
3. To identify all ongoing research on the topic.
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 document produced by attainment of the foregoing objectives will be called a synthesis of existing information on the topic. Objectives 1 and 3 imply full use of the Highway Research Information Service and other information systems for documented information. It is expected that information obtained for objectives 2 and 4 will be largely undocumented and will therefore be obtained through interviews in Federal, State and local agencies that have had first-hand experience with problems within the topic.

In conjunction with attainment of the stated objectives for each topic, overall project objectives will be to develop and refine (a) criteria for the selection of topics, and (b) systematic procedures for information synthesis. Achievement of these overall objectives will thus provide a system for the efficient production of syntheses that satisfy high-priority needs.

The document that results from the synthesis of existing information on a topic may be expected to contain answers to questions such as the following:

- (a) What are the problems under this topic? How do they arise in practice?
- (b) What is known about the solutions to these problems?
- (c) How are the problems handled in practice?
- (d) What are recommended practices?
- (e) What problems have not been satisfactorily solved?
- (f) What problems are being studied in current research?
- (g) What unsolved problems represent research needs?

The final report on Topic 1 has been published as: NCHRP Synthesis of Highway Practice 1, "Traffic Control for Freeway Maintenance."

The report describes the planning and scheduling for work-site traffic control, the protection of freeway work sites and lane closures, and the use and selection of control devices.

The final report on Topic 2 has been published as: NCHRP Synthesis of Highway Practice 2, "Bridge Approach Design and Construction Practices."

The report describes design, construction, and maintenance features relating to surface irregularities in pavement immediately adjacent to bridges.

The report for Topic 3, "Bridge Deck Durability," has been completed and is in the NCHRP editorial and publication process.

The final report on Topic 4 has been published as: NCHRP Synthesis of Highway Practice 3, "Traffic-Safe and Hydraulically Efficient Drainage Practice." The report treats median drainage structures, culvert end structures, curb inlets, roadside channels, special drainage structures, and standard prefabricated end sections. It also compares the cost of culvert extensions with guardrail barriers.

Topic 5, "Design of Bridge Piers to Withstand Scour," and Topic 6, "Application of System Analysis to Project Scheduling," are in the research and investigation stages. Draft reports are being prepared for topic panel review and comments.

Project 20-6 FY '69**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: October 31, 1971
Funds: \$200,000

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 there be initiated an appropriate mechanism 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 which have been undertaken, and perhaps more closely related, in the 1956-60 special HRB Highway Laws Project.

A paper entitled "Relocation Assistance Under Chapter Five of the 1968 Federal-Aid Highway Act," was published as NCHRP Research Results Digest 3 (Mar. 1969). The paper includes a discussion on the rule that compensation is for property taken and not as a payment to the owner and a discussion on constitutional authority to provide for payment of compensation in excess of the just compensation required by the Fifth Amendment. A proposed Act is also included which closely parallels Chapter Five of the 1968 Federal-Aid Highway Act.

The paper entitled "Standing to Sue for Purposes of Securing Judicial Review of Exercise of Administrative Discretion in Route Location of Federal-Aid Highways," was published as NCHRP Research Results Digest 6 (Apr. 1969). The paper discusses certain recent decisions in the Federal courts showing that changes are occurring which may indicate that traditional concepts of standing to sue to secure judicial review of the exercise of administrative discretion in respect to route location will no longer govern.

A paper entitled "Valuation Changes Resulting from Influence of Public Improvement" was published as NCHRP Research Results Digest 11 (Oct. 1969). The subject of discussion is the long-standing problem of whether to include or exclude in the valuation of lands condemned for a public improvement enhancement or diminution in value attributable to the improvement. The conclusion is reached in the paper, that legislative intervention is desirable, in order to achieve both harmony and practicality of judicial

approach to the problem. Hence, a suggested bill is appended to the paper, based in large measure on the approach taken by the legislatures of the States of Maryland and Pennsylvania, and prepared also with a view to the provisions of the Muskie Bill, S.1, before the Congress of the United States.

A study on legal matters pertaining to advance acquisition under the 1968 Federal-Aid Highway Act has been completed. The study includes a comprehensive discussion of relevant case law, a review of existing state legislation, a discussion of Section 7 of the 1968 Federal-Aid Highway Act as well as implementation thereof, and an Annotated Model Act.

A study on the influence of zoning on property valuation is in progress. The study will propose practical solutions to the question whether a highway department should be required to pay for an increased value of property where such increase in value is a result of a zoning change which would not have been effected were it not for the proposed highway.

A study on joint development and multi-use concepts is currently in progress. The study collects and collates existing case law and attempts to determine judicial trends. The objective is to present model legislation to include valuation, excess acquisition, and related problems.

Project 20-7 FY '69**Special AASHO Planning and Design Policies Committee Research**

Research Agency: Texas A & M University
Principal Invest.: C. J. Keese
Effective Date: December 2, 1968
Completion Date: March 1, 1970
Funds: \$100,000

The American Association of State Highway Officials (AASHO) Committee on Planning and Design Policies is continually called upon to rule on planning and design policies as a guide for state highway departments to follow. The Committee desires to attain guidance on a reasonably prompt schedule through a continuing research program geared to the needs and wishes of the Committee in the development of planning and design guides, standards, policies, and other AASHO activities. The Committee has further determined that the most expeditious means of obtaining research output usable by the Committee is by establishing a continuing research capability with the Texas Transportation Institute, thus permitting TTI to retain capable research staff specialists on a permanent basis.

Anticipated work will be a series of research studies (tasks) conducted to obtain practical and usable data for standard design criteria and the behavior of vehicle characteristics.

The types of tasks anticipated to be studied include, but are not limited to: (1) Cost-effectiveness studies of various roadside safety improvements that should be considered for provisions or adjustment in order to guide safety priority programs with available funds; (2) Run-down-the-slope

trials by typical passenger cars and trucks to establish combinations of slope-height-rounding that are "safe" in that the vehicle did not turn over or could be guided, as by a driver; (3) Vehicle-run trials to determine practical mounded earth shapes that could be used around median bridge piers in lieu of guardrails; (4) Wet pavement tests to explore feasibility of posting safe speeds for wet pavements, to examine correlation between skid resistance measured by skid trailers and by instrumented cars, and to confirm safe side-friction factors as presently established by AASHO; (5) Studies to re-evaluate stopping-sight distance; and (6) Test vehicle trials to determine optimum shapes and dimensions of curbs used in approach-nose and channelizing areas.

The first year's research consisted of four tasks:

Task 1, "Development of a Cost-Effectiveness Approach to the Programming of Roadside Safety Improvements," includes a survey of highway agencies' requirements of roadside safety improvements priority systems, explores the feasibility of adapting available cost and accident data for assigning safety improvements, and develops a recommended cost-effectiveness priority system.

Task 2, "The Relation of Side Slope Design to Highway Safety," explores the response of a vehicle when traveling a side-slope, ditch, back-slope terrain using variable vehicle encroachment angles, velocity, and physical characteristics of the vehicle and ground configurations. Analytical studies are performed using the single-vehicle accident mathematical simulation developed by Cornell Aeronautical Laboratories.

Task 3, "Development of an Effective Earth-Berm Vehicle Deflector," uses initially an analytical approach for preliminary selection of berm geometry. The Cornell simulation program used in Task 2 is also used for this study. The study includes a limited number of full-scale vehicle dynamics tests.

Task 4, "Re-Evaluation of Safe Side-Friction Factors Used in Design," examines the validity of the safety criteria employed for the design of horizontal highway curves. It includes a comprehensive review of the 1965 AASHO policy as it relates to highway curve design.

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: November 24, 1970
Funds: \$34,470

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 ultimate objective of research on this problem is to evaluate the suitability of existing instrumentation and techniques and to stimulate development of modified or new procedures to measure the amount and state of water in highway components such as embankments, subgrades, base courses, pavements, or structures.

The immediate need is for an evaluation of existing instrumentation, taking into consideration such factors as practicability, effect on sample, portability, sample size, accuracy, speed of measurement, stability, installation, versatility, precision, cost, simplicity of operation, durability, and serviceability.

Specific objectives of this project are to:

1. Review the state of knowledge regarding suitability of existing techniques and instrumentation to detect the presence of or to measure the amount and/or state of water in solid-water systems. Those techniques and devices that appear to be immediately applicable to highway problems are to be evaluated in detail. The development of a system for rating various techniques is believed to be inherent in meeting this objective.

2. Identify and make recommendations concerning moisture-measuring techniques that appear to be applicable to highway problems but which need further evaluation before their suitability can be determined.

3. Identify specific areas of investigation for which the development of new moisture-measuring instrumentation is needed and make recommendations concerning phenomena and devices which could lead to the development of suitable systems of measurement.

SUMMARIES OF UNPUBLISHED REPORTS

Research reports emanating from NCHRP projects normally are published in the *NCHRP Report* 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. The summary contained herein was prepared during the past fiscal 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 Bureau of Public Roads, 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 Program Director, Highway Research Board, 2101 Constitution Avenue NW, Washington, D.C. 20418

Project 12-4 FY '66

Thermal Characteristics of Highway Bridges

By: Thein Wah
Raymond E. Kirksey
Research Agency: Southwest Research Institute

It has long been recognized that temperature changes affect highway bridges in many different ways; however, in practice, design procedures have been limited to an estimate of the gross thermal expansion or contraction of the bridge span, and, in the case of reinforced slabs, to recommending certain percentage increases in the reinforcing steel to take care of thermal effects.

Recently, however, there has been a growth of interest in the thermal behavior of bridges, and investigations, both theoretical and experimental, have been undertaken in the U. S. and elsewhere. Much of the work in the U. S. has been carried out by William Zuk and his co-workers (1-7). The British Road Research Laboratory has also undertaken several investigations (8-11).

The work of Zuk et al. is notable for the enormous quantity of data collected on temperature gradients in actual bridges, both insulated and uninsulated. Agreement between theoretical predictions and measured values of stresses was generally unsatisfactory. The investigators attributed this to secondary and nonlinear effects such as creep and plastic flow of concrete.

A theoretical analysis of the thermal stresses in a beam-slab bridge under idealized conditions is possible and is given in the complete report. Despite simplifications, the equations are quite lengthy and involved.

Present design methods allow only for uniform thermal expansion of bridge structures. Consequently, simple span structures are assumed to remain free of thermal stresses by

virtue of relief provided by expansion joints. Only the effects of actual length changes are considered in continuous-type bridges. Field measurements indicate, however, that stresses may be induced by thermal gradients caused by rapid temperature changes or by solar radiation acting on only a portion of the structure. The magnitude and significance of these stresses are unknown.

The objectives of this research were to:

1. Determine the magnitude and significance of thermal gradients in girder-supported highway bridges.
2. Develop an analytical method for prediction of thermal stresses due to thermal gradients.
3. Revise present methods for prediction of longitudinal expansion and contraction of bridges to reflect stresses due to thermal gradients.
4. Validate the analytical method by field tests.

In keeping with these objectives, the theoretical investigation consisted of two parts, as follows:

1. An analysis of the thermal deflections and stresses as a result of arbitrary temperature gradients in the bridge slab and supporting beams. The configuration selected for the analysis is a slab supported on any number of identical and equally spaced girders which are simply supported at their extremities. This type, a beam-slab bridge, is extensively used. Another type—a multibeam bridge—is also widely used. In the second type, the slab surface is an integral part of the beams, while the beams themselves may assume any of several different configurations. Although this type deserves investigation in its own right, an analysis assuming such a configuration will not apply to the beam-slab bridge because slab action is largely absent. On the other hand, by assuming that the "slab" is very narrow, the multibeam bridge could be treated as the limiting case of the beam-slab

configuration. The success of such a procedure cannot be predicted in advance.

In this analysis, flexure is considered the dominant action because thermal gradients in the slab and beams result in bending. An investigation incorporating the in-plane displacements also is possible, but it is simpler to consider this as a separate problem.

This analysis was intended to provide predictions regarding stresses and deflections of bridge decks under thermal loading. However, the general solution for three-dimensional temperature variations resulted in cumbersome mathematical expressions. This was not unanticipated, but it was hoped that they could become the basis for simplified and semi-empirical equations.

2. A theoretical analysis of the in-plane displacements in a beam-slab bridge resulting from temperature changes. This simplified problem assumes that a sufficiently accurate picture of the displacements in the plane of the slab and beams was possible by considering the slab as being infinitely wide. Actually, it predicts what could happen in the central portion of the bridge. It yields formulas that are somewhat more general than those currently used for longitudinal expansion, which presuppose a uniform temperature change over the whole structure.

The purposes of the experimental phase of the program were (1) to provide data for verifying and/or modifying the theoretical analysis, and (2) to gain an insight into the major behavioral characteristics of a bridge under thermal gradients. The experimental work involved the following:

1. Testing of a laboratory model concrete slab, which included a single symmetrically located steel beam. The slab was lightly reinforced to produce measurable deflections over the relatively small lateral dimensions of the slab. The model was subjected to a heat source from three or four banks of heat lamps suitably placed above its top surface. The test set-up was designed to give several different types of thermal gradients in the slab and beam. The lateral deflections of the slab and beam were monitored at several points. The strains experienced in the concrete, the reinforcing steel, and the steel beam were also monitored.

2. Field tests were conducted on a multibeam bridge recently constructed near San Antonio, Texas, not yet opened to traffic. The bridge chosen consisted of a number of pan-formed beams, so that the slab portion of the superstructure is virtually indistinguishable from the beam. The choice was unfortunate because it bordered on the limits of applicability of the theoretical analysis developed for beam-slab bridges.

An attempt was made to correlate the theoretical and experimental results for both the laboratory model and the bridge. The difficulties encountered in this effort were (1) the deviation of the actual boundary conditions from the theoretically assumed ones, (2) the deviation of the experimental bridge from the ideal beam-slab bridge for which the analysis is strictly applicable, (3) the inaccuracy

of the assumed material properties, (4) the imponderable effects of the field conditions (such as wind) in the field tests, and (5) the time lag between the measurement of the temperature and the measurement of the deflection, particularly in the field tests.

Analytical Methods

The type of bridges under study may be broadly described as a roadway slab supported by longitudinal girders. A distinction has to be made between those bridges in which the beams are so closely spaced that the slab action is virtually absent (the slab in effect serving as the top flange of the beams), and those types in which the beams are widely spaced and the slab assumes true slab action between them. The former type is more properly called a multibeam bridge, whereas the latter is referred to as a beam-slab bridge.

Analysis is based on the idealization of the beam-slab bridge, and the notation used is shown in Figure 1. Two types of theoretical analyses were undertaken: one relating to the thermal expansion of beam-slab bridges, the other to the flexure of beam-slab bridges under thermal loads. In addition, an analysis of heat conduction in a bridge slab under arbitrary variations of atmospheric temperature was also carried out, but is not reported because of lack of experimental data.

A theoretical analysis of the thermal expansion in beam-slab bridges consisting of an arbitrary number of beams is possible, but quite complicated. The governing differential equations have been derived and appear in the complete report. No experimental verification was undertaken.

A general analysis of this problem was not carried out. A much simpler analysis that yields formulas that give the expansion of the beam and the slab for certain simple cases of temperature distribution was developed. The variations permitted are as follows:

1. The temperature may vary in any manner through the thickness of the slab and over the cross-section of the beams.

2. The temperature in the beam may vary in any manner along its length.

3. In the slab, the temperature is constant in the transverse direction.

4. The temperature in the slab may either be constant in the longitudinal direction or vary linearly.

Based on these and other assumptions, the following formulas were derived for the expansion of the beam and slab, respectively.

$$u_b = \sum_{m=1}^{\infty} \left(\frac{4}{(1 + \nu_c) A E} B_m + \frac{a \alpha}{m \pi} T_{bm} \right) \left(1 - \cos \frac{m \pi x}{a} \right) \quad (1)$$

for arbitrary longitudinal variation of the temperature.

$$u_b = \frac{4}{(1 + \nu_c) A E} \sum_{m=1}^{\infty} B_m \left(1 - \cos \frac{m \pi x}{a} \right) + a \left(T_{0b} x + \frac{T_{1b} x^2}{2} \right) \quad (2)$$

for a linear longitudinal variation of the temperature.

$$u = \frac{(1 + \nu_c)}{E_c h} \sum_{m=1}^{\infty} \frac{m \pi}{a} B_m \left[e^{-m \pi y/a} \left\{ \frac{3 - \nu_c}{1 + \nu_c} - \frac{m \pi y}{a} \right\} \cos \frac{m \pi x}{a} - \frac{3 - \nu_c}{1 + \nu_c} \right] + a_c \left(T_{0s} x + \frac{T_{1s} x^2}{2} \right) \quad (3)$$

$$v = \frac{(1 + \nu_c)}{E_c h} \sum_{m=1}^{\infty} \frac{m \pi}{a} B_m \frac{m \pi y}{a} e^{-m \pi y/a} + a_c \left(T_{0s} y + \frac{T_{1s}}{a} x y \right) \quad (4)$$

If the beam and the slab have the same coefficient of thermal expansion and also the same temperature distribution (that is, a linear function of x only), it is possible to get the same formula for the longitudinal displacement of the beam and the slab:

$$u = a_c \left[T_{0s} x + \frac{T_{1s} x^2}{2} \right] \quad (5)$$

In Eqs. 1 to 5

$$B_m = \frac{a^2}{m^2 \pi^2} \frac{E_c h}{(3 - \nu_c)} (a_c T_{sm} - a T_{bm}) \left\{ 1 + \frac{4 E_c h a}{A E (3 - \nu_c) (1 + \nu_c) m \pi} \right\} \quad (6)$$

E, E_c = modulus of elasticity of beam and slab, respectively;

ν_c = Poisson's ratio for slab;

h = thickness of slab;

α, α_c = coefficient of thermal expansion (in./in./°F) of the beam and slab, respectively;

A = cross-sectional area of beam;

a = span of beam and slab;

u_b, u = longitudinal displacement of beam and slab, respectively;

v = transverse displacement of slab;

x, y = longitudinal and transverse coordinates measured from fixed end of beam;

T_{0s}, T_{1s} = temperatures in slab, °F; and

T_{0b}, T_{1b} = temperatures in beam, °F.

The temperature variation in the beam and slab are assumed to be of the form

$$T_b = T_{0b} + T_{1b} \frac{x}{a} \quad (7)$$

$$T_s = T_{0s} + T_{1s} \frac{x}{a} \quad (8)$$

If the temperature in the beam is uniform, then $T_{1b} = 0$.

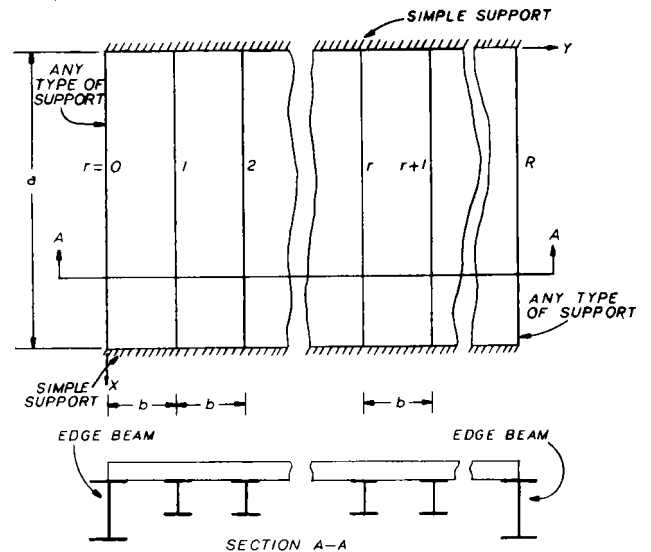


Figure 1. Analysis notation.

Eq. 7 thus represents a beam with the temperature, T_{0b} , at one end varying linearly to $(T_{0b} + T_{1b})$ at the other end. Similar remarks apply for the slab, Eq. 8.

The temperature may vary arbitrarily over the cross-section of the beam and thickness of the slab. At any cross-section of the beam, the temperature, T_b , is the "average" temperature

$$T_b = \frac{1}{A} \int_A T dA \quad (9)$$

Similarly, at any point in the slab, the temperature is

$$T_s = \frac{1}{h} \int_{-h/2}^{h/2} T dz \quad (10)$$

in which T is the actual temperature within the beam or slab.

In calculating the coefficients T_{sm} and T_{bm} , for the coefficient B_m in Eq. 6, a Fourier series expansion of the temperature distribution is required. These are given in the complete report.

A nonuniform temperature distribution through the thickness of the slab and the cross-section of the beam causes the system to bend just as if a lateral load were applied to it. The problem has been analyzed on the basis of certain assumptions: (1) the beams and slab are simply supported at the abutments, and (2) all the beams, with the possible exception of the two edge-beams, are identical and equally spaced.

The assumption of identical and equally spaced beams is made not only for mathematical convenience but also because such bridges are common in practice. The method admits of modification to cases where the beams and spacing vary, but the resulting equations are cumbersome and a mathematically elegant solution is not feasible. When the beams have differing flexural and torsional rigidity and are unequally spaced it is necessary to write the equations of

equilibrium for each beam and solve the resulting system of equations simultaneously. If, as assumed in this report, the beams are identical and have the same spacing, it is possible to use finite difference calculus and avoid the solution of simultaneous equations. The mathematical details are presented in the complete report.

Figure 1 shows the beam-slab bridge and the coordinate system used. Suppose that the slab as a whole is subjected to an arbitrary temperature distribution which may vary longitudinally, transversely, and through the thickness. The individual beams of the system are also subjected to an arbitrary variation of temperature over their lengths and cross-sections. It is desired to find the resulting deformations and stresses over the entire system.

The differential equations for the deflection of the slab and beams are very similar to the governing equations for plates and beams under lateral loading. It is thus convenient, for purposes of description, to speak in terms of the better-known concepts relating to the deflection under lateral loads.

Although analogous, differences naturally exist between the lateral load and the thermal load problems. The principal differences are:

1. The temperature can vary over the thickness of the slab as well as over the surface, whereas lateral loads can vary only over the surface.
2. The deflection of the beam is due to the shears from the adjacent slab panels as well as the variation in temperature in the beam itself. In the lateral load problem, the deflection is due to the shears only.
3. The expressions for bending moments and shears in the slabs and beams are somewhat different from the case of the nonthermal problem.

Assuming, then, that the slab is under some kind of lateral loading, suppose that all the supporting beams are initially prevented from deflecting and rotating. Each panel of the slab then becomes a plate simply supported at two opposite edges and clamped at the other two edges, and subjected to lateral loads. By ordinary plate theory, it is possible to find the "fixed-end moments" and "fixed-end shears" at the clamped edges.

The next step is to derive the "slope-deflection" relations for any panel of the slab. These equations are, of course, independent of the loading and merely give relations between the moments and shears at two edges of the slab panel when the same edges suffer given deflections and rotations.

The final step in the analysis is to write the equations of equilibrium of any beam of the system which is subjected to the resultant shears and moments from two adjacent plate panels, and satisfying the condition of continuity of the slope and deflection. It turns out that, when the beams are identical and equally spaced, it is possible to use finite differences calculus to obtain an explicit solution for the deflection of the entire plate beam system.

The solution of this problem gives expressions for the deflection and bending moments in the system. The expression for the deflection is

$$\begin{aligned}
 w = & \frac{T_{00} b^3 R^3}{\pi^4 a h} \sum_{m=1}^{\infty} \left\{ G_{rm} \phi_1(y) + G_{r+1, m} \phi_2(y) \right. \\
 & + F_{rm} \phi_3(y) + F_{r+1, m} \phi_4(y) - \sum_n \frac{a_{mn}}{\left(\frac{m^2 b^2 R^2}{a^2} + n^2 \right)^2} \\
 & \left. \sin \frac{n \pi y}{Rb} \right\} \sin \frac{m \pi x}{a} + \sum_{m=1}^{\infty} \left\{ b \theta_{rm} \phi_1(y) + b \theta_{r+1, m} \phi_2(y) \right. \\
 & \left. + W_{rm} \theta_3(y) + W_{r+1, m} \theta_4(y) \right\} \sin \frac{m \pi x}{a}^*
 \end{aligned} \tag{11}$$

The generality of the solution leads to rather lengthy equations, which can be solved conveniently only on a digital computer. A computer program has been developed for this purpose.

It is pertinent to note the difficulties inherent in any theoretical formulation of this complex problem. Some of these difficulties are the same as those associated with the common nonthermal stress analysis problems. Thus, any mathematical analysis must begin with certain idealizations of the structure, and, if the structure deviates too markedly from the mathematical model, the experimental and theoretical results could not be expected to agree. Yet, the mathematical model must be capable of accommodating some departures from the idealized picture, or the generality—the basic advantage of a mathematical analysis—is lost.

For example, concrete is assumed to be a homogeneous, isotropic, elastic material, so that it is possible to apply the theory of elastic isotropic slabs to the beam-slab bridge. This assumption, and others, are, to say the least, inaccurate, but other assumptions would have made the solution considerably more complicated, and, if nonlinear effects such as creep and plastic flow are included, a solution would be virtually impossible.

Experimental Study Using Subscale Laboratory Models

The primary purpose of the laboratory tests was to provide experimental data on a model bridge structure with a configuration that was close to the idealized mathematical model and yet not too different from a highway bridge.

It was at first supposed that a slab of proportions approximating those in a highway bridge and, similarly reinforced, should be used. Preliminary tests showed, however, that the thermal gradients, although reasonably large, did not produce measurable deflections in the slab or the beam. The attempt to duplicate a highway bridge slab was abandoned, and a second model was designed with a much thinner slab.

The second model was tested under various temperature distributions, and the data reported are confined to this model.

The experimental data sought consisted of (1) the deflections of the slab and of the beam at several points, (2) the strains in the concrete and in the wire mesh re-

* This equation is included only for the purpose of illustrating its form. Notation is explained in the complete report.

inforcement, and (3) the strains in the steel beam at various locations.

To compare experimental data and calculated values of deflections and stresses, it was necessary to measure the temperature distribution in three dimensions. This was achieved by appropriately embedded thermocouples.

The strains in the concrete and the steel reinforcement were obtained from embedded strain gauges, and, in the steel beam, from strain gauges placed along the length and over the cross-section of the beam. The deflections of the slab and beam were monitored by Ames dials.

The laboratory tests were to provide guidelines for the field tests to follow and also to provide data to evaluate the theoretically derived formulas.

The criterion for the design of the test article was to provide a flexible beam-slab model so that significant deflections and strains would be induced under the applied thermal loads.

Figures 2a and 2b show the slab and instrumentation details. Attention is drawn to the following details: the slab is supported all along its boundary by angles which form virtual knife-edges, thus simulating the theoretical "simple support" boundary conditions. The test arrangement did not permit the support of the beam to be coincident with the edge of the slab, as might ideally be wished. The "span" of the beam was thus somewhat shorter than the longitudinal span of the slab.

Embedment gauges were used for measuring concrete strains. Foil gauges were used for measuring strains in the steel reinforcement. Altogether there were 50 strain gauges in the model. Ames dial readings for deflection of the slab were taken at 15 locations.

Thermocouples were placed at six locations through the thickness of the slab, spaced as shown in Figure 2b. Twenty-five thermocouple stacks were placed in the slab, making a total of 150 thermocouples. An additional 20 thermocouples were placed in the beam at five different sections, with four at each section. Thus, temperatures could be measured at 170 points in the model.

Figure 3 shows the test model prior to concrete casting. It shows the position of the various sensors.

The model was heated by infrared bulbs placed in a bank covered by an aluminum hood so that the heat was directed downward on the slab. Each bank carried eight heat lamps, as shown in Figure 4. A maximum of four banks was available for the tests.

It was found that the simplest way of varying the distribution and intensity of heat input to the slab was by (1) varying the position of the banks by placing them transversely or longitudinally with respect to the slab, and (2) raising or lowering the hoods in a number of different positions. Some of the heating arrangements are shown schematically in Figure 5.

The tests were begun early in the morning. Ambient temperatures were recorded, as were readings of each of the thermocouples in the slab and the beams. This was accomplished by ten switches, each of which had 18 positions. A 100-channel BLH automatic recorder was used to record the "zero load" readings of the strain gauges. The deflec-

tometer readings were also taken at this time. It is to be noted that automatic recording was not used for the thermocouples.

The particular arrangement of the heat banks having been decided on, the heat was turned on, and kept on, with the banks in the same position for the remainder of the day.

The thermocouple, strain gauge, and deflectometer readings were taken approximately every hour during the day. Because the deflections and strains were to be related to the temperatures at any given instant, a certain time lag between the deformations and the temperatures was inevitable because of the manual reading and recording. However, this discrepancy is believed to be small, except possibly at the start of the tests.

The difficulty of converting strains to stresses in the circumstances of the test is also to be noted. The strain gauge in the slab or beam not only experiences a stress-produced strain but also undergoes a change in resistance due to changes in temperature. In these tests the gauges used for steel were of the temperature-compensating type. The only source of error was in correcting for change in sensitivity. An average value of the gauge factor was used for the temperature of the tests, instead of a different factor for every gauge for the particular temperature. The concrete gauges were not self-compensating, so that a temperature correction was made of the measured output.

Representative experimental data for selected tests are shown in Figure 6. The temperature variation at the nearest thermocouple station is given for both the top and bottom of the slab. As may be expected, the temperature is higher at the top of the slab than at the bottom in all the locations, and this feature is preserved throughout the day. The temperature difference between the top of the slab and bottom of the slab increases slightly during the day while the temperatures get higher as the test progresses.

Figure 6 also shows the lateral deflection of the slab at various locations. An interesting feature of these deflections may be noted. Soon after application of the heat, the deflections are upward, as may be expected from the fact that the top surface of the slab is everywhere hotter than the bottom. However, as time progresses, although the temperature difference between the top and bottom remains nearly the same, the slab deflection gradually decreases in magnitude and, in many of the plots, actually reverses itself in direction. This feature may be explained on the assumption that the slab creeps under the temperatures of the test.

The deflections of the slab were calculated from Eq. 11. The input parameters, apart from material and geometric properties of the beam and slab, are the integrals $\int Tzdz$, which express the temperature distribution. Theoretically, these integrals must be evaluated at every section of the slab, but in practice they are calculated at a discrete number of points. These discrete points were chosen at the thermocouple stacks. The integrals were evaluated by use of a computer program, using the thermocouple readings at the different stacks as input. After calculations of the integrals, the computer program automatically fitted a polynomial in x and y , and then expanded the Laplacian of the

polynomial in a double Fourier series. This yields the coefficients a_{mn} in Eq. 11. Eq. 11 gives the slab deflection everywhere, as well as the deflection of the beam.

The deflections of the slab as computed and measured are shown in Figure 6. Note in Figure 6 that the best correlation between theoretical and test data is immediately after the start of the tests. The trend of the test results then deviates from the theoretically predicted values.

As pointed out previously, the temperature difference between the top and bottom surfaces remains approximately the same. Specifically, the top of the slab is always hotter

than the bottom, although the distribution within the slab may be different. Clearly, the trend of the test data contradicts the common-sense expectation that the deflection remains negative, whereas the theoretical results reinforce this expectation. This anomaly may be explained on the assumption that the slab creeps under the influence of temperature. Because the basic equations do not take account of creep, the best that can be expected of them is a prediction of the response at the early stages of heating—that is, before creep effects begin to dominate the behavior of the slab.

The thermal stresses in the slab, both in the concrete and

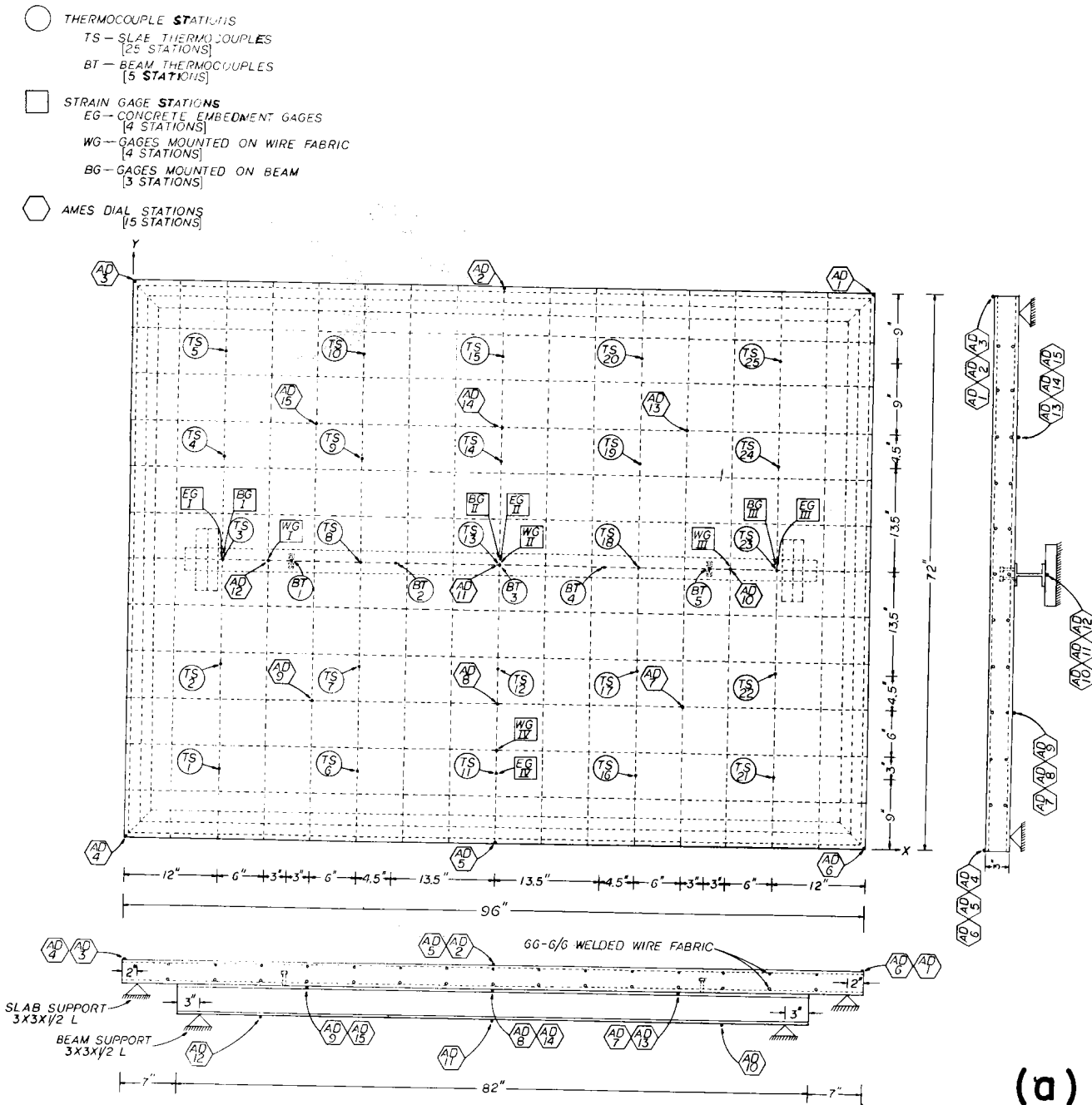


Figure 2. Test slab, typical details.

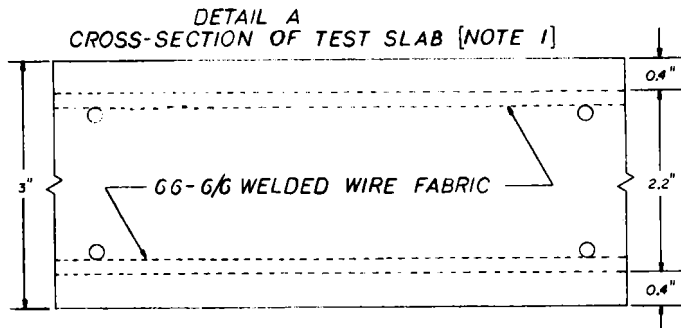
(a)

the reinforcing steel, were obtained experimentally from the strain-gauge readings and the usual elasticity formulas for converting strain to stress.

The difficulty of obtaining accurate stress data from measured strain data when creep is present is obvious. All that

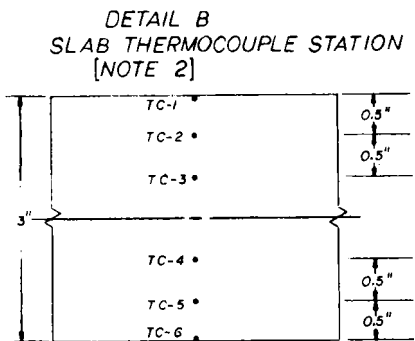
could be reasonably expected is to obtain stresses before creep effects become predominant—that is, at the very early stages of the heating.

Figure 7 shows computed “thermal stress” data, based on experimental strains, at the gauge at the center of the slab.

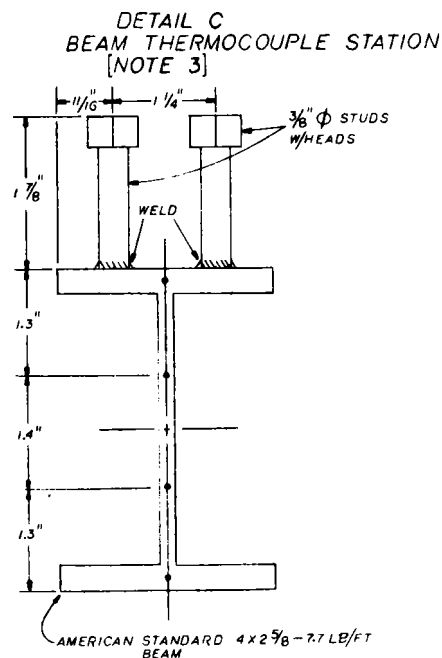
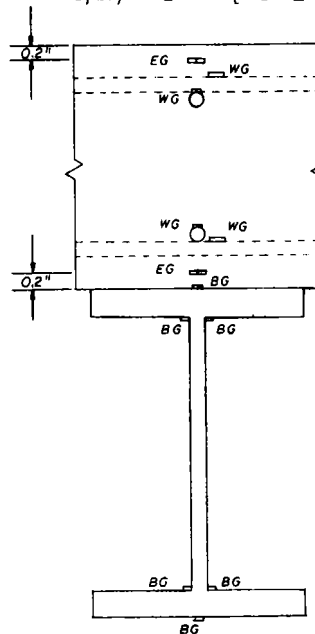


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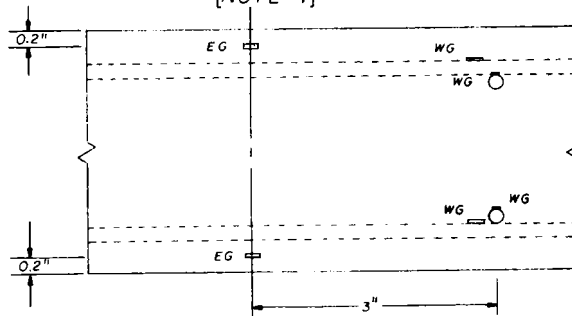
1. CONCRETE: 1-2.5-2.5 CEMENT-SAND-AGGREGATE PROPORTIONS, 5.5 GAL/SAC WATER-CEMENT RATIO, AGGREGATE-PEA GRAVEL.
2. TC-THERMOCOUPLE; SIX TC AT EACH STATION [25 STATIONS], TC-1 AND TC-6 BEING BELOW THE SURFACE OF THE SLAB.
3. FOUR TC AT EACH STATION [5 STATIONS], TOP AND BOTTOM TC'S BEING 3/12" BELOW THE SURFACE OF THE FLANGE. ALL TC'S ARE PLACED ALONG THE CENTER-LINE OF THE BEAM WEB AND HELIARCED IN PLACE.
4. EG-EMBEDMENT STRAIN GAGES [BLH AS-9]. GAGES PLACED LONGITUDINAL AND TRANSVERSE TO SLAB AT EACH LOCATION. WG-STRAIN GAGES [EA-06-031DE-120] MOUNTED ON WIRE FABRIC WITH RESPECT TO THE SLAB. LONGITUDINAL GAGES ARE MOUNTED ON THE INTER WIRES, AND THE TRANSVERSE GAGES ON THE OUTER WIRES. BG-STRAIN GAGES [EA-06-031DE-120] MOUNTED LONGITUDINAL WITH RESPECT TO THE BEAM.



STRAIN GAGE STACKS AT STATIONS I, II, AND III [NOTE 4]



STRAIN GAGE STACK AT STATION IV [NOTE 4]



(b)

Figure 2 (continued).

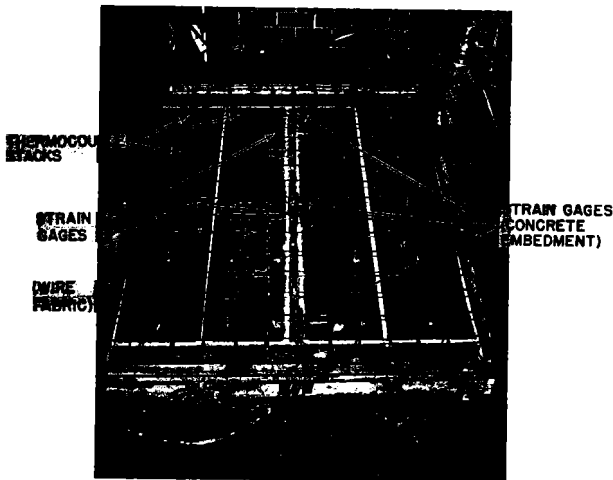


Figure 3. Beam-slab bridge model.

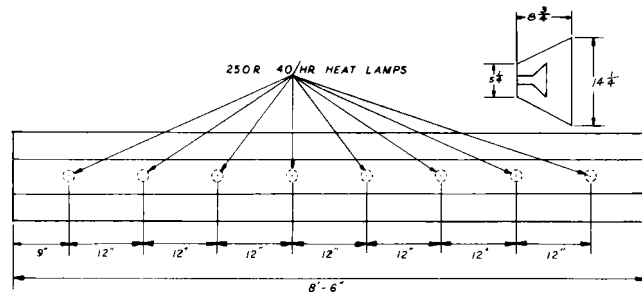


Figure 4. Typical heat bank.

The temperature data (TS 13) may be obtained from Figure 6.

Theoretical stress distributions were calculated by first calculating the bending moments and then applying necessary corrections. To obtain stresses from moments, the slab-stress formulas

$$\sigma_x = \frac{12 M_x z}{h^3}, \quad \sigma_y = \frac{12 M_y z}{h^3}$$

were used. Here, z is the distance to the strain gauge measured from the neutral plane of the slab.

The theoretically calculated stresses are not shown in Figure 7 because no reasonable correlation could be found. As might be noted, the experimental "stresses," derived from measured strains, are quite erratic.

If the laboratory tests are considered to be qualitatively representative of bridge behavior, certain conclusions may be drawn regarding the significance of thermal loads:

1. Creep effects appear to have a dominant influence on the behavior of heated slabs. Regarding deflections, the usual pattern of heating (hotter on the top surface than on the bottom surface) is such that creep deflections tend to nullify thermal deflections.

2. The thermal "stresses," as computed from measured values of strains, are quite large. But, because of the effects of creep, the experimental values of stress may not be indicative of the actual stress distribution.

Experimental Analyses of Highway Bridge

The purpose of carrying out field tests was to obtain experimental data on the variation of temperature distribution in an actual bridge, and to observe whether temperature changes in the field result in strains and lateral deflections which are of significant magnitude. Further, it was the aim to correlate the observed temperature distributions with the observed strains and deflections by means of a theory of the type described previously.

The selection of a suitable bridge for the field tests was

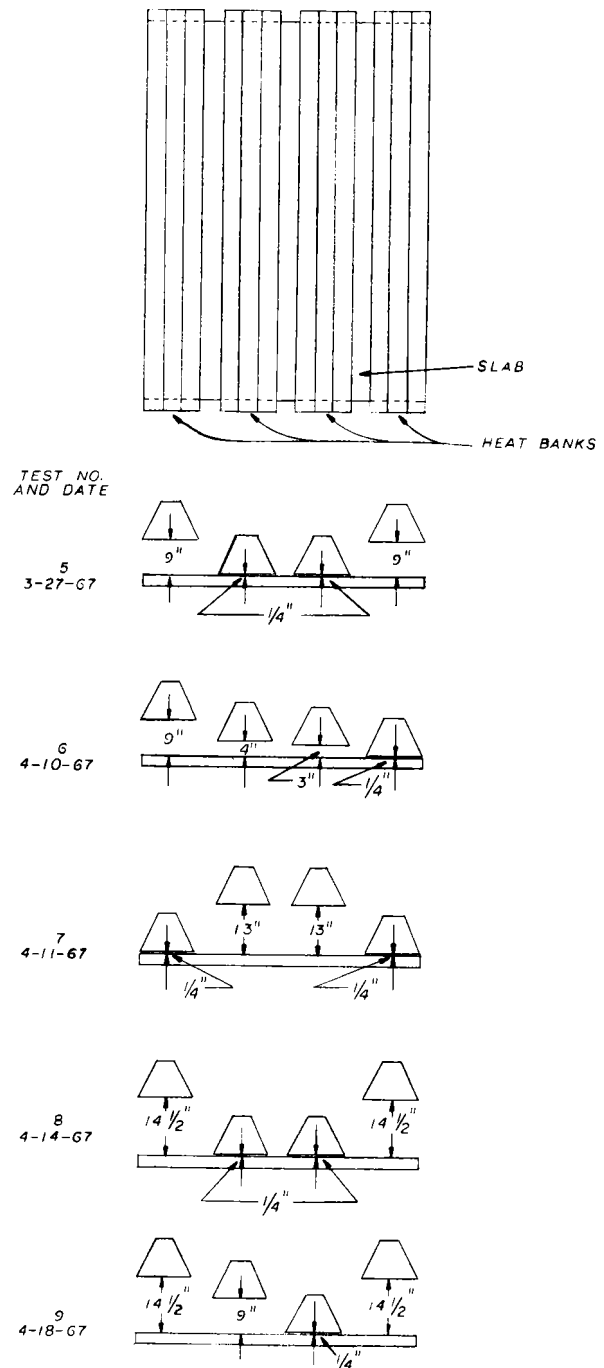


Figure 5. Some heat bank arrangements.

limited by several factors. First, it was important that the bridge be in reasonable proximity to the research agency. Second, although a large number of bridges was scheduled for construction around San Antonio, Texas, many of them

would not have met the time schedules required by the research program. Third, all bridges were not suitable for the purposes of the test, because it was thought essential that the bridge be simply supported, free from skew, etc.

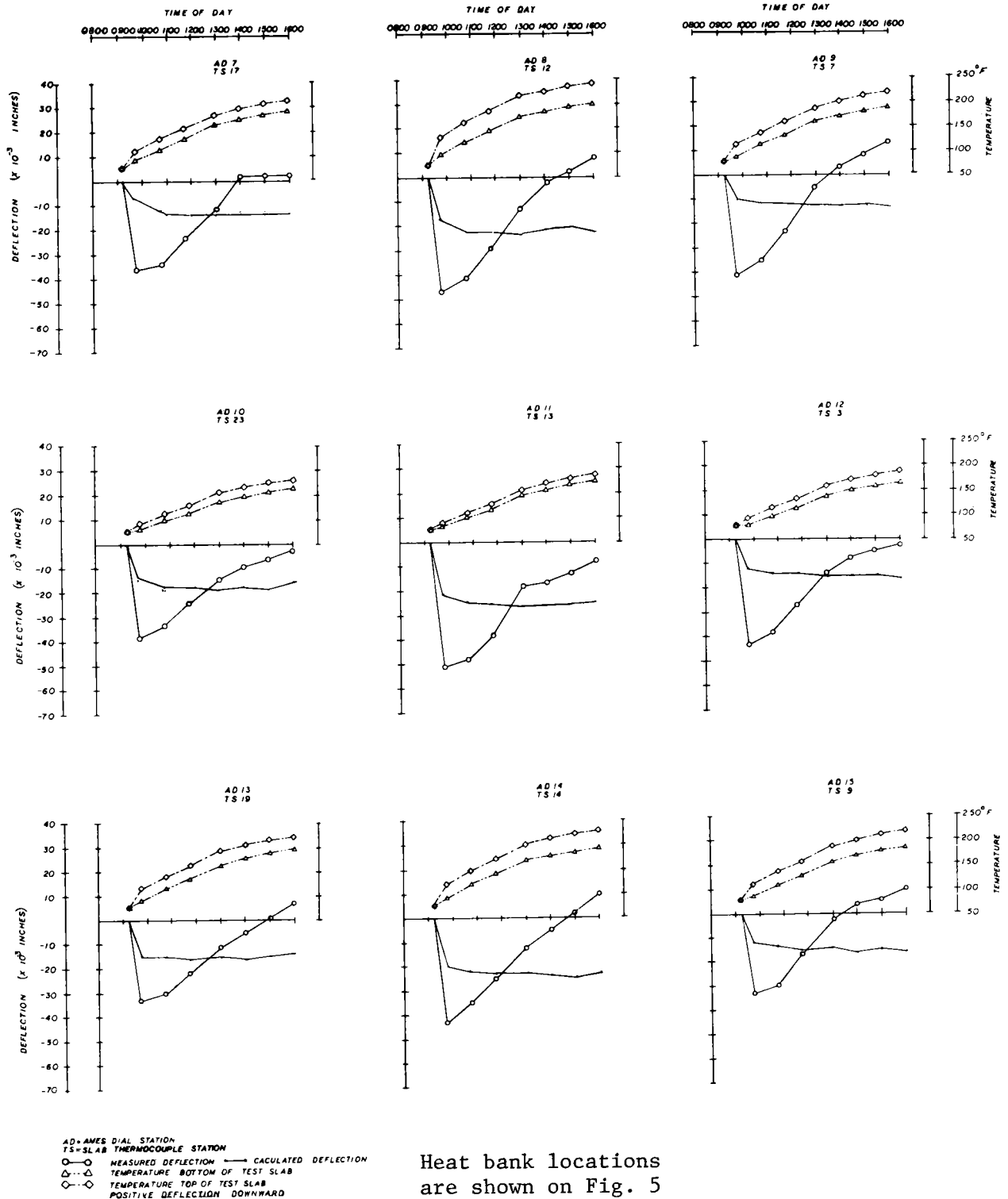


Figure 6. Deflections and temperature vs time, laboratory Test 5.

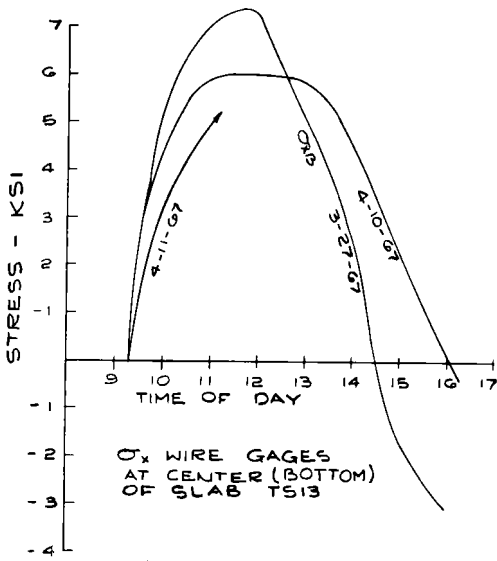
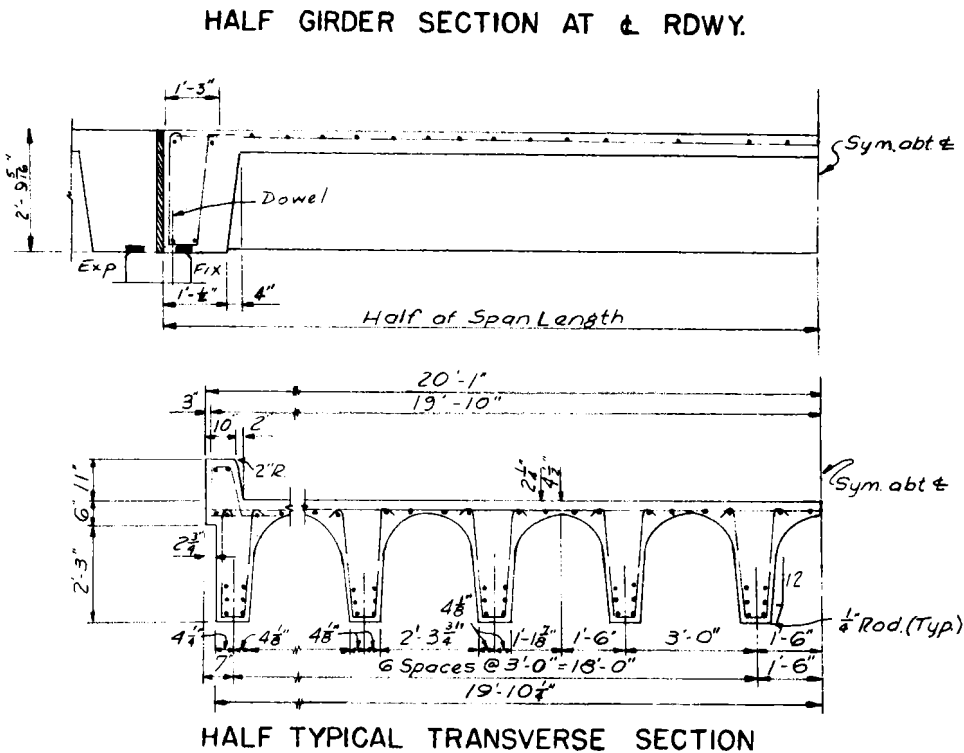


Figure 7. Stresses computed from measured strains, laboratory test.

These factors resulted in the selection of the De Zavala Overpass as the test bridge. This was a 46-ft span, simply supported, and with 14 pan-formed reinforced concrete beams as supporting girders. Although pan-type bridges are not particularly suited for application of the theory developed for beam-slab bridges, considerations other than validation of the theory influenced the selection. Pan-type beams are very commonly used in northern Texas, although perhaps not nationally. The bridge had no complicating factors such as skew or irregularities of beam spacing. Above all, the bridge fitted very well into the research schedule as it was cast and instrumented in early spring and ready for tests in the summer.

Figure 8 shows a plan view of the bridge, cross-sections of the edge and interior beams, and details of the bridge bearing at the piers. This information was obtained from the Texas Highway Department.

Two kinds of bridge properties are needed for analytical computations: material and geometric. Regarding material properties, the required constants are E_c , the flexural modulus of the concrete, and ν_c , Poisson's ratio. No experimen-



FOR COMPLETE DETAILS, SEE:

I H 10 OVERCROSSING
 @ DE ZAVALA ROAD
 & CAMP BULLIS ROAD

H20-S16-44 LOADING
 TEXAS HIGHWAY DEPARTMENT

Figure 8. De Zavala Overpass details.

tal determination of these was carried out by the research agency. The properties of the concrete and the type of reinforcing steel, as reported by the Texas Highway Department, are given in Table 1.

Time limitations made it impractical to instrument all 14 beams in the bridge; therefore, only six beams were instrumented. Each of the six beams was instrumented with 65 thermocouples, making a total of 390 points at which temperatures could be monitored in the bridge. Fourteen BLH concrete embedment strain gauges were installed also. The deflection of the bridge was measured by means of a transit. Figure 9 shows the location and designation codes for instrumentation throughout the bridge.

Figure 10 shows strain-gauge detail prior to casting the concrete. A single switching unit was used for the strain gauges. The strains were indicated on a digital indicator, and the readings were recorded by hand.

The following switches were used for the thermocouples:

No. of Switches	Switching Positions	Total Channels
2	8	16
8	18	144
18	12	216
1	1	1
Total		377

The temperature was recorded on a Honeywell recorder and the readings were hand-tabulated.

The arrangement allowed for the reading of only 377 thermocouples because 13 of the thermocouples (one stack) were lost during concreting.

The tests were run in August and December, 1967. The August tests were scheduled for the hottest summer month; the December tests were run during the blowing of a "norther," which brings a sharp drop in temperature within a few hours.

Table 2 gives a chronology of the field experiments, from placement of reinforcement, to installation and calibration of instrumentation, to data acquisition.

The "ambient" temperature was recorded at two locations for each test: one under the bridge, and the other just above the bridge slab. It might be noted that whereas there were, at times, considerable differences in the temperature at these two locations for Tests 1 and 2, the difference was generally negligible for Test 3.

Figures 11, 12, and 13 show temperature logs for field Tests 1, 2, and 3.

The adaptation of the theory developed for the analysis of beam-slab bridges to the analysis of multibeam bridges requires a careful examination of the behavior of multibeam bridges. In multibeam bridges, the "slab" portion, if it exists, serves merely to transfer shear. This may be approximated by omitting the effect of temperature on the slab, and assuming that the entire cross-section (beam plus slab) is the beam section.

The next step is to define the width, b , which, in the theory, is taken as center-to-center of two adjacent beams.

TABLE 1
CONCRETE AND REINFORCING STEEL,
DE ZAVALA OVERPASS

ITEM	CHARACTERISTIC
Reinforcing steel	Intermediate grade ASTM A-305, A-15, and A-160
Concrete breaking beam tests ^a	4 days—719 lb 7 days—606 lb
Monthly averages ^a	4 days—722 lb 7 days—706 lb
	Slump, 2½ in.; air entrainment, 4%
Composition (per cu yd)	Coarse aggregate—1,921 lb Fine aggregate—1,248 lb Water—29.5 gal Cement—5 sacks

^a A 500-lb breaking strength corresponds to a 3,000-psi concrete.

TABLE 2
CHRONOLOGY, FIELD EXPERIMENTS,
DE ZAVALA OVERPASS, 1967

DATE	ACTIVITY
March 10	Reinforcement in the bridge completed.
March 11-12	Thermocouple stacks and embedment gauges installed on the bridge.
March 13	Concrete cast.
May 25-July 26	Cables run from the gauges to the instrument house. Read-out equipment connected to cables and instruments calibrated.
August 3	Trial run.
August 8	Test 1.
August 9	Test 2.
December 10-11	Test 3.

Clearly, several choices are possible here. Mathematically, the simplest is to continue to take b as the distance between beam center lines. Depending on the shape of the beam, the value of b could be reduced by some more or less arbitrary amount. However, any reduction in the value of b would result in some degree of mathematical error, because shears that are transferred away from the center line of the beam will result in a torsional moment on the beam.

In any event, whether b is chosen as center-to-center of beams, or some fraction thereof, an error is unavoidable. For this reason three calculations were made, taking b as equal to 36 in. (the actual distance between center-to-center of beams), 8 in. and 22 in.

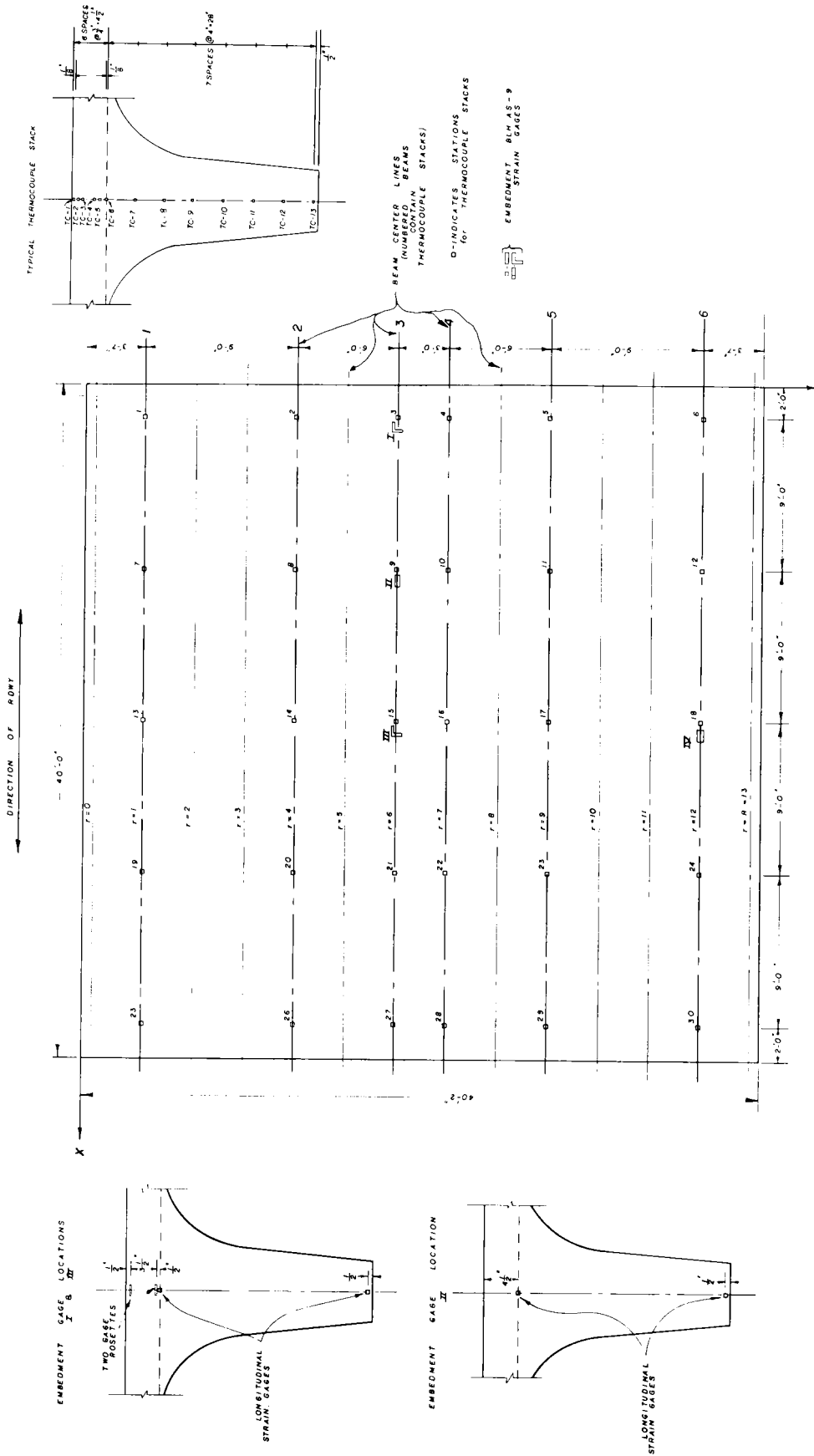


Figure 9. Instrumentation, De Zavala Overpass.

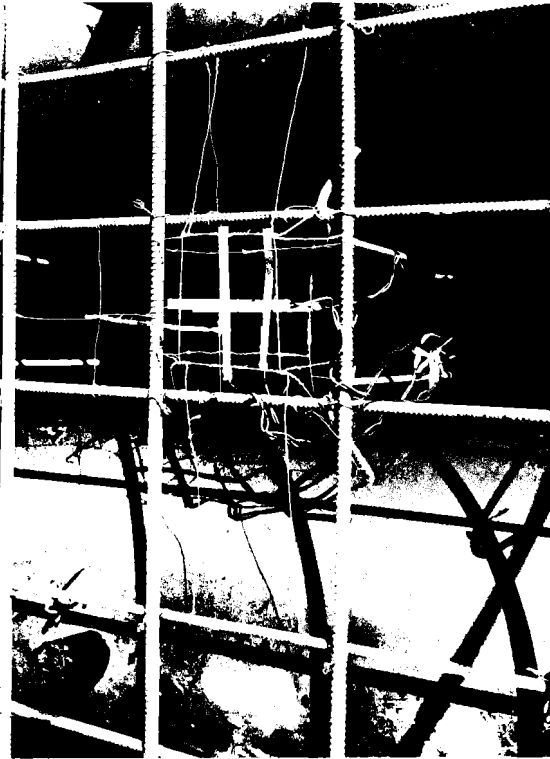


Figure 10. Strain gauge detail, De Zavala Overpass.

The preceding represents by far the most important changes required in the theory.

Other sources of error exist, and these apply to both beam-slab bridge analysis and multibeam bridge analysis. These include inaccuracies in obtaining the material properties E_c and ν_c for concrete and geometric properties such as the moment of inertia, I , for a reinforced concrete section and the torsion constant, J , for the beam section.

Table 3 gives the different values of the parameters used in the analysis. Figure 14 shows the deflection near the center of the bridge for Test 1 using values of $b = 36$ in. and $b = 8$ in., representing the two extreme values. The values of the other parameters used in the calculations are shown in the figure. It was found, generally, that $b = 36$ in. gave the most reasonable results. The other parameters did not have much effect.

Figure 15 shows typical measured deflections for Test 1.

There are several reasons for the observed difference between the calculated and measured deflections. Note that the temperatures over the bridge are measured over a discrete number of sections, and these measured values are integrated and then expanded in a double Fourier series. Clearly this process represents but imperfectly the actual temperature variation. Besides this, the theoretical boundary conditions of "simple support" are nonhomogeneous in the thermal stress problem, and although such problems may be solved exactly for a plate alone or a beam alone,

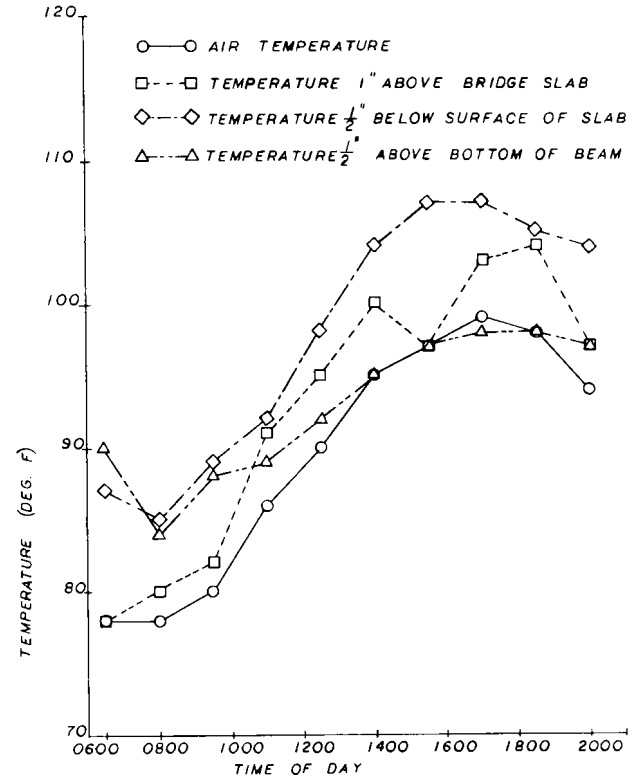


Figure 11. Plot of temperatures for Test 1 at stack 15.

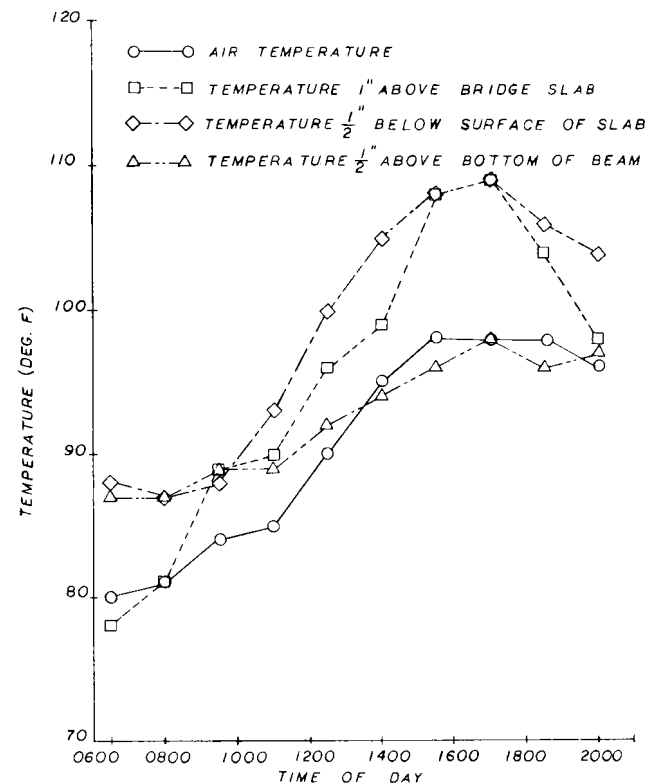


Figure 12. Plot of temperatures for Test 2 at stack 15.

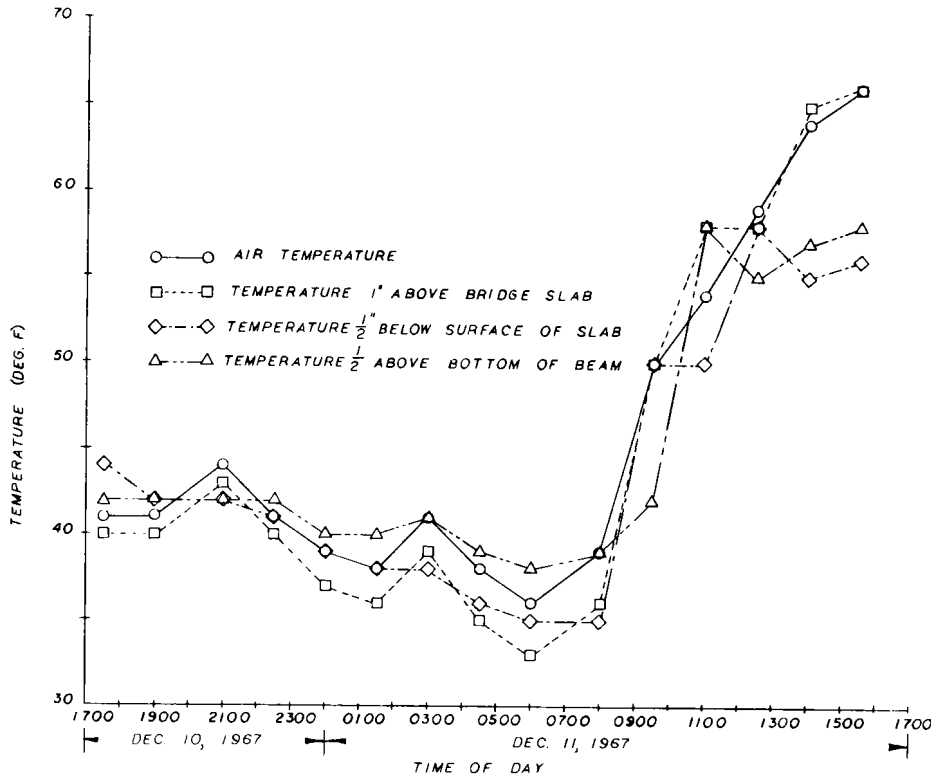


Figure 13. Plot of temperatures for Test 3 at stack 15.

an exact solution is not possible where an interaction between beam and slab takes place. In brief, the theoretical analysis is not "exact."

The ambiguity relating to the value of b and the material and geometric properties has been previously discussed.

These could compound the error, although, in all probability, some errors will tend to nullify each other.

It seems unnecessary to dwell on the possibility of considerable deviation of the actual bridge from the theoretical model. These deviations extend not only to the bridge

TABLE 3
PARAMETERS, DE ZAVALA OVERPASS^a

PARAMETER	SYMBOL	UNITS	SET 1	SET 2	SET 3
Elastic modulus of concrete	E_c	10^6 psi	3.79	3.79	3.79 ^b
Elastic modulus of steel	E	10^6 psi	29	29	29
Poisson's ratio (conc.)	ν_c		0.2	0.2	0.2
Width of bay	b	Inch	8	22	36
Length of bridge	a	Inch	467.5	467.5	467.5
Cross-sectional area—int. beam	A	Sq. in.	520.5	520.5	568.28 ^c
Cross-sectional area—edge beam	\bar{A}	Sq. in.	538.1	538.1	585.8 ^c
Moment of inertia—int. beam	I	10^4 in. ⁴	4.728	4.728	5.98 ^c
Moment of inertia—edge beam	\bar{I}	10^4 in. ⁴	7.363	7.363	9.08 ^c
Torsion const.—int. beam	J	10^4 in. ⁴	1.398	1.398	1.398
Torsion const.—edge beam	\bar{J}	10^4 in. ⁴	2.89	2.89	2.89
Thickness of slab	h	Inch	4.5	4.5	4.5

^a All possible combinations of parameters were used in the actual calculations.

^b Calculated from data in Table 1.

^c Includes steel area.

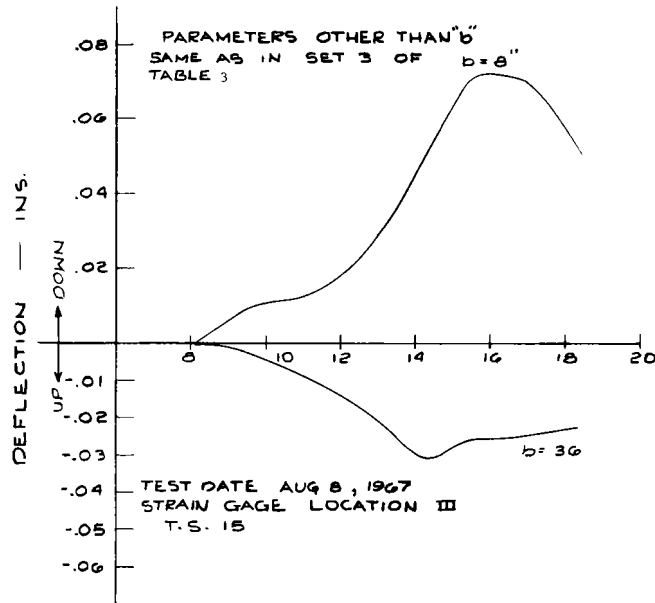


Figure 14. Calculated bridge deflection, Test 1.

structure but also to the boundary conditions. For example, at the two ends of the bridge span the longitudinal beams were connected together by a heavy transverse girder at the points of support. The effect of these transverse beams is difficult to take into account analytically. The longitudinal beams also did not rest freely at the supports—one end virtually butted against the abutment (the space between the beam end and the abutment was filled with a bituminous compound) and the other end butted against the beams in the next span. Such features are unavoidable, but do influence the behavior of the bridge and defy theoretical analysis.

The equations used for the determination of thermal stresses resulted from the changes required for adapting the theory, as previously explained. The significance of the various parameters remains the same.

It follows from the assumption that the structure consists of beams, and the neglect of the temperature distribution in the "slab" as such, that stress calculations may be limited to the beams. Of course, the connecting slabs experience stresses but these result solely from the beam deflections.

Figures 16 and 17 show stresses calculated from measured strains in Tests 1 and 2 at the embedment gauges near the center of the bridge. It may be noted that the stresses computed from measured strains reach a maximum value of about 1,500 psi in the concrete.

It was noted in the test model studies that the effect of creep could render the measured strain meaningless for stress calculation purposes. A similar remark applies to the "stress" figures given here, except that they are probably more nearly true stresses than in the case of the laboratory test models because of the considerably smaller temperatures experienced by the bridge slab. Nevertheless, they need to be interpreted with caution.

Another point to be noted is the time lag involved in recording temperature variations. The temperatures in the bridge are constantly changing and by the time the last

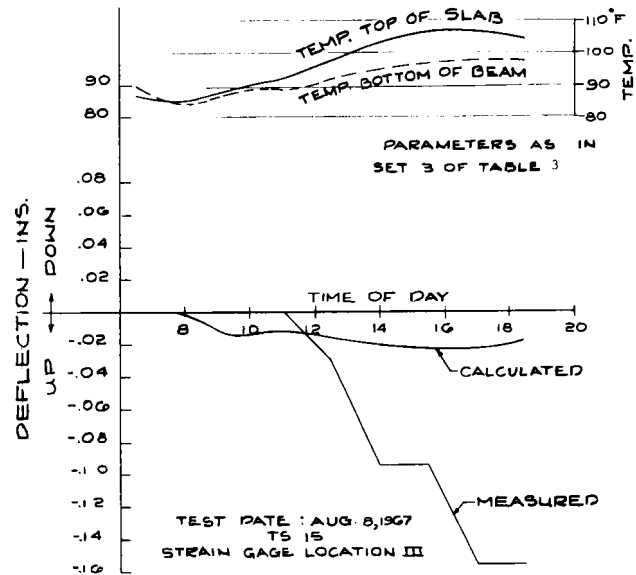


Figure 15. Bridge deflection, Test 1.

thermocouple stack readings are recorded, the temperatures at the other thermocouples have already changed. The calculations assume therefore that the temperatures are "frozen" temporarily over the entire bridge during the time it takes to record one complete set of readings. Unless all thermocouples are read instantaneously, a discrepancy between calculated and measured stresses is unavoidable.

Conclusions

In judging the results of the experimental program, it seems evident that although reasonably detailed and reliable tests may be carried out under laboratory conditions, the conduct of field tests poses peculiarly difficult problems. Field conditions introduce several uncontrollable variables such as wind and rapid change of temperature. In addition, bridges are generally too large for effective instrumentation. Even for a 40-ft span, a large amount of instrumentation is required to acquire data. Time for placing instrumentation is generally short. Because of the rapid change of atmospheric conditions, hand recording of temperature, strain, and deflection data is not desirable.

Creep is a complicating problem in measuring strains in concrete, and it must be accounted for at least approximately in interpreting the strain measurements. It has been possible to do this only in qualitative terms.

Thermal deflections generally are not serious under normal conditions—that is, when the bridge is heated by the sun. In cold weather the bridge may be warmer in the bottom surface than on the top, but thermal gradients are negligibly small. So, in this situation also, deflections may be ignored for design purposes.

Thermal stresses appear to be significant on the assumption that creep is *not* a dominant effect. The stress in the concrete is on the order of about 1,000 psi under conditions of the test.

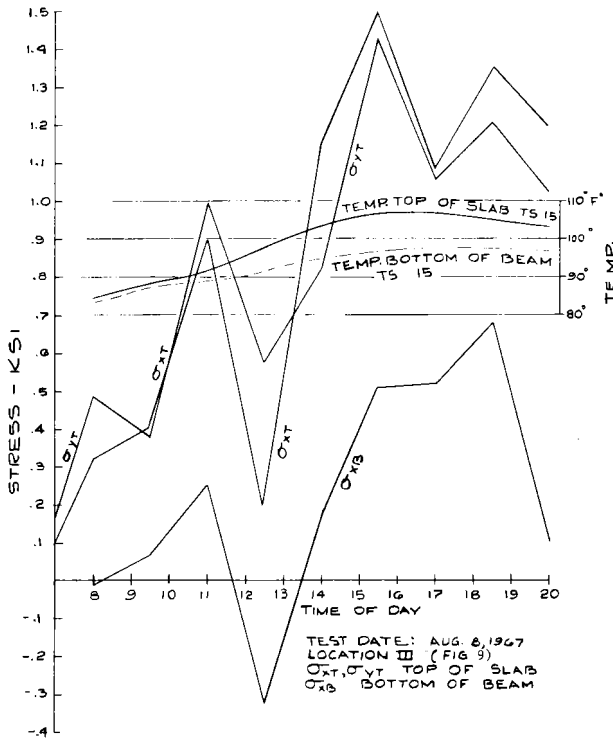


Figure 16. Stresses computed from measured strains, Test 1.

Effort should be directed toward developing simple formulas for thermal stresses in beams and slabs. Because it is almost impossible to specify the temperature distribution through the bridge slab and beams, formulas must be devised on some simplified approach that would render the solution independent of the variation through the thickness. For example, a linear or parabolic variation could be assumed through the thickness everywhere.

Regarding the in-plane thermal expansions, the formulas developed in the study are sufficiently simple and flexible for design office use. They agree reasonably well with current AASHTO specifications.

Research Recommendations

Some future research and developmental programs are inevitably suggested as a consequence of this study.

Creep Behavior of Concrete Under High Temperature

A study of the creep behavior of concrete beams and slabs under high temperature should be accomplished. The program should involve a thorough search of the literature of both the U.S. and other countries prior to the undertaking of any new experimental work. The temperatures should probably be in the range of from 70°F to 200°F.

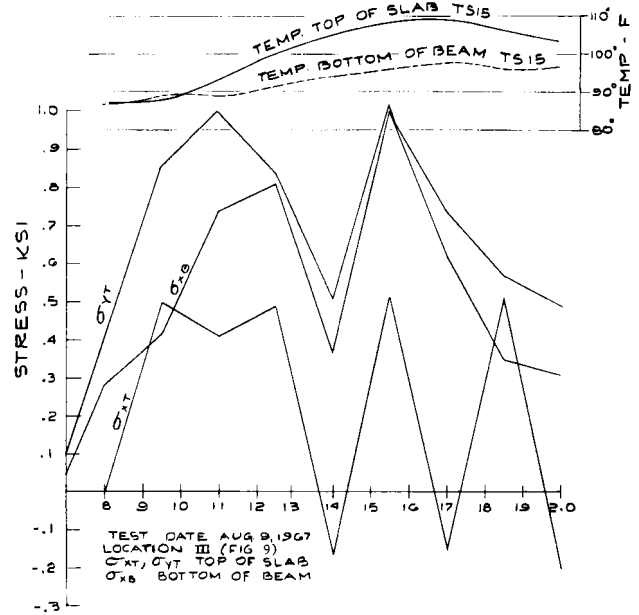


Figure 17. Stresses computed from measured strains, Test 2.

The effect of reinforcement on the creep rates would be of particular interest. As an end product it would be desirable to deduce theoretical or semi-empirical equations that would permit modifications of the thermal stress or strain equations.

Heat Conduction in Bridge Slabs

A theoretical analysis of heat conduction was made as part of this study and a report (not included here) was submitted. The theory attempts to answer the question: Given an arbitrary variation with time of ambient temperature surrounding a slab, how does the temperature distribution in the slab itself vary with time? The answer to this question would make it possible to assess the effects of temperature in the slab, given only the data regarding temperature readings at any location.

Although the mathematical formulation was completed, a computer program was not written, nor was there any experimental verification of the theory.

A series of heat-conduction tests on slabs, with suitable provisions for the possible difference in the thermal conductivity and surface conductance on the top and bottom surfaces, seems desirable. This program could also assess the relative merits of different types of thermal insulation.

Thermal Stresses in Continuous Spans

The study in this summarized report is confined to simply-supported beam-slab bridges. The behavior of continuous spans under the influence of thermal loads cannot easily be

extrapolated from the present results. The continuity of the spans as well as the influence of intermediate piers will have to be taken into account in any rational analysis.

In view of the complexity of the analysis for simple spans, it would seem desirable to make some simplifying modifications in the corresponding analysis of continuous spans. For example, it might be possible to omit the lengthwise and transverse variation in the temperature in the slab while taking into account the temperature variation in the supporting beams.

It seems that an extension of the research to continuous spans might be very worthwhile, and might lead to results that would not be expected from the study of simple spans. Experimental studies in such a program could be on either laboratory models or actual bridges, or both.

Development of Semi-Empirical Formulas

The fullest benefits for the design engineer could accrue only if he is able to use the theoretical equations in some manner to obtain quantitative information. This could take the form of either charts and computer programs or simplified semi-empirical equations. The latter approach seems preferable because (1) the solution, in any event, is approximate, and (2) it is possible, with a minimum of extra effort, to incorporate some of the effects of creep in the semi-empirical equations.

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