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WHEELCHAIR SECUREMENT

on

BUS AND PARATRANSIT VEHICLES

Interim Report No. 1

April 1981

Prepared for
U. S. DEPARTMENT OF TRANSPORTATION
Urban Mass Transportation Administration
Washington, D. C. 20590

NOTICES

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BUS AND PARATRANSIT VEHICLES

by

Carl F. Stewart
Herbert G. Reinl

California Department of Transportation
Sacramento, California

Interim Report No. 1

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15. Supplementary Notes This is the second of four reports to be published under UMTA grant CA-06-0098 to study the "Safety of Loading & Securement Hardware for Transporting Wheelchair Passengers". The first report, "Safety Guidelines for Wheelchair Lifts on Public Transit Vehicles" was published in July 1980. Two additional reports on wheelchair securement tests will be published in 1981.

16. Abstract

Securement systems for wheelchairs on public transportation vehicles can vary with respect to the degree of help the driver gives the wheelchair user in loading and securing the chair. The greater the degree of driver involvement the greater the flexibility of location and number of attachment points on the wheelchair which are acceptable for a securement system.

To determine the performance of wheelchairs under various types of securement systems (12 in all), forty-two dynamic tests were conducted with wheelchairs occupied with anthropomorphic dummies. Both manual and electric powered chairs were used. Forward, rearward and side facing orientations were represented.

This report gives the results of those tests. It also discusses many of the problems associated with providing securement for wheelchairs and their users, as well as with setting up dynamic tests for securement systems and evaluating the test results.

Recommendations are made for: design loading criteria, improvements for some systems, non use of some systems, consideration for adopting a "standard" system for full size (35-40 foot) line haul buses, and for wheelchair users to provide their own personal securement to their chair before boarding the bus.

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EXECUTIVE SUMMARY

After entering a public transit bus, most wheelchair users cannot readily transfer from their chair to regular passenger seats. Even for those who can make the transfer, there is no place for them to store their chair during transit.

Tests conducted by the California Department of Transportation showed that the normal motions of a moving transit bus will cause an unsecured occupied wheelchair, with its brakes set, to slide or tip over. Also, like any other unsecured object on a bus, an unsecured wheelchair is a potential hazard to passengers during a bus accident.

Therefore, space and a wheelchair securement system must be provided on public transit buses so that both wheelchair users and other passengers can be transported safely while the wheelchair users remain in their chairs.

A wheelchair has many areas for a securement system to attach to -- lower frame, upper frame, cross brace, one rear wheel, both rear wheels, etc. A logical assumption is that a wheelchair has greater ability to absorb shock and provide better protection to its occupant during a vehicular accident when secured at one attachment point over another.

This report presents and discusses data from forty-two dynamic crash tests conducted with wheelchairs occupied by anthropomorphic dummies. Twelve different types of securement systems were used. A compressed-air-propelled sled simulated a vehicle during the tests. The sled's speed at impact for the tests varied from 5.7 to 23.3 miles per hour with deceleration rates ranging from 5 to 12 g's.

All tests simulated a frontal crash. In all but one test, the wheelchair faced either in the direction of travel before impact or perpendicular to it. The exception was a test with the chair facing in the opposite direction to travel.

A 50th percentile male anthropomorphic dummy (165 pounds) occupied each chair during the tests. Accelerometers in the dummy's head and chest provided deceleration rates of these parts, and the excursion of the dummy's head was measured from high-speed films taken of each event.

The dummy was secured either to the chair or sled by various methods incorporating web belts commonly used in automobiles. However, the method most often used was one developed during the tests. It consisted of a common type of seat belt with the ends attached to the axles of the chair's rear wheels, passed up and underneath the chair's armrests on each side, over the hip bone area of the dummy, and latched in the dummy's lap.

This report also identifies and discusses several of the general issues associated with securing a wheelchair on a public transit vehicle. Major issues covered include the limited ability of average wheelchair users to secure themselves, the needed space at wheelchair stations on public transit vehicles, and the responsibilities of both the transportation providers and users.

The interim results, when reviewed along with the disabilities of a large percentage of wheelchair users, do not identify a practical near-term solution for securing wheelchairs on public transit vehicles. However, they do identify a potential long-term solution.

Because of varying chair sizes and designs, the limited dexterity and strength of many wheelchair users, and safety needs during an accident, the authors conclude that the following conditions would help achieve a long-term solution:

- Responsibility for his or her personal securement to the chair should rest with the wheelchair user.
- A standard securement system for wheelchairs should be sought and adopted.
- A standard securement system proposed would consist of a permanent attachment of a mating bracket on the chair that would engage with a standard counterpart in the bus.

Systems proposed for testing during the next phase of this research project are identified in the report.

PREFACE

The California Department of Transportation (Caltrans) has a grant from the Urban Mass Transportation Administration (UMTA) to study the "Safety of Loading and Securement Hardware for Transporting Wheelchair Passengers" (UMTA Grant CA-06-0098). Four reports are scheduled under the study: a report on "Safety Guidelines for Wheelchair Lifts"; two interim reports on "Wheelchair Securement on Bus and Paratransit Vehicles"; and a final report with the study title.

The report on the safety guidelines has been published and made available through the National Technical Information Service (NTIS), Government Accession No. PB 81-104655.

This is the interim report on the first segment of wheelchair securement research.

Since early 1974, the authors of this report have been studying the subject of loading and securing wheelchairs in transportation vehicles. During this period they have reviewed films and reports on vehicle crash tests and wheelchair crash tests similar to those reported herein. They have also discussed wheelchair securement problems with many individuals, including other researchers, wheelchair users, transportation providers, and equipment manfacturers.

These studies have led the authors to conclude that:

1. Available literature on the subject of loading and securing wheelchairs is very limited.
2. Information on wheelchair securement would be very useful to transportation providers and equipment manufacturers.
3. Although untested in a research environment, there are practices in use, or contemplated, which appear to be viable solutions to some of the problems of securement.
4. Many of those who are developing wheelchair securement systems appear to be doing so hampered by misconceptions and a lack of understanding of what occurs during a vehicle accident.

Ideally, this report would provide proven solutions to the various wheelchair securement problems. Unfortunately, there has been insufficient research completed thus far to be able to do that. In the interim, until the research is completed, the authors have selected this report as a method of sharing with others the information accumulated on the subject. Consequently, this report contains not only research data, but also general information obtained from subjective observations and discussions with others.

There are two major reasons for sharing the information at this time. They are: 1) to benefit those faced with the need during the near term to provide wheelchair securement, and 2) to encourage a dialogue between those responsible for providing the securement, the wheelchair user, manufacturers and others interested in the subject. The underlying intent of the latter reason is to hasten a solution to the wheelchair securement problem. The authors believe that the sooner persons who are interested in or who are responsible for wheelchair-users' transportation are acquainted with the attendant issues, the sooner they can communicate with each other and develop safe and effective chair-securement and user-securement systems.

The contents of this report reflect the views and interpretations of the authors, who are responsible for the facts and the accuracy of the data presented. The contents do not necessarily reflect the official views or policies of Caltrans or UMTA. Neither do they represent standards, specifications or regulations.

It is to be understood that the performances of the various securement concepts tested resulted from test conditions used, and that the performances may be different under other test conditions.

Neither the United States Government nor Caltrans endorse products or manufacturers. Trade or manufacturers' names or products appear herein solely because they are considered essential to the objective of the research and this report.

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WHEELCHAIR TRANSPORTATION SAFETY

Advisory Panel

Organization	Name	Characteristics of Members
California Highway Patrol	Mr. Charles Allen	Responsible for approving loading and securement equipment used in California's Special Education Program.
Wheelchair Manufacturer	Mr. Keith Rodaway	Chief Designer
Public Transit Operator	Mr. Phil McGuire	Consultant to the Calif. Assoc. of Publicly Owned Transit Systems
Lift and Securement Manufacturer	Mr. John Abbott	Chief Designer
Academic	Dr. Jim Matheny (C.S.U., Fresno)	Consultant on wheelchair problems
Academic	Dr. Robert Roemer (UC at Santa Barbara)	Biomedical Engineer
Academic	Dr. M. McDermott, Jr. (Texas A&M Univ.)	Handicap researcher for the Veterans Adminis.
Handicapped Group & Public Transit Operator	Mr. Dennis Cannon	Wheelchair user, active member of Calif. Assoc. of Physically Handicapped and consultant to So. Calif. Rapid Transit District.
Private Citizen	Mrs. Jan Browne	Wheelchair user, consultant on handicapped transportation
Private Citizen	Mr. Richard Barlow	Wheelchair user, Registered Civil Engineer
Calif. Dept. of Rehabilitation	Mr. A. G. Garris	Wheelchair user, consultant on matching wheelchairs to the needs of persons
Calif. Dept. of Rehabilitation	Mr. John Littlefield	Handicap transportation consultant

Caltrans	Mr. Herbert Reinl	Project principal investigator-Panel Secretary
Caltrans	Mr. Carl Stewart	Project manager-Panel Chairperson

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DEFINITIONS

Definitions of some of the terms as they are used in this report are as follows:

- Acceleration: Acceleration is the rate of change of velocity. Since velocity is a vector having both magnitude and direction, acceleration also has both magnitude and direction. The direction of this vector is indicated in the text by using the term acceleration to indicate an increase in velocity and the term deceleration to indicate a decrease in velocity.

  The graphical presentations in this report do not use the term deceleration and indicate the direction of acceleration on a positive and negative scale. The reader may ignore these technical distinctions and think of the terms acceleration or deceleration interchangeably since the direction of the vector is usually obvious.

  The magnitude of acceleration is indicated in terms of G's (one G = 32.2 ft/sec./sec.).

- Back-up securement: A device or devices used to prevent continued movement of the dummy and chair in the event the securement system being tested fails upon sled impact. The device is usually a belt(s) and is also referred to as a "hold back belt."

- Chair: Wheelchair.
- Chest Severity Index (CSI): Method used to approximate the severity of a crash involving the chest (See Injury Criteria).
- Crashworthiness: A measurement of resistance to the effects of a collision.
- Effectiveness of securement:

  Good - The securement retained positive contact with its attachment point(s) on the chair throughout impact and prevented the chair from tipping over or from making an otherwise undesirable movement (as described in this report). The system is judged satisfactory under the conditions tested; it is acceptable.

  Poor - The securement either lost contact with the chair, did not prevent it from tipping over during impact, or did not prevent it from making an otherwise undesirable movement. The system is judged not satisfactory under the conditions tested; it is unacceptable.
- Excursion: The distance traveled by the wheelchair or anthropomorphic dummy, from an initial position, relative to the test sled. (See Head Excursion in the Study Design section).

- Facing direction: The direction a person, while sitting in a wheelchair, would be facing with respect to the direction of travel of the vehicle or test sled.
- Head Injury Criteria: Method used to approximate the severity of a crash involving the head (See Injury Criteria in the Study Design section).
- Initial impact: When the sled first makes contact with the slowing mechanism and begins its rapid deceleration while simulating a vehicle collision.
- Jackknife: The dummy bends forward around the securement belt; its arms and legs are outstretched forward and together, so that the dummy's body is bent at the waist and is approximately horizontal with the floor.
- Longitudinal: Parallel to the side of the bus; in seating, a seat where the passenger faces the center aisle of the bus.
- Obstruction: Simulated fixtures usually found above the front wheel area on buses -- longitudinal seat, armrest and stanchion placed at the forward end of the wheelchair securement station.
- Panic stop: An emergency stop required to avoid an accident. Typical deceleration rates would range from 0.3g to 0.5g.
- Secondary impact: A second collision that occurs after an initial collision, such as a vehicle's striking one object with a glancing blow (initial impact) and

continuing on to strike another object. (There were no actual secondary impacts in this study, but a subjective evaluation was made on each securement systems's ability to be in position for functioning effectively for a secondary impact after it rebounds from the initial impact.)

- Securement hardware: The individual parts that make up a securement system.
- Securement system: An assembly of securement hardware, including any installed on the wheelchair, which acts to fasten the wheelchair to the vehicle, or the occupant to either the wheelchair or the vehicle.
- Tether: Attachments to the anthropomorphic dummy or the wheelchair to prevent excessive differential movement between either of these objects and the sled during the acceleration phase of a test. They become inactive either before or upon sled impact.
- Transverse: Perpendicular to the side of the bus; in seating, a seat where the passenger faces the front of the bus.
- User: The occupant of a wheelchair.
- Wheelchair Damage:

  Minor - Damaged parts still function with very little applied effort. The chair's rolling and maneuvering ability is only slightly impaired.

  Moderate - A great amount of effort is required to move and maneuver the wheelchair. An inexperienced and able-bodied person seated in the damaged wheelchair would find it very difficult to move or maneuver it.

<u>Major</u> - The wheelchair is so badly damaged that it can not be rolled, is unusable.

INTRODUCTION

The authors conducted a state-of-the-art study of handicapped student transportation for the California Department of Education in 1974(1). At that time, interest in full accessibility for wheelchair users of all public transportation facilities was reaching a peak. Consequently, while conducting the study, the authors took advantage of the opportunity to look at the wheelchair-fastening and passenger-securement equipment being used in student transportation to see if it could also be used on public transportation vehicles.

To gather information on the needs of equipment in public transportation, contacts were made with several organizations that provide various types of public transportation, such as demand responsive, subscription, and fixed-route.

Based on the information obtained during the student transportation study and from the organizations contacted, the authors concluded that the equipment used in handicapped student transportation did not lend itself to the needs of all types of public transportation for the handicapped. The primary reason was that the level of assistance given the wheelchair passenger (in boarding and securing the chair) by drivers of vehicles used to transport students was greater than that which would be expected in many transit operations.

Driver Participation

Because of the diversity of conditions and rules under which the various providers of public transportation must operate, public transportation can be thought of as divided into three categories with respect to the amount of assistance given by the driver in securing the wheelchair.

In the first category, driver involvement is total. The driver assists in the loading, maneuvering and securing of the wheelchair and the securing of the wheelchair occupant (hereafter referred to as the user). School bus transit and some paratransit operations (especially those furnished by most private, nonprofit organizations) are of this type.

In the second category, there is driver involvement, but to something less than one hundred percent. The driver may leave his or her seat to operate the lift controls and assist in securing the wheelchair and its user; however, the wheelchair user maneuvers the wheelchair with little assistance. Most paratransit operations are of this type.

In the third category, driver involvement is minimal. The driver operates the lift controls, usually while remaining seated, but is in no other way actively involved, except occasionally to instruct on how to use the equipment. This type can be found in paratransit, but it is predominantly found on line-haul or fixed-route services (35- to 40-foot buses).

Since it is necessary that a wheelchair securement system be effective, no matter who was involved in engaging it, the degree of involvement does not dictate safety requirements for the securement systems, per se. Nevertheless, whether or not the system was engaged at all affects safety. Hence, the amount of driver involvement expected, along with the number and location of points on the chair where the system has to be manually engaged, must be considered when one is designing such systems. In addition, consideration must be given to the various disabilities and dexterity of the wheelchair user.

Securement Problems

A question often raised is "Why secure a wheelchair on a public transit vehicle?"

Before the project began it was suspected that forces generated by a "panic stop" of a vehicle would be sufficient to cause an occupied, but unsecured, wheelchair to slide.

Also suspected was that in the event of an accident or a sudden, sharp movement of the vehicle, an unsecured wheelchair could become an undesirable moving object inside the bus.

From a safety point of view, it was therefore concluded that if the assumptions were correct, the wheelchair should be secured on public transit vehicles.

Research under this project demonstrated that indeed the chair will slide during a "panic stop" of the bus, even when the brakes of the chair have been properly set (2). Furthermore, results of the sled tests clearly showed that an unsecured chair will experience violent movement during a moderate accident.

In addition to the question of securing the chair to the vehicle, the need to provide personal securement for wheelchair users was also questioned. The reasoning went like this:

Ambulatory passengers on regular buses are not provided with personal securement equipment. Ambulatory passengers more often than not have the ability to sufficiently brace themselves with their arms or legs to prevent injuries during minor accidents. On the other hand, few wheelchair users have this ability. Even low-velocity impacts will probably eject most unsecured wheelchair users from their chairs.

Finally, the wheelchair user should be given the same degree of protection during a vehicle accident as that provided ambulatory passengers. The seats for ambulatory passengers are required to be secured to prevent them from coming loose when subjected to a given force (28). Accident reviews (3) and research done by others (11) show that when seats remain secured they provide a containment area for the passenger(s) behind them, which results in less severe injuries. Because of the space needed in which to maneuver a wheelchair (Table 1), wheelchair users on regular buses are not usually located where containment is provided by the regular seats. Therefore, to offer comparable protection for the wheelchair user, another form of containment needs to be provided. Personal securement to either the chair or vehicle (with the chair also secured to the vehicle) would provide that containment.

When this research project was started there were no legal requirements to secure the wheelchair user or the wheelchair on public transportation. Subsequently, however, some states have instituted such requirements. The states of California and Minnesota established regulations in 1979 requiring that wheelchair securement systems be provided in public transportation. The California and Minnesota requirements currently require securement sufficient to restrain the wheelchair or wheelchair and user during normal movements and braking of the bus.

Wheelchairs presently used were not designed for use on public transportation. They are light in weight to reduce energy required to propel them, especially the manual ones; and most have an articulated frame so they can be folded for easy storage. Neither the lightness in weight nor the articulated frame contribute in a positive way to the process of securing a chair in a transportation vehicle. The thin-walled tubing used for frame members, needed to reduce weight, is vulnerable to crushing or bending when subjected to unusual loads such as those produced by an attached securement system. The articulation feature offers very little stiffness for distributing loads to other members of the chair.

Because of the factors listed, a secured wheelchair in a vehicle during an accident, an environment it was not designed for, is very prone to damage. The authors felt it should be possible to minimize the damage, however, by choosing the securement attachment point on the chair which affords the greatest support to the chair during a crash. In other words, can a chair withstand a greater shock if it is secured by the wheels where they contact the floor as opposed to where they contact the wall; or, is the chair stronger in a crash situation if the securement is attached to some point on the lower portion of the frame as opposed to some point on the upper portion of the frame.

Until recently (4, 5, 6) there were no test data available on the effect of securement on the chair's crash-worthiness. The lack of knowledge on this issue was a primary reason for initiating this project.

STUDY DESIGN

Armed with the finding that wheelchair securement needs vary with driver involvement and the demonstrated need to secure the chair during normal transit operation, plus the question of how best to secure a chair and its occupant (regardless of the type of transportation provided), the California Department of Transportation applied to the Urban Mass Transportation Administration for a grant to fund research on the wheelchair securement problem.

The securement project has three tasks. The object of the first task was to develop safety guidelines for wheelchair lifts. The report covering this task has been published.

The objective of the second task is to investigate the effects of collisions on wheelchairs and their occupants when they are secured by various securement systems.

This interim report covers work conducted thus far on this task. Additional research under this task will be described in a subsequent report.

The objective of the third task is to determine user acceptance of information developed in the first two tasks. This effort will be reported on in the final report.

Dynamic Tests

This report presents and discusses data from forty-two dynamic crash tests conducted with wheelchairs occupied with anthropomorphic dummies. Twelve different types of securement systems were used. A compressed air propelled sled simulated a vehicle during the tests. The sled's speed at impact for the tests varied from 5.7 to 23.3 miles per hour with deceleration rates ranging from 5 to 12 g's.

All tests simulated a frontal crash. In all but one test, the wheelchair faced either in the direction of travel or perpendicular to it. The exception was a test with the chair facing in the opposite direction to travel.

Dynamic-Static-Analytical Correlation

Of the various exploration methods available, dynamic testing, being close to the real world situation, provides the most accurate information on what happens to a wheelchair and its occupant during a crash situation. Facilities for conducting dynamic tests however, are not always available; consequently, when information is needed on the effect a securement system has on a chair during a crash, it may be desirable to use either static testing or mathematical analysis. On the other hand, questions have been raised regarding the correlation of dynamic, static, and analytic wheelchair crash results. Accidents are variable, moving, dynamic events that are difficult to duplicate particularly with a static or analytical method of analysis. Unless reliable correlation can be shown with dynamic results, conclusions based on static or mathematical analysis may be misleading. During static tests, forces are concentrated for simplicity and can not be applied at the same rate as in dynamic tests. Because the wheelchair is a complicated space frame containing many hinged joints, assumptions must be made to simplify an analysis. The effect of these factors could give completely different results from those obtained during dynamic tests.

As part of this project it was decided to examine the correlation between dynamic, static and analytic results of one of the securement systems. That work is still to be completed. It will be included in a subsequent report.

Dynamic Test Parameters

When designing the dynamic tests, the authors had to make decisions on test parameters in the following areas:

- Size and type of chair
- Size of test dummy
- User securement
- Chair securement
- Chair facing direction
- Sled impact speed and deceleration rate

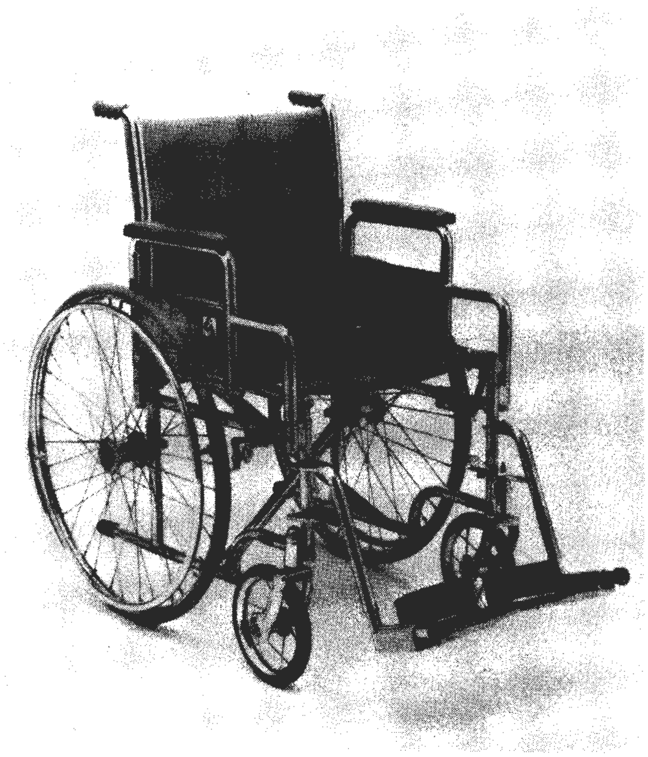
The following discussion will explain the reasoning used in making a choice for each parameter.

Chair Size and Type. Chairs used by most handicapped persons are very similar with respect to the diameter of frame members and thickness of metal. However, they vary in overall size and geometry. Individuals select chairs to fit their particular dimensions just as people select clothing; hence, there is a difference in widths, lengths, and heights of chairs. The geometry of a chair is usually selected to satisfy an individual's personal preference or needs. For instance, some chairs have two large and two small wheels, while others have all small wheels. In addition, some of those with the two large and two small wheels have the large wheels in front whereas others have them in the rear. Most chairs in use outside medical facilities are manually operated, but nevertheless a large percent are electrically powered (7). Yet, with all of these available variations, the Everest and Jennings' manual model P8AU260-770 (Figure 1) and electric-powered model P8AU200-32-770 (Figure 2), except for slight differences in dimensions, represent at least 75 percent of those used by the non-ambulatory who are outside hospital or related facilities (7). Figure 3 identifies specific parts of the chair referred to in this report. These chairs, with minor exceptions, were used in this project. The exceptions were that some chairs were tested without their rigid footrests (type 770) and some were tested with elevating leg rests (type 774). Elevating leg rests are hinged to allow the leg and foot supports to swing up.

A few chairs had a full-length removable arm rest (type 250) rather than the standard desk model (type 260).

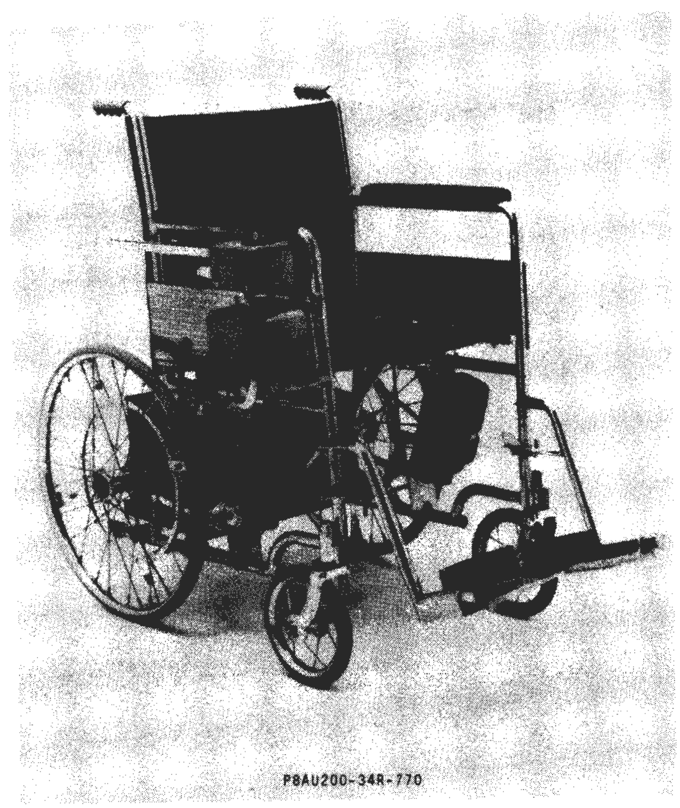
All exceptions are noted in the descriptive portion of the tests.

The electric-powered chairs were outfitted with two regular battery casings filled with colored water and type 32 drive motors; but a control system was not provided.



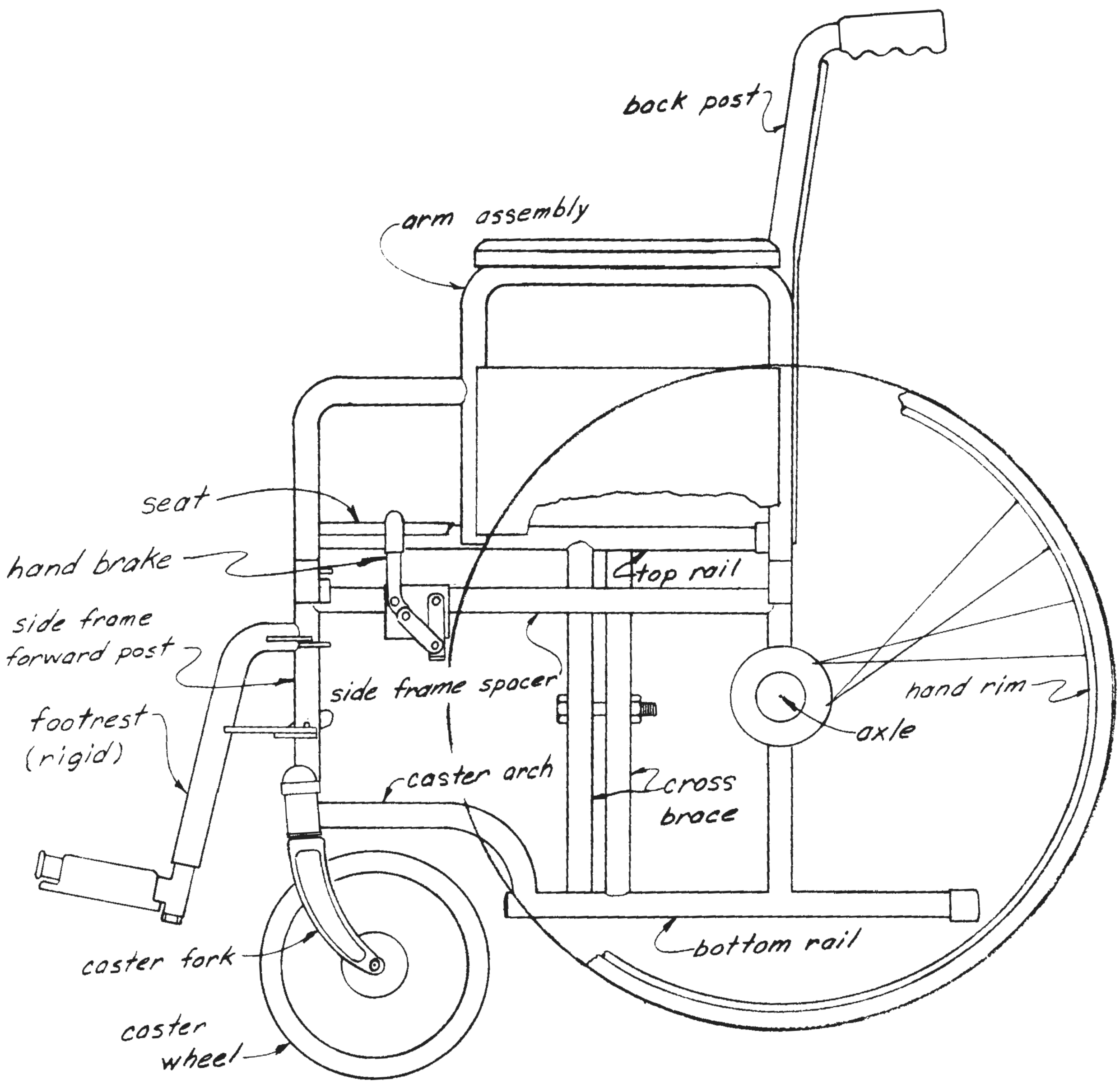
Manual Wheelchair

Figure 1



Electric Powered Wheelchair

Figure 2



WHEELCHAIR DETAILS

FIGURE 3

The batteries were secured to the chair with regular bungee-type tie downs. All chairs were randomly selected from Everest and Jennings' warehouse in Los Angeles by a representative from either Caltrans or Caltrans' test consultant.

Dummy Size. In crash simulations which could cause injury to humans, it is general practice to substitute anthropomorphic dummies for the humans. It is recognized, however, that anthropomorphic dummies may not react exactly the same way a human would in a given situation, nor would the effects be the same for dummy and human.

Besides not having the ability to anticipate and react instinctively (which could cause some difference between real world and test results), an anthropomorphic dummy does not have the same muscular structure, soft tissues or body organs as a live person. Therefore, measurements made on dummies cannot be used to predict damage to soft tissues and body organs, or injurious effects on and stress to the heart or nervous systems. This limitation is true when trying to apply test data from anthropomorphic dummies to predict injuries to all humans. It would appear to be especially so for wheelchair users. Because of their usually limited physical activities, they are more likely to have underdeveloped muscles and soft tissue, as well as restricted joint movement.

On the other hand, the anthropomorphic dummy is an excellent engineering tool which may be used in repetitive tests that are hazardous for humans. Dummies do have the same basic body components with respect to size, shape, mass, and kinematics. Also, instrumentation placed within the dummy and on its restraints can report the resulting forces and restraint loads of each test.

Cadavers have been used to determine effects of crashes on tissue, bone and organs. However, due to the cost and lack of availability, present use of cadavers is extremely limited, even in medical training; accordingly, no cadavers were used in this program.

A 50th percentile male anthropomorphic dummy--Humanoid Systems, Inc., Model Type 572, Serial #184--was used. It weighed 165 pounds.

The 50th percentile male dummy is based on the average static physical dimensions of young military persons. There are no statistics on the 50th percentile wheelchair user (male or female), nor is there an anthropomorphic dummy constructed especially to represent a wheelchair user. In conversations, some wheelchair users have stated to the authors that they lost part of their "before" weight after starting to use a chair. However, others claimed that the reduced activity from being in a chair caused them to gain weight. The weight of those who have used chairs even from childhood appears to vary just as it does with ambulatory persons. Consequently, the lack of available size and weight information on the average wheelchair user, and the fact that the range of difference in weight for the wheelchair user appears to be similar to the ambulatory, led to the selection of the 50th percentile male dummy for this project. In addition, selection of the 50th percentile male dummy for the dynamic tests is consistent with general practice. In fact, the injury criteria (18), discussed in more detail later, used in this report to evaluate the securement systems were developed through experiments with the 50th percentile male dummy.

<u>User Securement</u>. In the transportation of wheelchair users, the user can be secured either to the chair or to the vehicle (1). Usually the to-the-chair method is accomplished by passing a belt around the user's midsection (abdomen) and the back support of the chair. Securement to the vehicle is usually accomplished also with a belt (which has its ends fastened to the floor) that is passed <u>over the armrests</u> of the chair, around the user's midsection and fastened together with a common seat belt latch. Both methods result in the belt's being located high on the midsection.

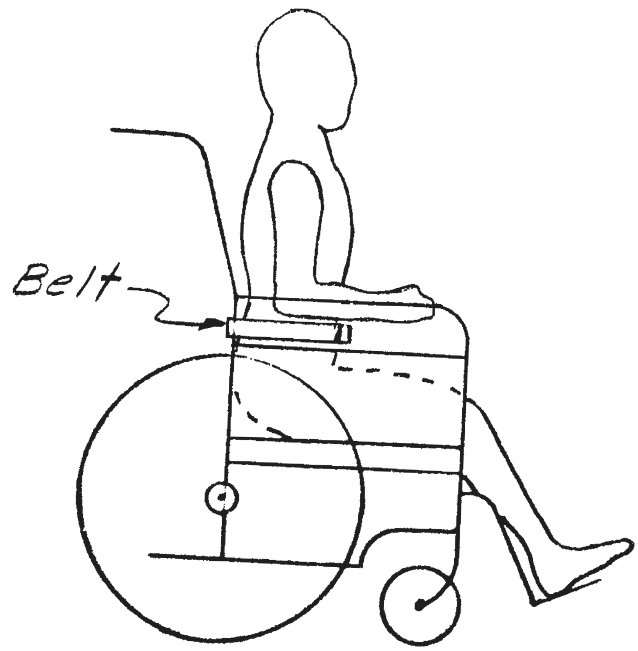
Research has shown that a belt around the user's midsection is undesirable in an accident. When in that position, a belt is more likely to contribute to internal injuries (4, 8, 10). For example, during forward-facing, frontal impacts, a person tends to jackknife around his securement system. If a belt is not near his hip hinge joint, he could suffer severe internal injuries or severe back damage as he exerts pressure on the belt and the belt, in turn, exerts pressure on these areas.

The Society for Automotive Engineers (SAE) Standard J128 and J383 (10) recommends that a pelvic restraint be designed to remain on the pelvis under all conditions and that it should not shift into the abdominal region. SAE Standard J383 further recommends that the anchorage or attachment point of a pelvic restraint be located so that a line from the anchorage point to the passenger's hip joint forms an angle within the range of 20-75 degrees from the horizontal.

Since securement of the user to the chair with the belt around the user's midsection and the back of the chair was common practice when this project started, it was used during the first five tests (Figure 4). In three later tests a lap belt secured to the test sled (simulating the floor of a vehicle) was used (Figure 5). A lap belt plus a single shoulder harness was used in three other tests (Figure 6). A method consisting of belts attached to the chair's axles, passed up underneath the armrests, over the hip joint area of the dummy and latched in the dummy's lap was developed and used during all other tests (Figure 7).

Chair Securement. Since the degree of assistance to the wheelchair user varies so greatly on public transportation, it was decided that the degree of assistance needed for its attachment would not be a consideration of whether or not to test a securement concept. If a securement proved to be a good system, it was reasoned that a place would probably be found for its use in some of the various types of transportation facilities, regardless of its attachment complexities.

Most of the securement equipment tested was an over-design of a generic type or system concept (method and point of attachment) instead of off-the-shelf equipment. The reason for using over-designed equipment was to ensure that the equipment would not fail and thereby jeopardize the test. It should be remembered that it is determining the effect the concept has on the degree of passenger and wheelchair securement that is the primary objective of the

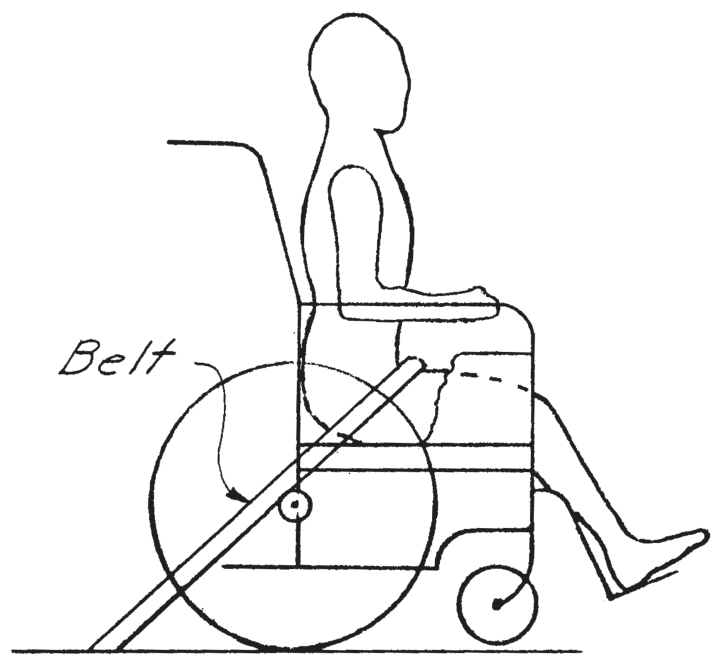


Belt Looped to
Chair Back

Figure 4

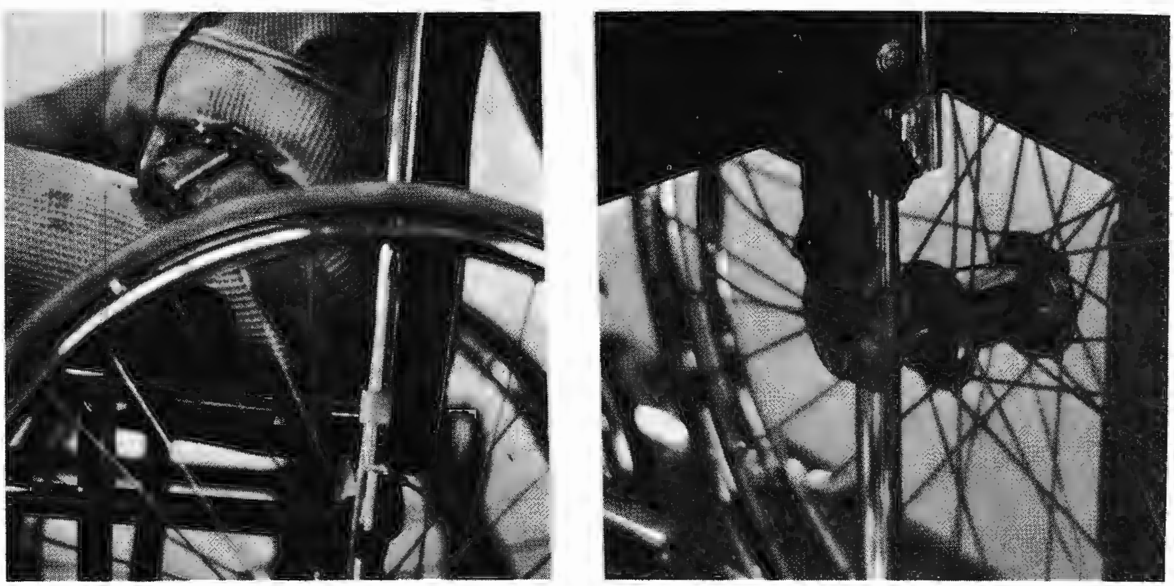
Lap Belt to Sled

Figure 5



Lap and Shoulder Harness

Figure 6



Lap Belt to Chair Axle

Figure 7

test, not the strength of the equipment per se. If the concept proves effective, and information on the required design loads is known, off-the-shelf equipment with sufficient strength can be designed. In a few tests, off-the-shelf equipment which "looked" strong enough was tested without modification. In others, modified off-the-shelf equipment was used.

In addition to the attached securement systems, the chairs' brakes were locked in all tests.

Chair Facing Direction. In most transit systems wheelchair users face either in the direction of travel or perpendicular to it. There are diagonal and backward facing orientations, but neither are very popular because of the space required for the diagonal and the dislike of riding while facing backwards. During one of the tests, the chair faced backwards. In all others, it faced either forward or sideways, with respect to the direction of sled travel. (The facing direction subject is addressed thoroughly in the section on SELECTED TECHNICAL and POLICY ISSUES).

All tests simulated a frontal crash.

Sled Speed and Deceleration at Impact. Wheelchair users being transported in a vehicle could be subjected to objectionable deceleration or acceleration forces when the vehicle experiences either a panic stop, a minor crash, or a major crash. A crash could be caused by either the vehicle's hitting something or something's hitting the vehicle.

The degree of securement needed to resist the objectionable forces resulting from the stop or crash varies with the speed and deceleration of the event. During a panic stop, a relatively low-strength securement system is all that is needed to hold the chair and passenger in place. On the other hand, if the vehicle is involved in a major crash, a high-strength system is needed to hold the chair and its occupant in place inside the vehicle.

The researchers attempted to identify generic types of securements which would retain the chair and the occupant during a major crash. The rationale for going to the upper limit was that if the needs for a major crash are known, it would be easier to design downward than to design upward from information on the needs for lesser crash forces.

For the purpose of designing this research, a major crash was defined as a 35- to 40-foot bus (standard size, weighing 18,000 - 22,000 lb) hitting a solid object at a speed of 30 mph.

The maximum speed of the sled at the time of impact for this project was therefore chosen as 30 mph.

Previous tests by others (11,12,13,14,15) showed that when a full-sized bus traveling approximately 20-30 mph hits a solid object head on, a deceleration rate of approximately 10 g's occurs at the floor level of the vehicle in the area just aft of the front wheelwells--where wheelchairs often are secured. ("g" is the acceleration of gravity. An indepth explanation of g and its importance in these tests is given in the section on SELECTED TECHNICAL and POLICY ISSUES). The duration of the deceleration pulse in the tests by others was approximately 100 milliseconds.

The average deceleration rate of the sled was therefore chosen as 10 g's, with an approximate rectangularly shaped pulse over a 100 millisecond duration. Samples of the sled's deceleration (acceleration) pulse can be found in the Appendix.

Test Parameter Summary

Following is a summary of the proposed test parameters:

- o Common type wheelchair--manual, E & J P8AU260/770, and electric, E & J P8AU200-32-770
- o 50th percentile male anthropomorphic dummy, weight 165 pounds
- o Test dummy secured to the chair for most tests
- o Over-designed (with respect to strength) chair securements
- o Predominantly forward and side chair facing directions
- o Sled impact speed 30 mph maximum
- o Sled deceleration rate of 10 g's; rectangular pulse of 100 millisecond duration

Except for minor exceptions and the sled's impact speed, all proposed parameters were followed during the tests. Most tests were conducted at a speed of approximately

20 mph rather than the proposed 30 mph because early tests showed that the chair could not withstand forces generated by impacts from speeds much higher than 20 mph. Some tests were performed at lower speeds (approximately 10 mph) to establish an upper limit for systems that performed poorly at higher levels.

Data Collection

Besides the test sled speed and deceleration data, loads on the anthropomorphic dummy's lap belt, and deceleration rates in its head and chest were also collected. In addition, loads on specific areas of some of the securement systems were recorded. High-speed movies were taken of each test and were used to analyze the dynamic events--what happens to the dummy and chair during the deceleration period--and measure excursions of the dummy and chair. Chair damage was recorded during post test inspections. Events were also documented with a sequence camera and by still photography.

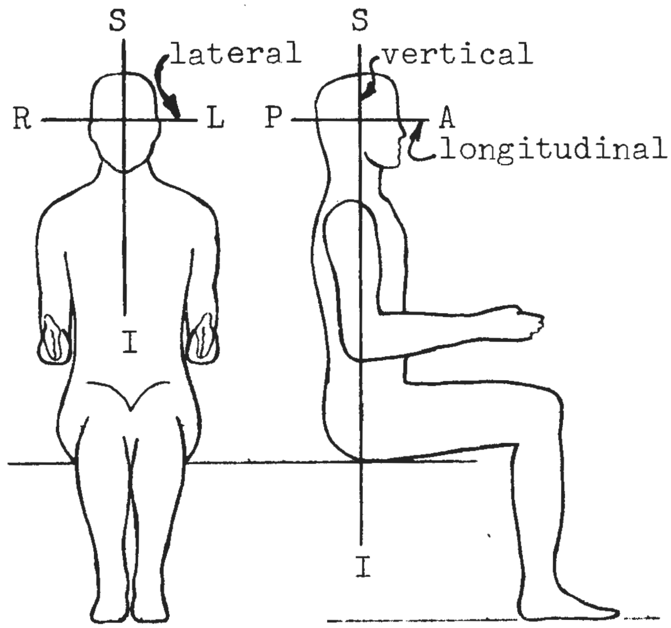
The dummy's lap belt load was measured by load cells inserted into the belt.

The head and chest decelerations were collected on tape from triaxial (three directional) accelerometers (transducers) mounted in the anthropomorphic dummy's head and chest. Data from the tape was fed through an electronic filter which screens out unwanted high-frequency material which would cloud the data traces. The level of filtering, called filter class, used depends on the location of the accelerometer and the type of data being collected. In conformance with S.A.E. recommended practice (10), a filter class of 1000 was used for the head and 180 for the chest.

Four separate traces (longitudinal, vertical, lateral and resultant) were plotted for the head and chest. The vertical scale (g's) of the first three scales include the following directional references (with respect to the dummy; i.e., as seen from the dummy's position):

A = anterior (toward the front)
P = posterior (toward the rear)
I = inferior (down)
S = superior (up)
R = right
L = left

The accelerometer directional references are shown in Figure 8. The resultant trace is a vector combination of the longitudinal, vertical, and lateral traces; it is used by the computer to calculate the head injury criteria (HIC) and chest severity index (CSI).



ACCELEROMETER REFERENCES

Figure 8

Further explanation of HIC and CSI can be found in a subsequent subsection, Injury Criteria. In calculating the HIC, the computer samples or looks at data at frequent time intervals. The time interval (T) used was 0.8 millisecond.

Loads on specific areas of some of the securement hardware were obtained from load cells and SR-4 strain gauges mounted on opposite sides of the object on which the load was measured.

Test Setup

The testing (both dynamic and static) and mathematical analysis was done by Minicars, Inc., Goleta, California.

The dynamic testing was conducted on their Horizontal Impact Test Sled I (HITS I) (Figure 9). The HITS I is capable of moving payloads up to 800 pounds at speeds up to 25 mph. The sled's platform is attached to a test-tube-shaped cylinder which travels along a double track guide. The open end of the cylinder fits over a fixed piston. Compressed air discharged from the piston propels the cylinder forward in a soda straw/wrapper fashion.

Minicars' HITS I

Figure 9

The sled's velocity is controlled by the pressure of discharged compressed air, and is measured by a high-speed electronic pulse counter which is turned on and off by means of a sled-mounted narrow metal blade interrupting the path between an infrared source and detector.

Sled deceleration is achieved by a forward mounted probe striking mild steel bands drawn over a series of steel rollers. The amplitude and shape of the deceleration wave form or "crash pulse" may be varied by changing the shape (tapering, changing width, or changing thickness) of the bands.

Outputs of sled and dummy accelerometers and load cells were recorded on separate FM tape channels for reduction by the Minicars's Automatic Data Processing System.

Three high-speed (400-1000 frames per second [fps]) cameras, one each on the side, overhead and front of the sled, recorded the action on 16mm color film. In addition, a stop-action Polaroid camera photographed eight scenes from time of impact to near the end of deceleration.

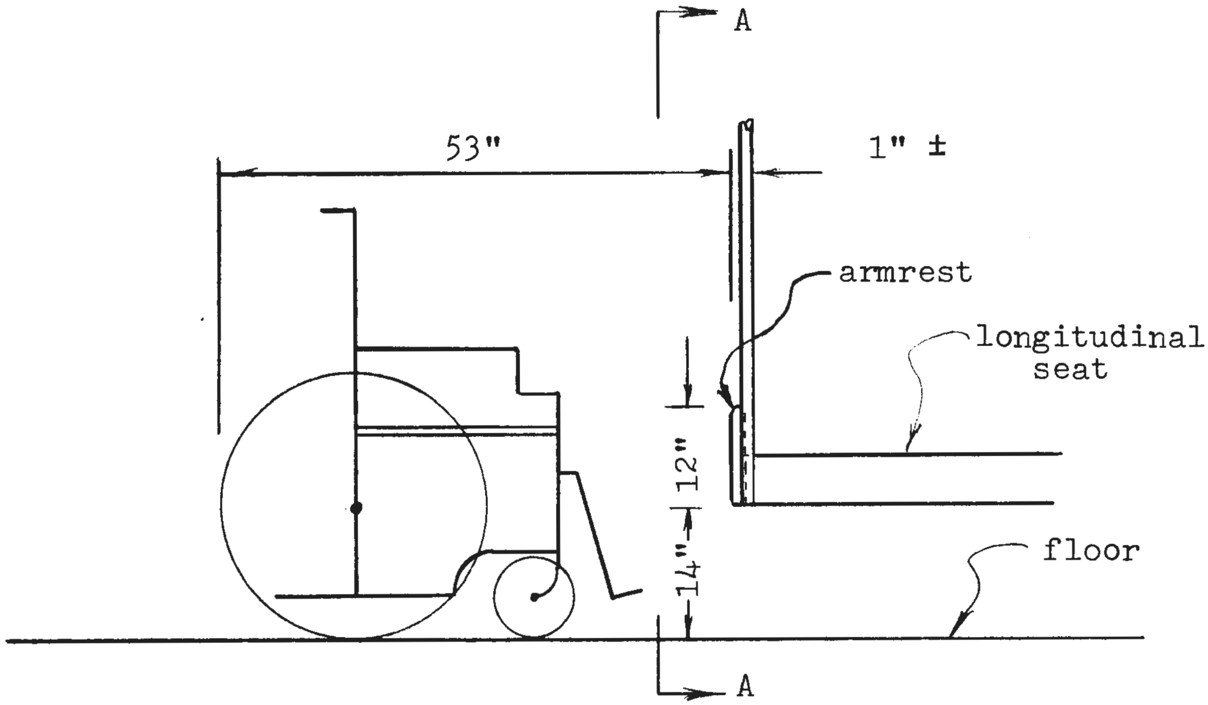
Pre-test and post-test shots of the chair were made with a still camera.

During some of the dynamic tests, belts (tethers) were attached to the chair frame or dummy's neck to minimize rearward movement during sled run-up (acceleration). The belts became passive upon sled impact, hence did not affect the crash results. In some other tests a prop against the back of the chair served the same purpose.

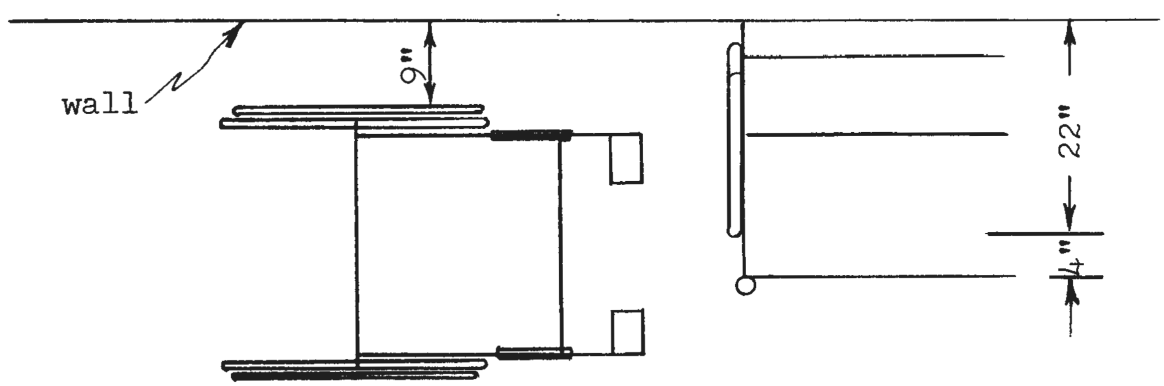
No attempt was made in the first 28 tests to simulate the actual interior conditions normally present in a transit vehicle. In the remaining 14 tests; a longitudinal seat with attached stanchion, to simulate normal hardware in the forward area of most 35- to 40-foot transit buses, was placed downrange from the wheelchair station. For a forward facing chair, the edge of the hardware nearest to the wheelchair was 53 inches from the vertical plane of the back edge of the large wheels (Figure 10). The need for approximately 53 inches of free movement space was derived from measurements of dummy head excursions in the first 28 tests. The 53 inches also agreed closely with that found necessary for wheelchair maneuvering and that furnished by several transit operators who are presently providing wheelchair transportation on full-size buses (Table 1).

Securement Systems Tested

Tests were conducted in two phases. In Phase I, five generic systems that were popular in student transportation and paratransit at the time the research was proposed



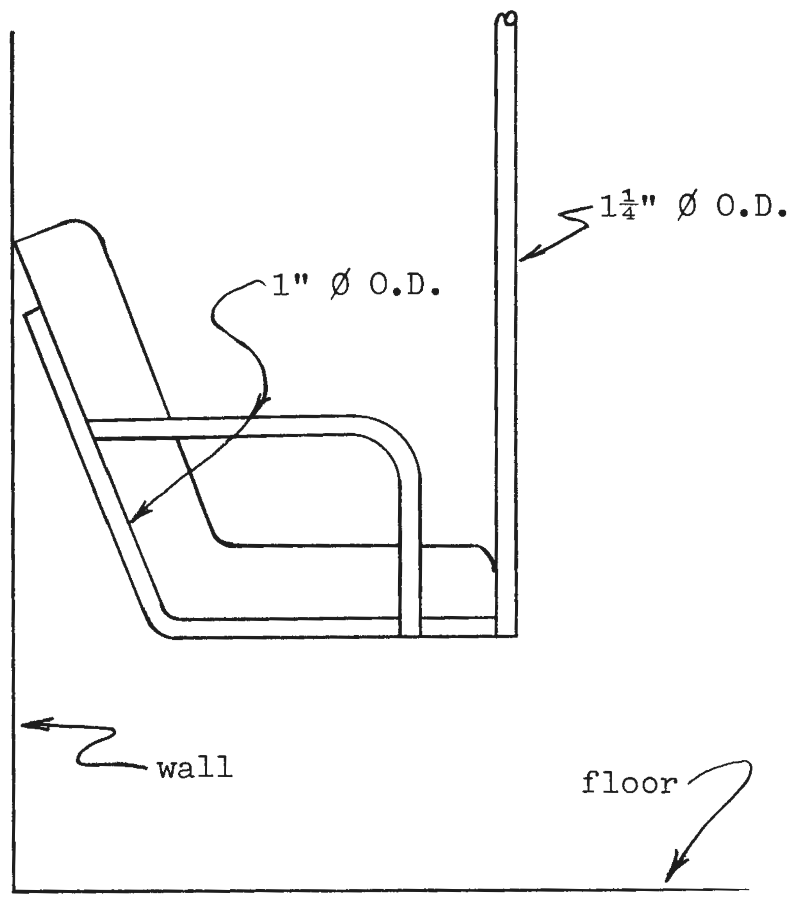
SIDE ELEVATION



PLAN

(no scale)

Phase II Securement Envelope
Figure 10



ELEVATION A-A
(no scale)

Phase II Securement Envelope

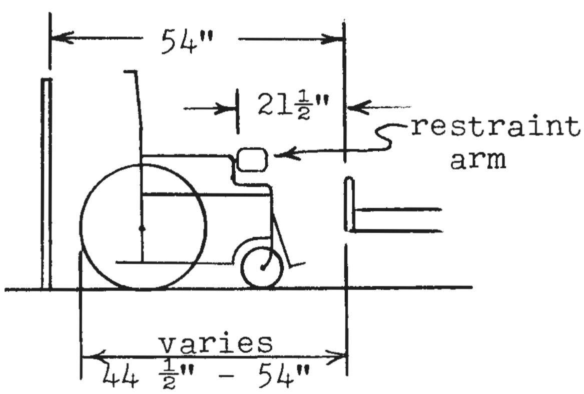
Figure 10 (cont'd)

FORWARD FACING WHEELCHAIR POSITION

EXCURSION ENVELOPES IN USE OR PROPOSED

(May 1978)

Transit Property	Distance from rear wheel to forward obstruction*
Samtrans (San Mateo)	53", 57" (47" to wheel well)
SCRTD (Los Angeles)	48 1/4", 58"
Sacramento Regional Transit	53", 54"
AC Transit (Oakland)	53" (to wheel well)
WMATA (Flxible) (Washington, DC)	varies from 44-1/2" to 54" (the total envelope is 54", however, the securement arm is fixed 21-1/2" from the obstruction. This, rather than the rear wheels, determines the location of the chair.



Minimum Envelope Requirements for Conventional Wheelchairs (including 3 inches of foot overhang)

Manual chair = 45"

Power chair = 46"

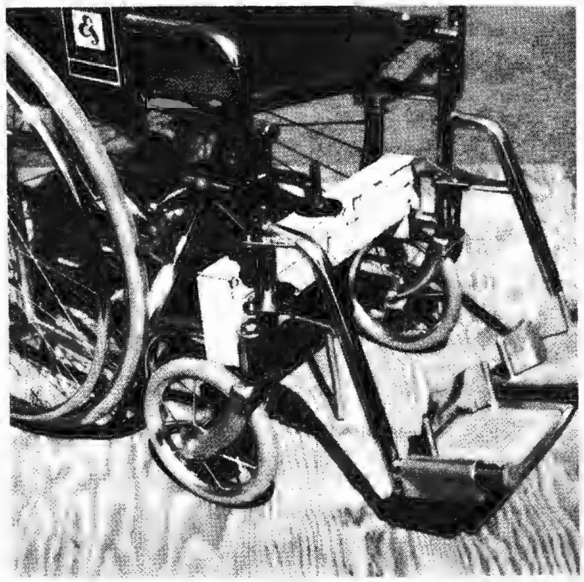
Large power chair = 54"

*The obstruction in front of the wheelchair is usually a transverse metal armrest approximately 26 inches above the floor and attached to the end of the longitudinal seat over the wheelwell. A vertical stanchion 25 inches from the bus wall is also a part of the obstruction. Two distances represent excursion envelopes of two different wheelchair stations.

Table 1

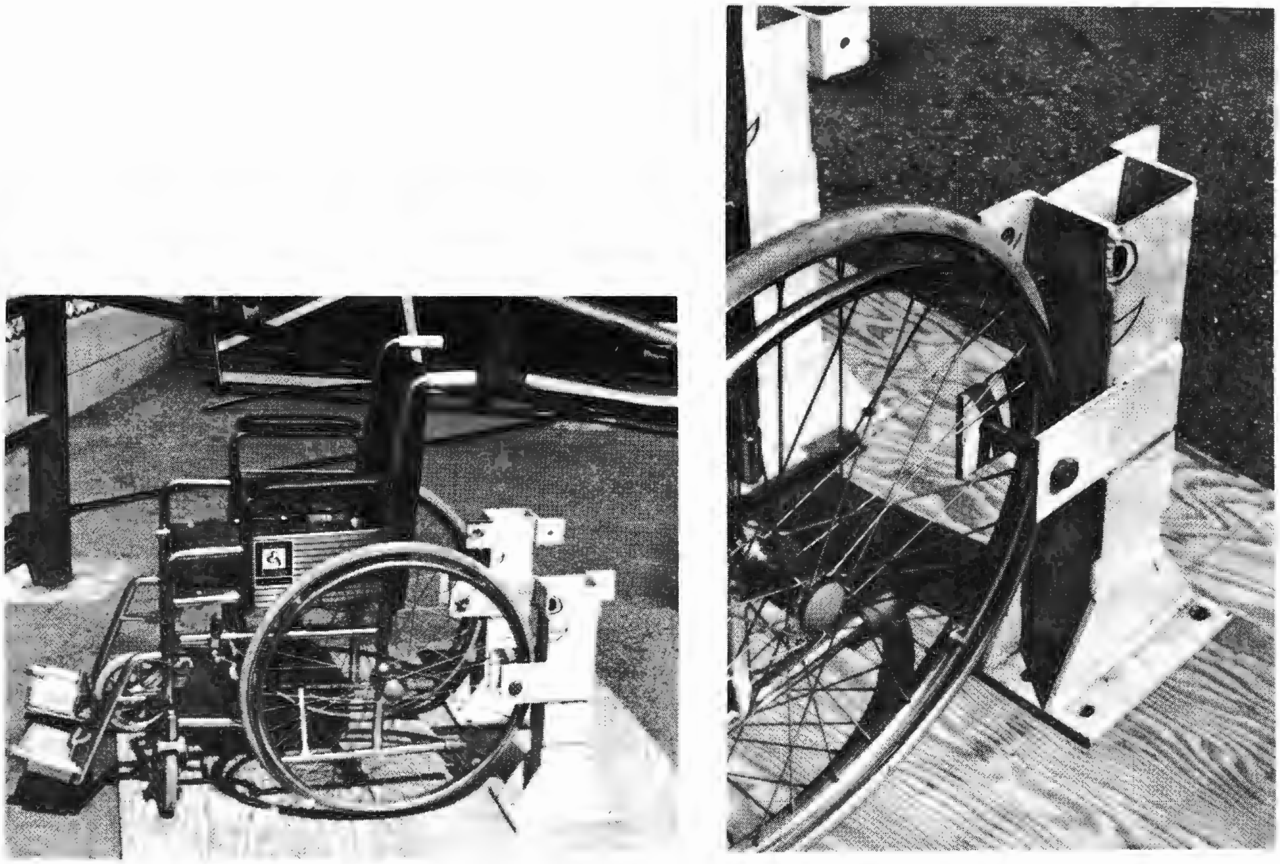
were tested (Figures 11 through 15). As discussed earlier, the securement devices used in Phase I were designed with reserve strength to avoid their failure during testing.

In Phase II, seven additional systems were tested. These were ones that had grown in popularity, had come onto the scene in California after the project began, or had been developed during this project (Figures 16 through 22). All systems will be described in detail along with how they performed, in the section, DYNAMIC TEST RESULTS.



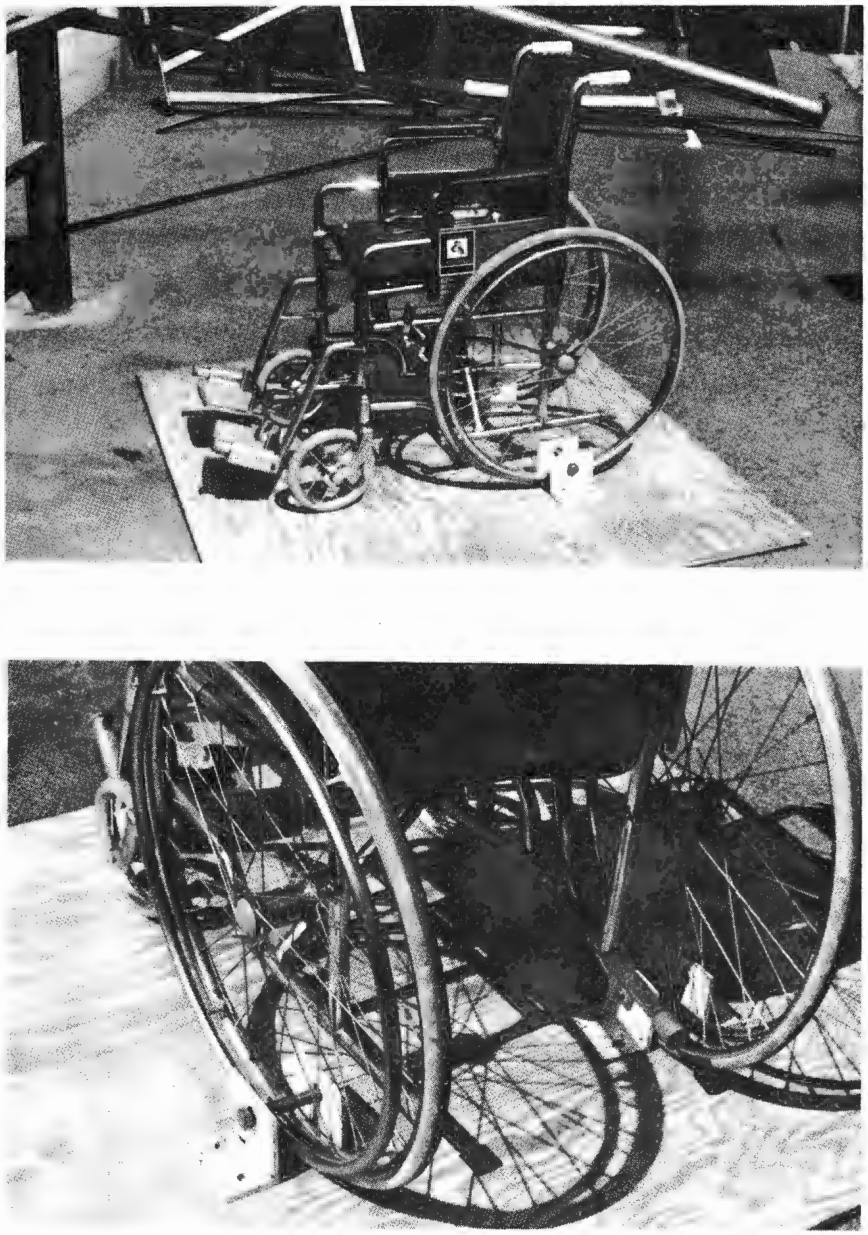
T-Bar--Front Position

Figure 11



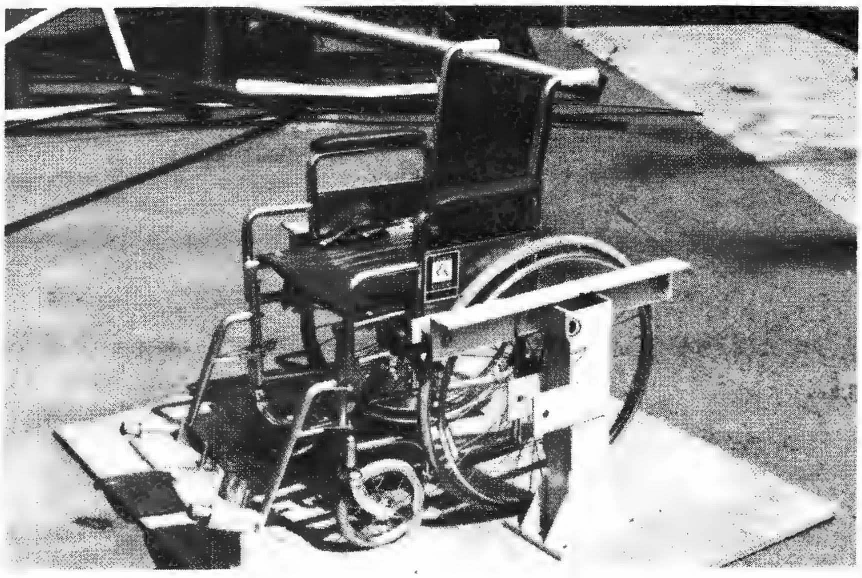
Wall Rim Pin

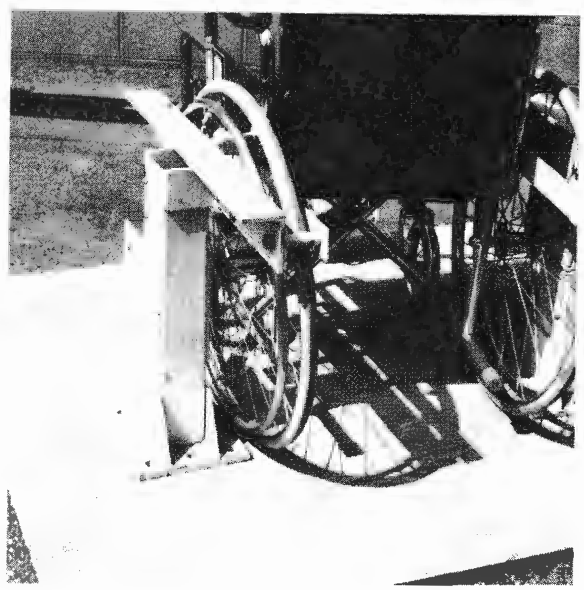
Figure 12



Floor Rim Pin

Figure 13

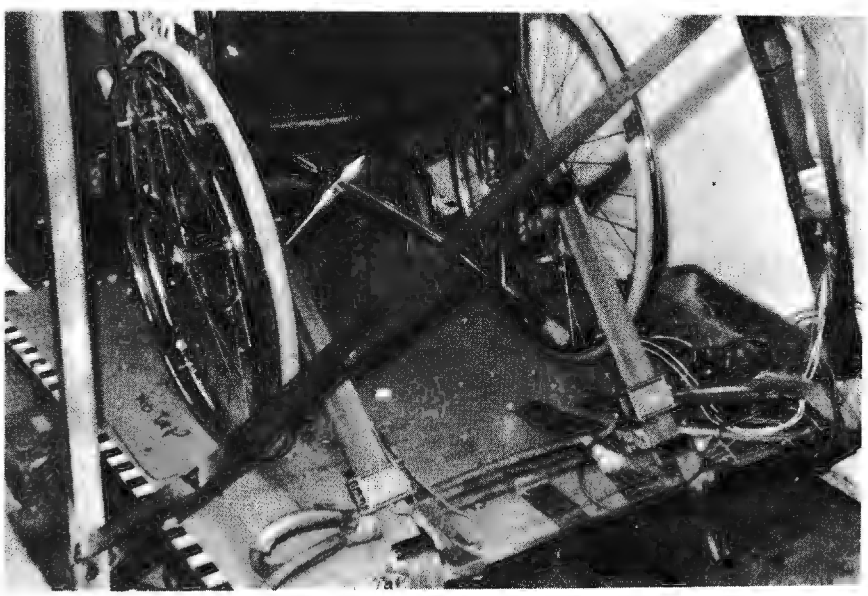




Fender

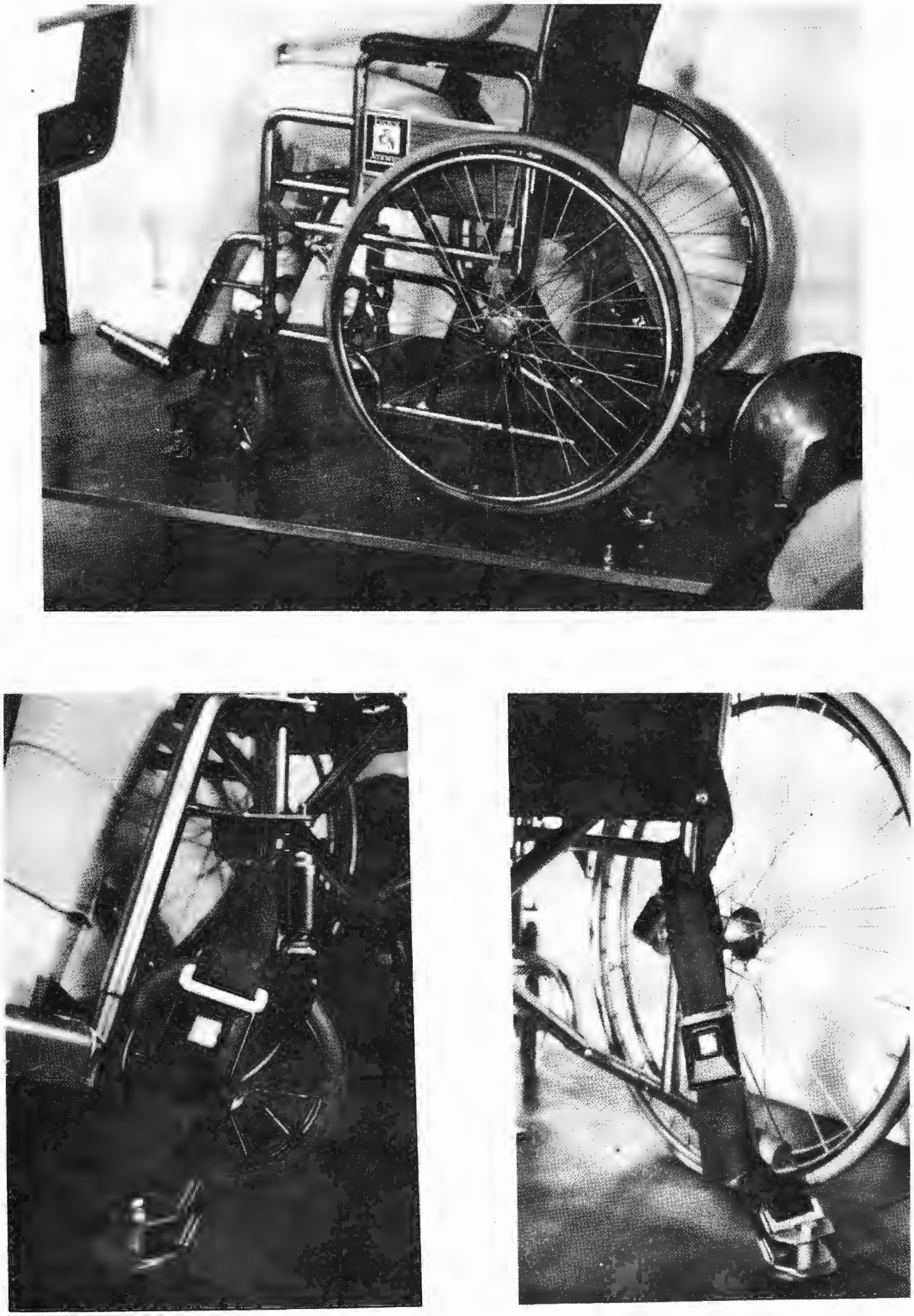
Figure 14

Side Facing
With Arm Rest
Removed



User and Chair Belt

Figure 15

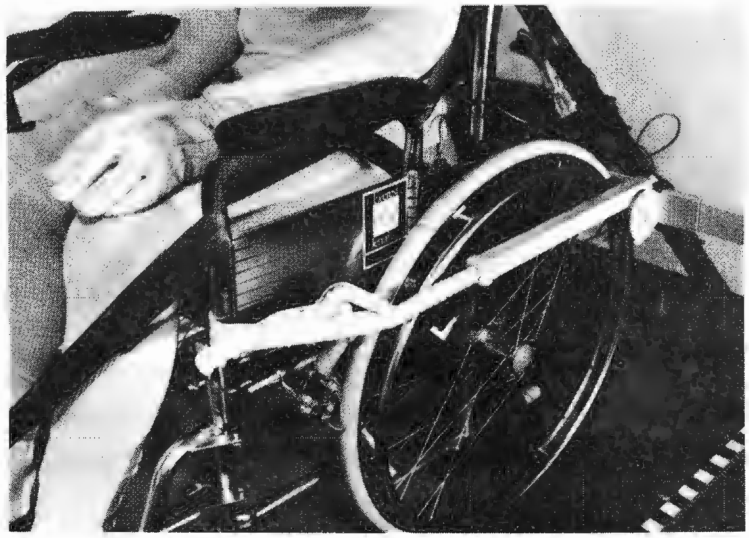


Three Point Belt

Figure 16

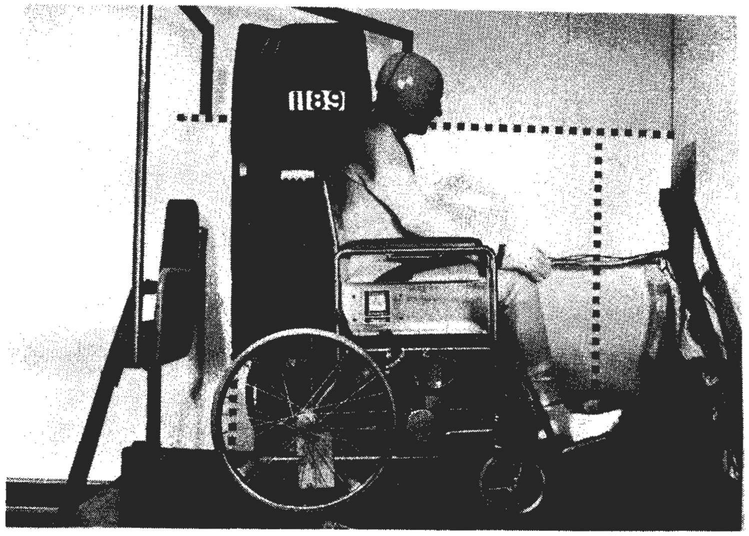
Horizontal Bars

Figure 17



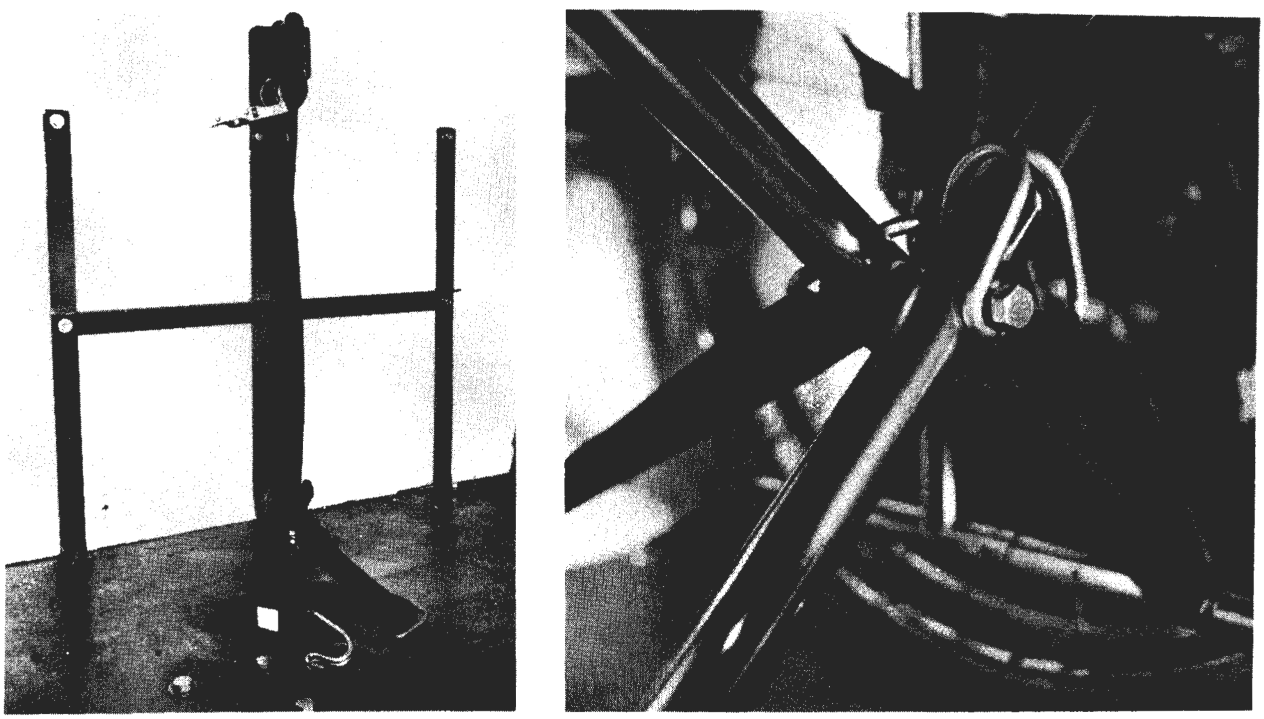
Single Rim Latch

Figure 18



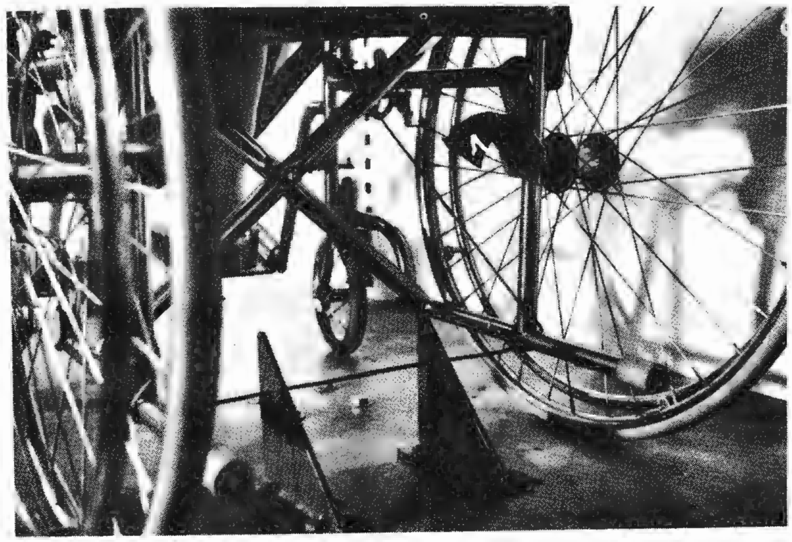
Wayne State

Figure 19



Cross Brace Belt

Figure 20



Frame Cable

Figure 21

Frame Anchor

Figure 22

Injury Criteria

Many attempts have been made to develop methods to assess experimental data in a way that allows predictions to be made about injuries to humans subjected to similar conditions. All of the methods developed so far are imperfect and involve a great deal of subjectivity. However, some of the methods can be useful, as long as their imperfections are recognized, in obtaining comparisons between the behavior of dummies during accidents and anticipated injuries to humans subjected to the same accident condition.

Head injury has been found to occur in 70% of automobile accidents and is considered to be the major cause of fatalities in these accidents (8). Chest (thoracic) injuries are the second most common cause of fatalities in automobile accidents. Based on work by Wayne State University and C. W. Gadd (23), methods have been developed to calculate severity indexes for the head and chest from impulse data measured in 50th percentile male anthropomorphic dummies. During the wheelchair securement tests, time versus deceleration plots were developed using output from triaxial decelerometers located in the dummy's head and chest. Information from these plots was used to compute severity indexes by two methods.

A Head Injury Criteria (HIC) was calculated in conformance with the requirements of the Federal Motor Vehicle Safety Standard (FMVSS) No. 208 (18). Using the formula

$$HIC = \left[\frac{1}{t_2-t_1}\int_{t_1}^{t_2} a \, dt\right]^{2.5}(t_2-t_1),$$

trial and error integrations of the head deceleration pulse using 0.8 milisecond (ms) samples were made to find the maximum HIC for each test. In the formula, a = resultant deceleration at the center of gravity of the head expressed as a multiple of g; and t_1 and t_2 = any two points in time during the crash.

The conventional method of computing HIC is to limit the calculation to time intervals when the head is in contact with a part of the vehicle. However, HIC's reported in Tables 2 and 3 also include those where no head strike occurred. A HIC of 1000 or greater is frequently referred to as an indicator of the threshold of very serious or fatal injury (18).

An impulse integration procedure was also used to calculate a Chest Severity Index (CSI). The severity index was defined as $CSI = \int_{t_o}^{t_f} a^n \, dt$

where:

a = resultant chest deceleration

n = weighting factor (2.5)

t_o = pulse starting time, sec.

t_f = final time of the deceleration pulse, sec.

Use of this formula as a method of attempting to quantify pulse data has been suggested by the SAE J885a(10) and others (8, 14). Results of the computations are reported in Tables 2 and 3.

Emphasizing again that severity indexes are imperfect and should only be used for making relative comparisons between systems being tested and obtaining indicators of possible injury, HIC's and CSI's above 1000 are considered an indication of very serious or fatal injury. Indexes between 500 and 1000 are an indication of moderate to severe injury. Minor injury would be indicated by indexes below 500 (8, 23). Indexes below 500 in Tables 2 and 3 are particularly questionable as valid injury predictors since many of them resulted from pulses which did not involve an actual strike of the dummy's head or chest.

Head Excursion

The excursion of the anthropomorphic dummy's head was defined as the maximum forward travel of the head, from its "at rest" position, relative to a reference point on the test sled. The excursion is made up of two components:

1) the forward rotation of the dummy about its pelvic hinge,
2) the forward movement of the pelvic hinge relative to a fixed point on the test sled.

The second component was usually the result of a combination of elongations of the dummy's securement belt, movement and distortion of the wheelchair, and distortion of the securement system.

The horizontal excursions of the head were scaled from projections of the high-speed test films. Reference targets afixed to the dummy and test sled, known chair dimensions, and a Vanguard motion analyzer were some of the tools used to scale the excursions.

Seat Belt Loads

Load cells were attached to the lap belts securing the anthropomorphic dummy to determine possible injuries.

Research by the National Highway Traffic Safety Administration and others has indicated that passengers with lap belts properly placed around the pelvic area can withstand belt loads of 2,000 to 2,500 pounds without injury. Belts around other parts of the body allow injury at lesser loads. For example, load for a shoulder belt, to minimize overall injuries, is about 1,500 pounds (32).

SUMMARY of DYNAMIC TEST RESULTS

This section summarizes the results of tests on each of the 12 generic types of securements used. A detailed description of each of the 42 tests run, the results, and photographs are given in the appendix.

Typical Conditions

The regular wheel brakes of the chairs were set before all test runs.

The securement systems tested in Phase I are commonly used in vans. During the loading of wheelchairs in vans, the chair is usually pushed forward, especially with rear end loading. Consequently, the chair's front caster wheels are usually aft of its forward frame posts. The casters of the chairs tested in Phase I were positioned aft of the forward frame posts (See Figure 3).

Most of the securement systems tested in Phase II require that the chair be backed into them. Consequently, when in position for securement, the chair's front caster wheels were forward of its forward frame posts. They were placed in the forward position for the tests in Phase II.

During the forward facing tests, the anthropomorphic dummy invariably jackknifed about its seatbelt when the speed of the sled at impact was greater than 10 mph. During some of the 20 mph tests, the jackknife action resulted in a violent impact between the head and the legs of the dummy. Three of these impacts resulted in high HIC measurements, with one reaching the probable fatal threshold, apparently because in these tests the head of the dummy hit its kneecaps.

A lesson learned from viewing the films of the tests of forward facing dummys with a lap belt, is that even if a wheelchair user is properly secured with a lap belt and has ample space in front to project into, serious injury may be incurred from the impact of the head upon the kneecap. A shoulder harness restraining the upper torso should minimize the possibility of a head-to-kneecap impact.

During the side facing tests, the anthropomorphic dummy twisted about the leading (nearest the forward end of the vehicle) armrest of the wheelchair. Unless otherwise noted, all side facing tests were conducted without a restraining structure--such as a wall--on the leading side of the chair to resist the movement of the chair or dummy. Without such a support, the chair has to resist all side thrusts.

Unless otherwise noted, the dummy was restrained in the wheelchair by an automotive type seat belt attached to the axles of the wheelchair's large rear wheels. From the axles, the two halves of the belt were passed up and under the chair's armrests and buckled together in the lap of the dummy.

All references to wheelchairs refer to the manually propelled type unless the electrically powered type is specifically mentioned.

Neither the "bungee" secured batteries nor the drive motors came loose from the wheelchairs during tests with the electrically powered chair. Except for one minor spill, the acid (colored water) remained confined in all batteries.

Summaries of the individual dynamic tests will not repeat the above typical conditions; each will describe only the additional pertinent conditions. Occasionally, representative HIC data below the severe level are given; on the other hand, all HIC data in the severe range are given.

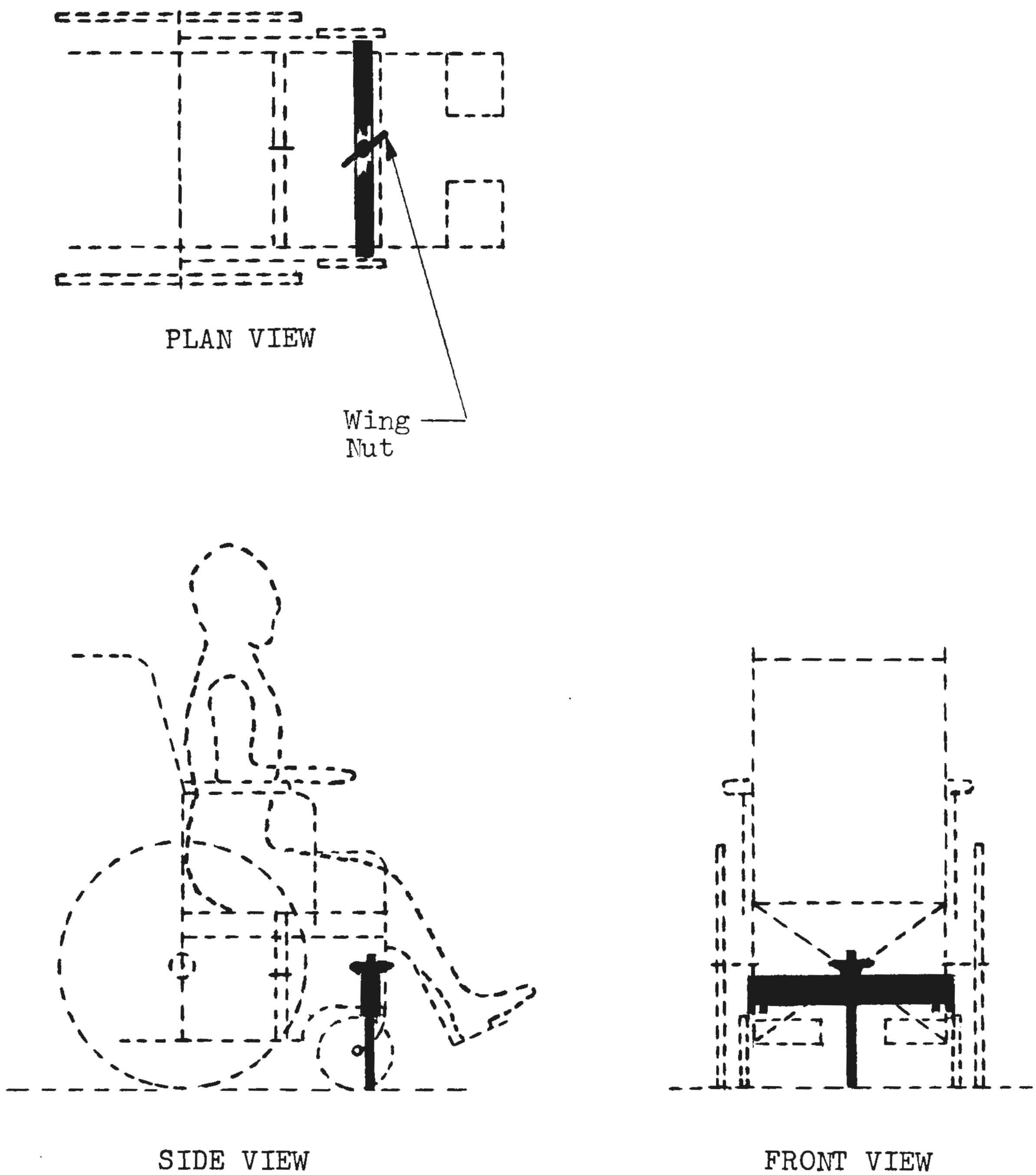
For the reader's convenience, two tables containing summary information on the individual tests appear at the end of this section. Table 2 covers Phase I tests, and Table 3 covers those of Phase II.

Phase I

The following is a summary of 28 tests on 5 securement systems. Except for one test, during which a wall was provided, there were no simulated obstructions to impede the movement of chair or dummy. These tests represent Phase I.

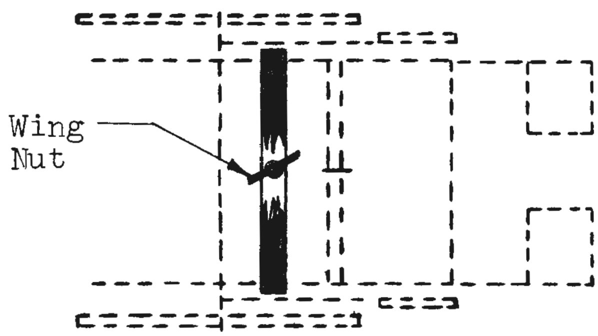
T-Bar

The T-bar system consists of a horizontal bar with end flanges and a center adjustable anchor rod that is attached to the floor. The bar, or top portion of the T, spans between the lower horizontal frame members of the chair with the end flanges straddling the frame. Its points of engagement on the horizontal members are either forward of the chair's cross brace or aft of it, depending upon the preference of transit providers (Figures 23 & 24). The T-bar was tested in each location. For chairs with offsets in the lower horizontal member (caster arch) to facilitate turning of the front casters, the T-bar usually has to be placed on the top portion of the arch because of insufficient room for it between the cross brace and the beginning of the arch. During all T-bar tests, the T was cinched down with a pre-load of 600 pounds. This load is easily obtained by hand tightening the

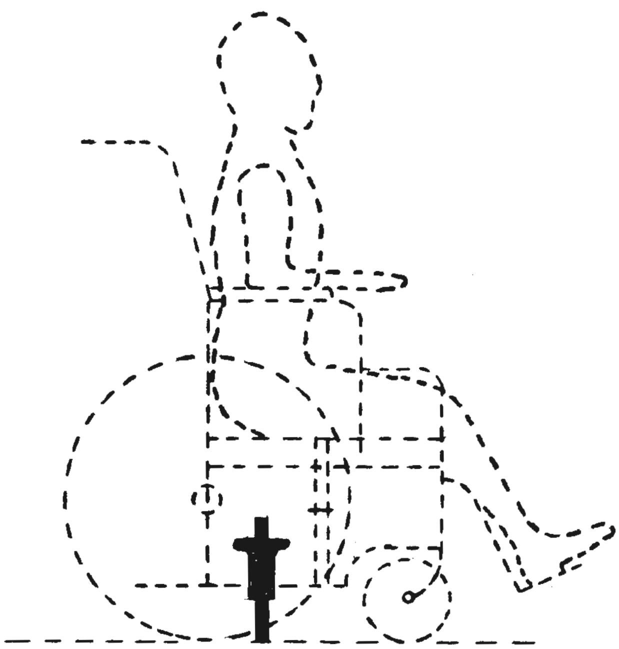


T-BAR/FORWARD POSITION

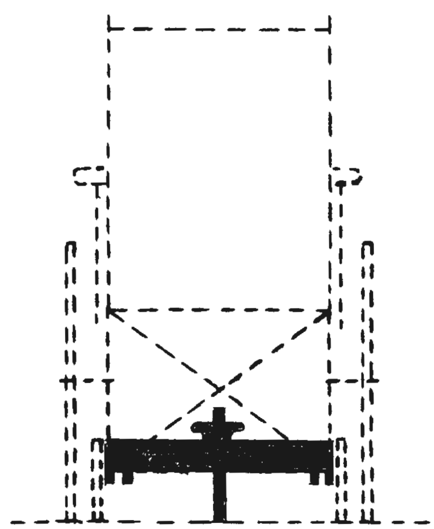
Figure 23



PLAN VIEW



SIDE VIEW



FRONT VIEW

T-BAR/REAR POSITION

Figure 24

wing nut which is usually provided with T-bar systems.

T-bar/forward position/forward facing chair. Six tests were run with the T-bar placed on the caster arch on forward facing chairs (with respect to the direction of travel before impact). In each test the T-bar slid off the caster arch and engaged the bottom rail just forward of the chair's cross brace. This action resulted in the securement system's being in fact detached from the chair. The T was trapped to some degree by the chair's frame members, but could easily have become completely free if there had been a secondary crash. (Secondary crashes are not uncommon in real vehicular accidents).

The chairs used in the first tests of the forward T/forward facing chair combination, were equipped with the rigid type of footrests. In each test, the chair tipped forward, allowing the footrest to engage the platform of the test sled and support the load of the chair and dummy occupant.

To determine if the forward casters of a chair without a footrest would prevent the chair from tipping all the way over when it was secured with a forward placed

T, three tests were conducted on chairs without footrests. The first test was at a speed of 19.7 mph and 12 g's. The chair rotated forward almost 90 degrees, thus causing the dummy, which was belted to the axles of the chair, to fall forward onto a part of the sled's hardware. The second test was at 5.7 mph and 10 g's. In this test, the chair did not tip over. The third one was run at a speed approximately half way between the first two--11.7 mph--and at 12 g's. The chair again tipped approximately 90 degrees.

Damage to the chair in the forward placed T/forward facing tests was minor when the chair was equipped with a rigid footrest. Major damage was incurred by the front casters when chairs were not equipped with footrests.

T-bar/rear position/forward facing chair. Two tests were conducted with forward facing chairs secured with T-bars placed to the rear of the chairs' cross brace (Figure 24). One chair was equipped with footrests (rigid), the other without. Each was tested at approximately 20 mph and 12 g's.

During the test with the footrest-equipped chair, the T-bar slid along the bottom rail after initial impact until it engaged the back posts. The chair then rotated forward onto its casters, causing them to bend and deflect far enough to allow the footrest to contact the platform and begin carrying some of the vertical load. The rear wheels did not leave the platform.

There was moderate damage to the chair's side frame members, casters and footrests.

During the test of the chair without a footrest, the anchor bolt for the T failed, probably from fatigue since this was the eleventh test in which the T system had been used. The failure caused chair and dummy to continue downrange after the sled came to rest.

It was decided not to retest a rear-placed T on a chair without a footrest. This decision was made on the assumption that it is highly unlikely that the same undesirable tipping action which occurs with a forward-placed T will occur with a rear placed T. This assumption was based on the fact that the final position of the rear-placed T--resting on top of the bottom rail and against the vertical members to which the rear wheels are attached--prevents the rear wheels from lifting off the platform.

T-bar/forward position/side facing chair. Two tests were conducted with the chair and dummy in a side facing position and with the T-bar placed on the caster arch.

In the first test the speed of the sled was 7.7 mph and the deceleration rate was 5 g's. The damage sustained by the chair was minor and the measured decelerations of the dummy's head and chest indicated that it was subjected to minor forces.

In the second test the speed of the sled was increased to 17.2 mph and the deceleration rate was increased to 12 g's. The leading side caster bent inward and the wheelchair tipped in the direction of travel onto its side. The head excursion of the dummy was 71 inches, which far exceeds the 53 inch envelope.

T-bar/rear position/side facing. One test was conducted with the chair and dummy in a side facing orientation with the T-bar placed between the cross brace and rear posts. The speed of the sled was 19.3 mph and the deceleration rate was 12 g's. The wheelchair sustained major damage.

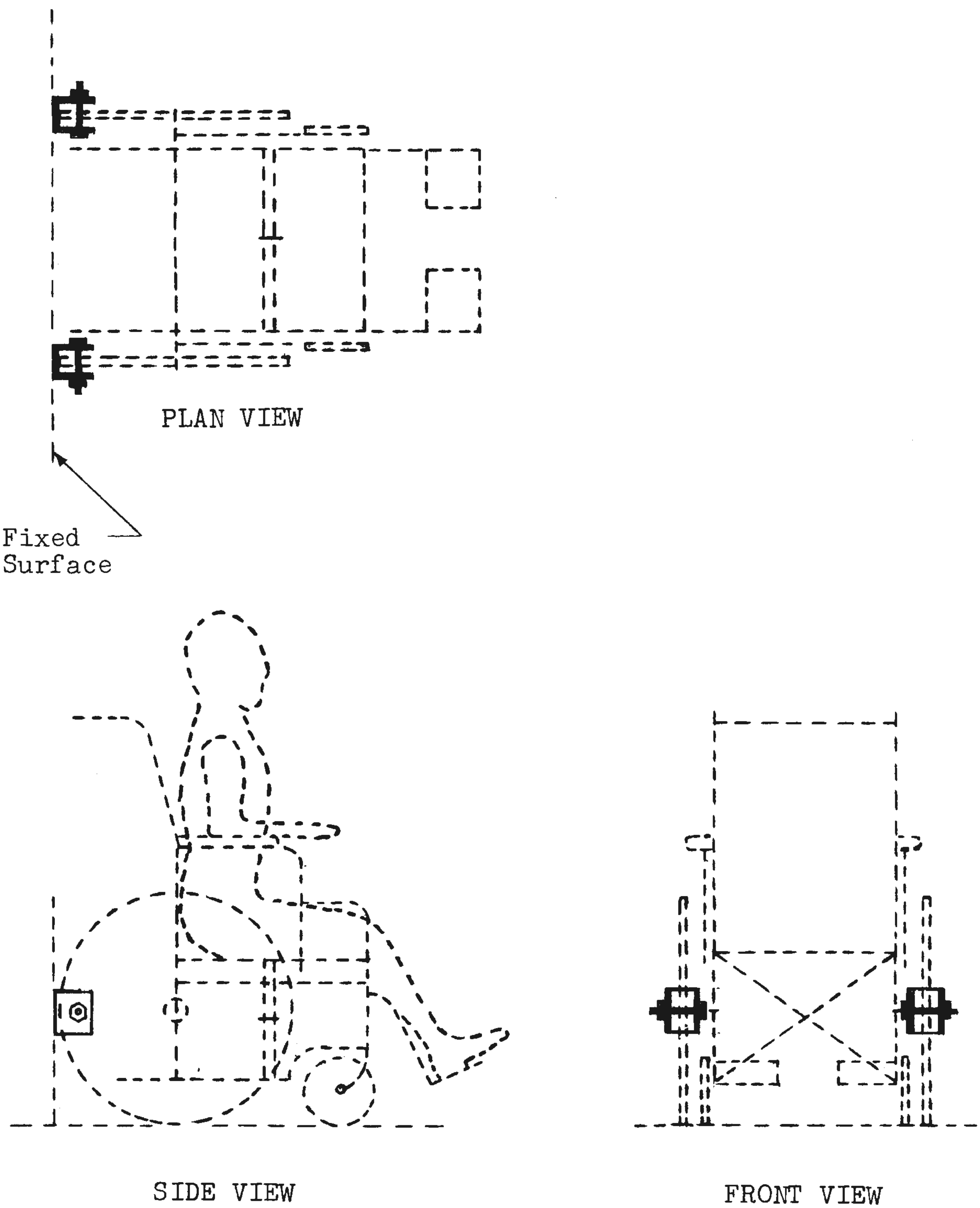
Wall Rim Pin

The wall rim pin securement system consists of two U shaped brackets mounted on a vertical surface approximately at the axle level of the wheelchair's large wheels (approximately 13 inches above the floor). Securement is accomplished by placing both of the large wheels into the U's and retaining them by passing a bolt through holes in the legs of the U's (Figure 25).

Wall rim pin/forward facing. Three tests were conducted with the wheelchair and its occupant facing forward and secured by a wall rim pin system.

The first test was run at 19.3 mph and a 12 g deceleration rate. The high center of gravity of the jackknifing dummy caused the chair to rotate forward, lifting the rear wheels off the sled. The rear wheels rotated up the securement support until the rigid footrests contacted the sled.

The chair appeared capable of absorbing additional energy; consequently, its energy reserve capacity was measured by statically testing it.



WALL RIM PIN

Figure 25

The static tests indicated a latent energy reserve equivalant to a 22.3 mph critical velocity (at 12 g's). During the static tests the footrests appeared to play a significant role. Because of the experience with the forward placed T-bar system without footrests, it was decided to test the wall rim pin system and a chair without footrests at 22.3 mph and 12 g's.

The planned velocity of the test was exceeded by approximately one mph--23.2 mph.

The rear wheels of the chair rode up the support in the same manner as in the first test. However, unlike the first test in which a chair with footrests was used, the chair continued to tip until it had rotated approximately 90 degrees, dumping the dummy onto the sled's platform.

The third test was a repeat of the second, except the wheelchair had rigid footrests. The results were similar to the first test, the major difference being greater damage to the secured wheels caused by the higher energy that had to be dissipated (impact speed of the first test with a footrest was 19.3 mph whereas in the third it was 23.1 mph).

Wall rim pin/side facing. Two tests were conducted with the wheelchair and its occupant facing sideways to the direction of travel and secured by a wall rim pin system.

One test was performed at a sled speed of 11.3 mph and a 9 g's deceleration rate. The chair took up the slack in the securement system by rotating approximately 10 degrees in the direction of travel. The dummy leaned in the direction of travel against the armrest. The chair sustained minor damage. The head excursion was 44 inches, which is the same as that experienced by the jackknifed dummy in forward facing tests with the same securement system at higher speeds of 19 to 23 mph and 12 g's.

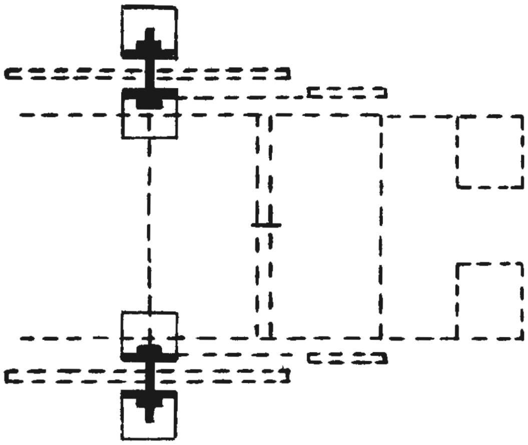
The other side facing test was performed at 19.4 mph and 12 g's. The chair sustained major damage and the head excursion was 61 inches, thus exceeding the 53-inch area free of obstructions believed to be optimum for forward facing chairs. Test films show that the dummy violently impacted the chair armrest with his ribcage, which suggests that a person in the same situation would suffer rib damage. [Since side facing chairs need less longitudinal room for positioning (26" wide vs. 45" long), the obstruction free area in the direction of travel can be expected to be much less than the 53 inches suggested for forward facing chairs. It may be possible to pad adjacent obstructions for side facing chairs and thereby mitigate the excessive excursion as well as reduce impact.]

Floor Rim Pin

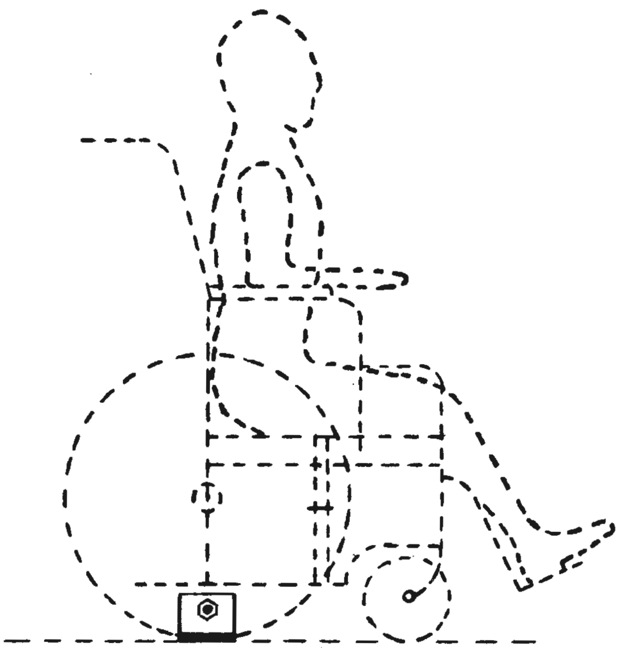
The floor rim pin securement system is the same as the wall rim pin system except the two U-shaped brackets are bolted to the floor and the user centers the large wheels on the brackets before inserting the bolts through the legs of the U's (Figure 26).

Floor rim pin/forward facing. Two tests were conducted in the forward facing mode, both at approximately 19 mph and 12 g's. In both tests the chair sustained moderate damage. In the first test the dummy was secured to the chair with a belt about its midsection and around the back of the chair. Upon impact the belt rode up the back of the chair to the handgrips, breaking the left back post tube just above the axle mount, and bending both tubes forward and inwards. The dummy came close to becoming free of the chair. The position of the dummy's waistband--high on the stomach area--caused the dummy to remain in a sitting position, and to experience pressures on the soft stomach area as opposed to pressures on the more preferable hip area.

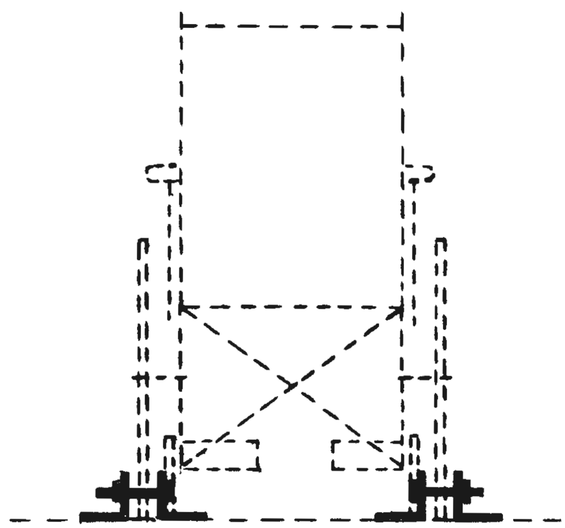
In the other test, the regular lap belt method of anchoring to the axles was used. The primary damage to this chair was badly bent wheels.



PLAN VIEW



SIDE VIEW



FRONT VIEW

FLOOR RIM PIN

Figure 26

Floor rim pin/side facing. Three tests were conducted with the wheelchair and its occupant facing sideways to the direction of travel. Two of the tests were at approximately 19 mph and 12 g's and the other at 10 mph and 10 g's.

In one of the higher velocity tests the dummy was secured to the chair with a belt about its midsection and looped around the back of the chair, with the same unsatisfactory results as in the preceeding forward facing/floor rim pin tests.

In both of the higher speed tests, the chair sustained major damage and the dummy was thrown partially (axle belt) or fully (loop belt) out of the chair. In the lower velocity test, the wheelchair sustained minor damage and the dummy remained seated in the wheelchair.

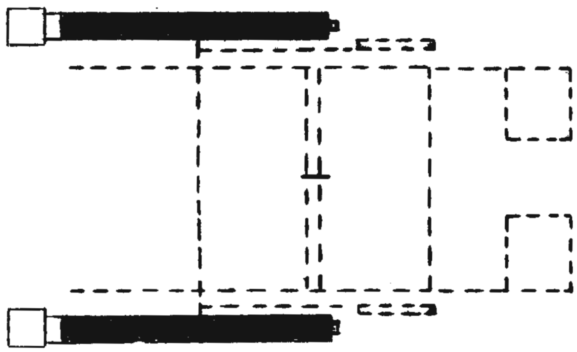
Fender

A fender securement system consists of two bicycle-like fenders attached to rigid supports. The fenders are lowered over the large diameter wheels of a wheelchair and locked in position. When in proper position they closely surround approximately the upper third of the wheels. Inasmuch as the wheels of a forward facing chair will tend to slide or be forced under the fenders during a frontal impact, (thereby contacting only the lower edge of the fenders), only the lower portions of the fenders were constructed for this project (Figure 27).

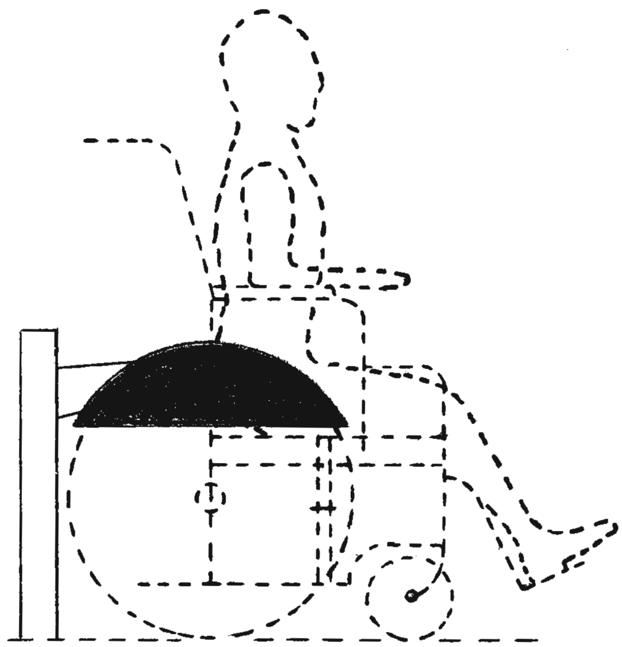
Two tests were conducted with the fender securement system. The sled velocity and deceleration g's were the same in both tests--19.5 mph and 12 g's. In one test the chair and dummy faced forward and in the other sideways.

During the forward facing test, damage to the wheelchair was moderate and no unusual loads were imposed upon the dummy.

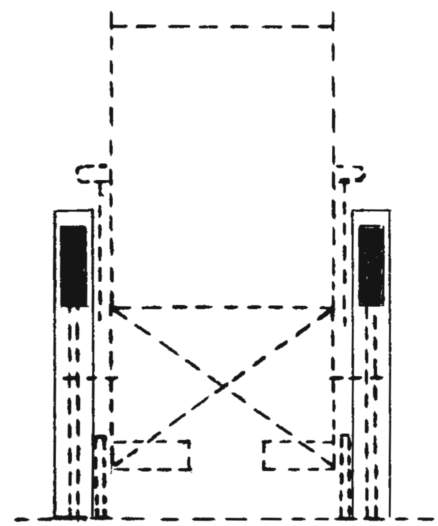
In the side facing test, the support bracket for the fender system provided some support for the chair, with a result of minor chair damage. This helps to support the assumption that less chair damage will



PLAN VIEW



SIDE VIEW



FRONT VIEW

FENDER

Figure 27

result if something is provided along the side of the chair to help absorb some of the impact energy. The dummy's lap belt load was higher than it was in the forward facing test. The reason could not be determined, but may have been uneven tension in the belt resulting from friction and entrapment of the belt on the dummy in the side facing position.

Although the measured head and chest decelerations were low enough not to indicate potential injury, sideways bending of the torso and impact of the ribs on the armrest raised the suspicion that there would have been internal injuries had a person been in the chair.

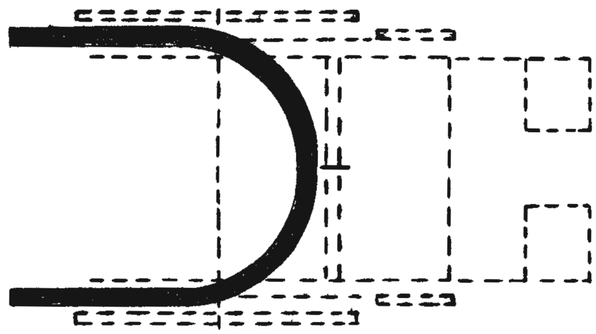
User and Chair Belt

The user and chair belt securement system consists of an automotive type seat belt that is anchored to the floor and secures both the user and the chair (Figure 28).

User and chair belt/forward facing. Three tests were conducted with the dummy and wheel chair facing forward. The sled velocity in all three tests was 20 to 22 mph and the deceleration rate was 12 g's.

In all three tests the wheelchair sustained minor damage. The seat belt load on the dummy was twice as great as in other tests, probably because the belt slackened during sled run-up, which delayed the onset of belt loading. Another possible reason for the high belt load is the fact that the belt retained the chair as well as the occupant.

User and chair belt/side facing. Two tests were conducted with the dummy and wheelchair facing sideways with respect to the direction of travel. The sled velocity in both tests was approximately 11 mph. The deceleration rate was 10 g's in the first test and 12 in the second.



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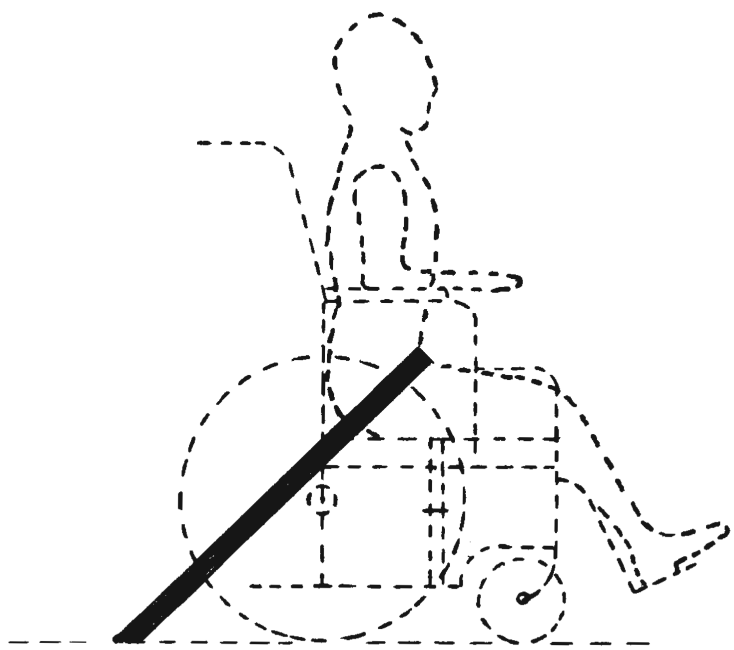

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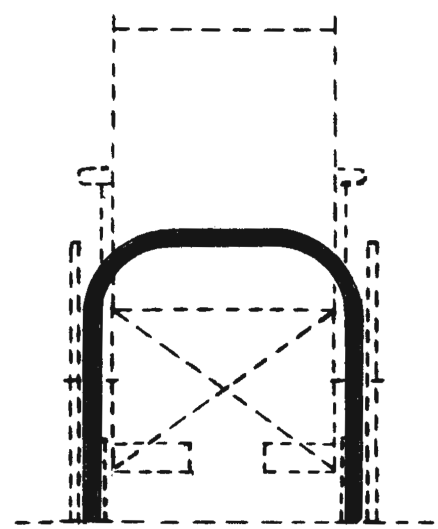


FRONT VIEW

USER AND CHAIR BELT

Figure 28

In the first test there was no wall on the sled to simulate the side of a vehicle. This allowed the wheelchair to rotate about the belt anchorage points, causing the chair to tip onto its side and contact the nearby wall of the test building. In practice, the wheelchair is usually placed with the rear wheels against the vehicle sidewall when this system is used in the side facing position. Therefore, in the second test a wall was installed on the sled and the rotation of the wheelchair during impact was reduced to about 20°. Damage to the wheelchair in the second test was minor and the dummy experienced no unusual deceleration.

Phase II

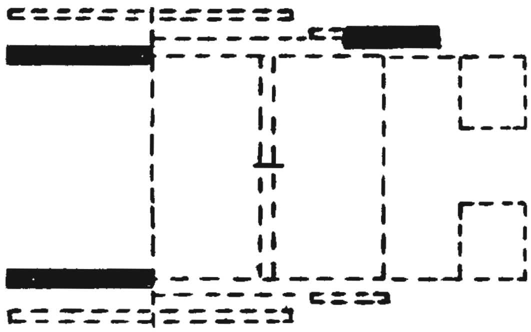
The following is a summary of 14 tests on 7 securement systems.

Each test incorportated a simulated obstruction (longitudinal seat, armrest and stanchion) on the sled forward (in the direction of travel) of the chair and dummy (Figure 10). These tests represent Phase II of the project.

Three-Point Belt

A three-point belt securement system is one that uses automotive-type seat belt equipment to secure the wheelchair to the floor (Figure 29). Two of the three belts are attached to the frame of the chair near the large wheel axles, one on each side. The third belt is attached to the frame near one of the front casters. The anchorages of the axle and caster belts are positioned to create opposing forces to minimize longitudinal movement and prevent overturning of the chair.

Two tests were conducted with the three-point belt securement system, one forward facing and one side facing. The sled velocity was 20 mph in both tests



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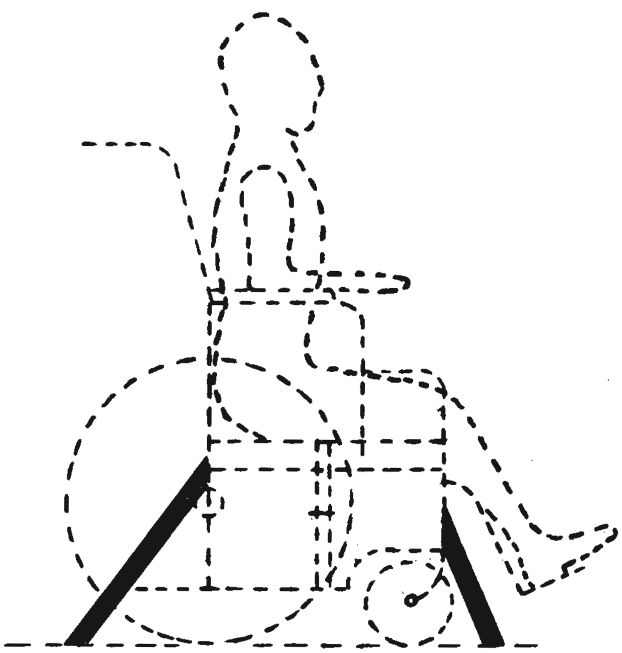
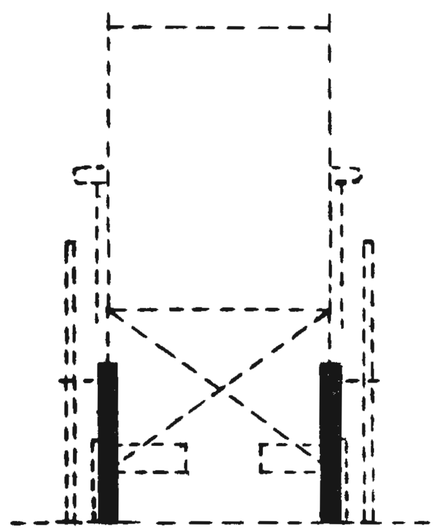


SIDE VIEW



FRONT VIEW

THREE POINT BELT

Figure 29

and the deceleration of the sled was 12 g's in the forward facing test and 10 g's in the side facing test.

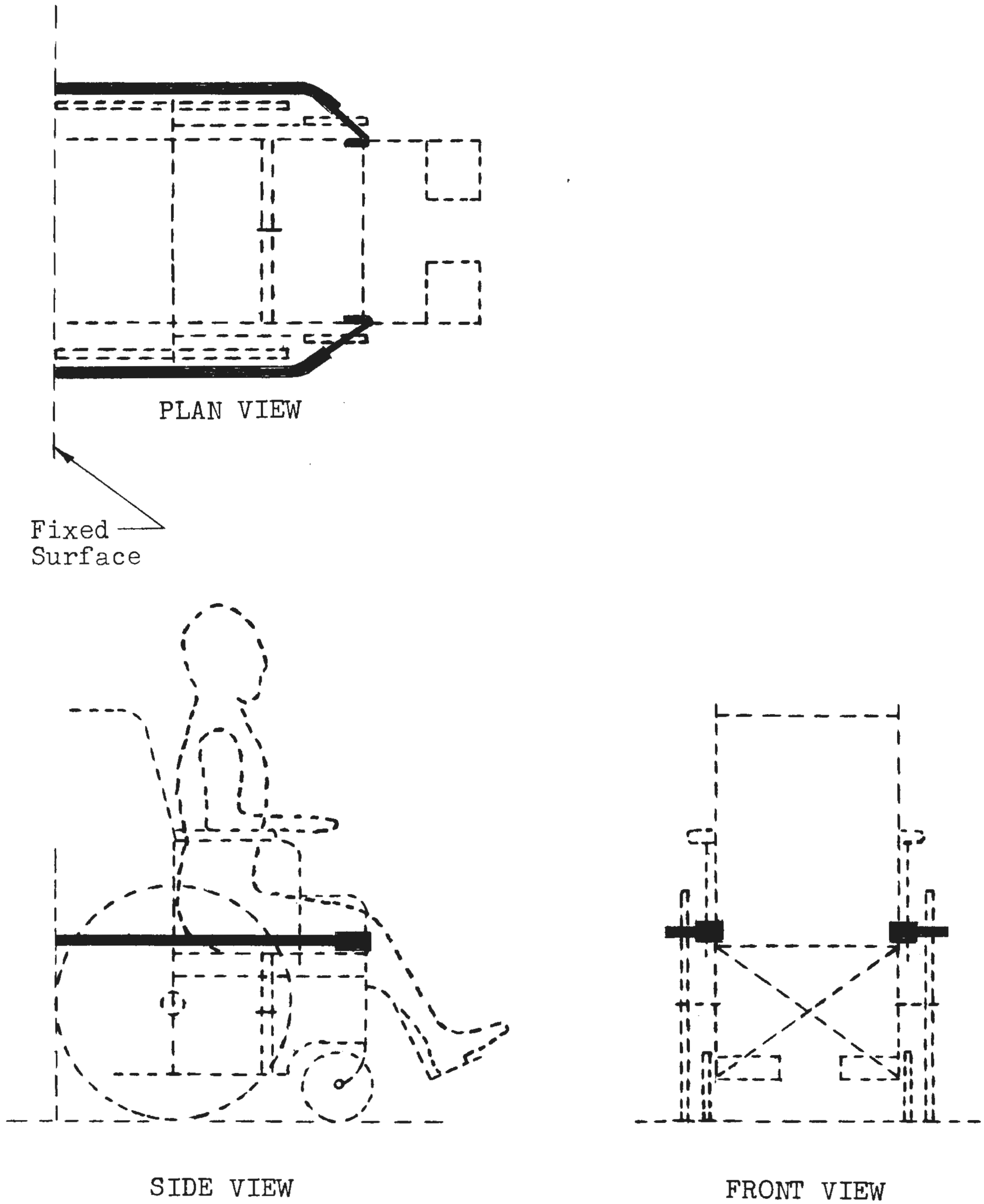
In the forward facing test, the chair sustained minor damage and the dummy experienced no high loads. In the side facing test, the chair sustained major damage, the dummy's head struck the armrest of the simulated obstruction, and the dummy experienced a blow giving a HIC measurement indicating a fatal injury.

Horizontal Bars

A horizontal bar securement system consists of an adjustable bar along each side of the wheelchair at its seat height. One end of the bar is attached to the vehicle at the rear of the chair and the other end has a hook that "grasps" a front vertical frame member of the chair. A tension method is provided to draw the chair's rear wheels against a fixture behind the chair (Figure 30).

One forward facing and one side facing test were conducted with this unmodified, off-the-shelf securement system supplied by the manufacturer. The sled velocity for both tests was approximately 20 mph. The deceleration was 10 g's for the forward facing test and 12 g's for the side facing.

The results of both tests are invalid because the securement system failed in both cases. During the forward facing test, the right-hand hook straightened out, thereby releasing the chair. During the side facing test the horizontal bars slid forward in their anchorage track far enough to allow a back-up tether to become taut and prevent further movement of the chair. Without the tether the bars would have slid free of their anchorage.



HORIZONTAL BARS

Figure.30

Hence, the unmodified horizontal bars did not retain the chair in either the forward or side facing position.

The securement system was modified to minimize the possibility of such failures and the tests were rerun. The results are reported next under "Modified Horizontal Bars."

Modified Horizontal Bars

For this system, the off-the-shelf horizontal bars were modified by strengthening the hooks to prevent their straightening during impact and by adding rubber padding on the inside of each hook to reduce its tendency to slide on the chair's frame. In addition, bolts were placed in the keeper track alongside the horizontal bars to limit their sliding.

One test each of forward and side facing orientation was conducted. The sled's velocity and deceleration were 20 mph and 10 g's respectively in each. Electric powered wheelchairs were used in both tests.

In the forward facing test, the modified hooks did not straighten. However, on rebound, the bars fell away because of the rearward bending of the chair's tubing at the point of original contact. There was no damage to the wheelchair other than the bent armrest supports. The dummy's left hand struck the stanchion of the simulated obstruction and its right hand struck the obstruction armrest. Head injury measurements were fairly high in the minor range, a HIC of slightly less than 500.

In the side facing test, the keeper bolts prevented excessive sliding of the horizontal bars in their anchorage track. However, the bars allowed the chair to swing in an arc about their anchorage points. The force on the armrests severely bent them outwards. The right wheel was also bent. The dummy's head struck the seat back cushion of the simulated obstruction with a force producing a HIC which indicated a minor head injury.

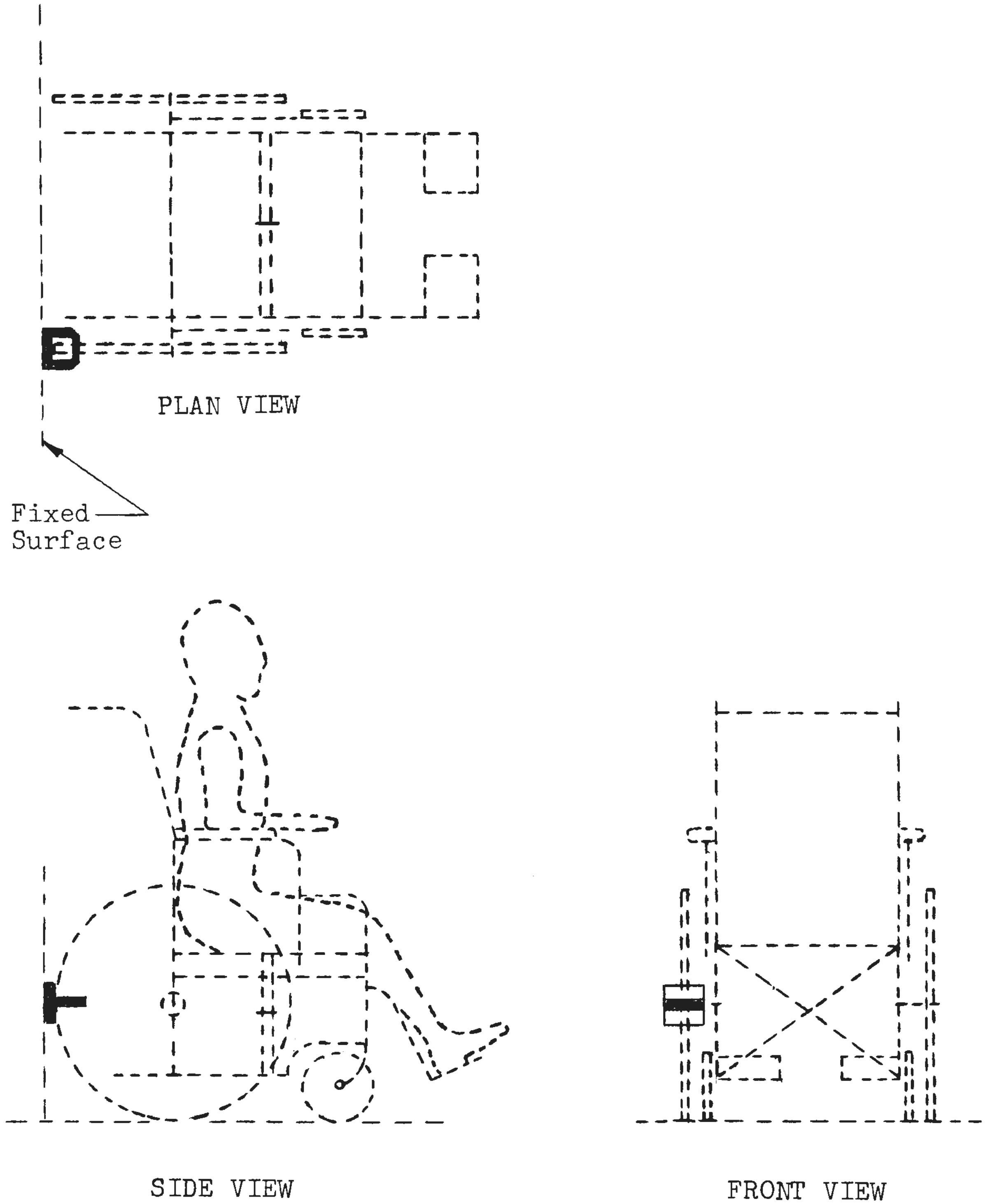
Single Rim Latch

A single rim latch securement system is a device that grasps one of the large diameter wheels at about 13 inches above the floor level. The system tested was mounted on the bottom of a fold-down-seat (Figure 31).

Two tests were conducted with this off-the-shelf securement system. The sled speed in both tests was approximately 20 mph and the sled deceleration rate was approximately 10 g's. A manually propelled chair, with the dummy's seat belt attached to the axles of the chair, was used in the first test. An electrically powered chair, with the dummy's seat and shoulder belts attached to the sled, was used in the second test. The dummy and wheelchair faced forward in both tests.

In both tests the forward pull on the latch caused the bus seat to fold downward, forcing the securement to unlatch and release the wheelchair.

The latching device was modified to ensure that the latch could not open upon impact. One test was conducted at approximately the same velocity and deceleration as in the above two tests (the dummy's



SINGLE RIM LATCH

Figure 31

seat belt was attached to the axles of the chair). The manually propelled wheelchair sustained major damage to the secured wheel, resulting in a virtually unsecured chair. The dummy's left shoulder and both knees struck the simulated obstruction.

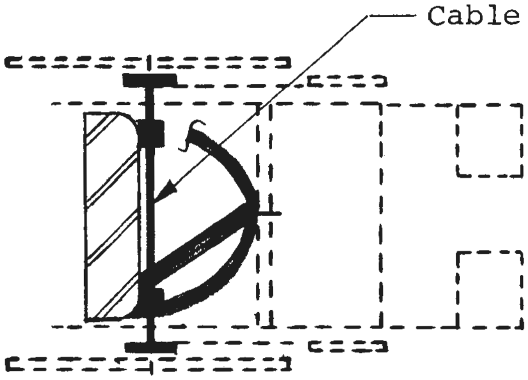
Wayne State

The Wayne State securement system (developed by personnel at Wayne State University) is primarily for use in a rearward facing orientation. It consists of a well-padded back and head support mounted on energy absorbing posts, a lap and upper torso harness for the user, and a cable-latch system to restrict chair movement (Figure 32). The cable-latch system is the primary securement for the chair when impacts occur in the same direction as the chair is facing.

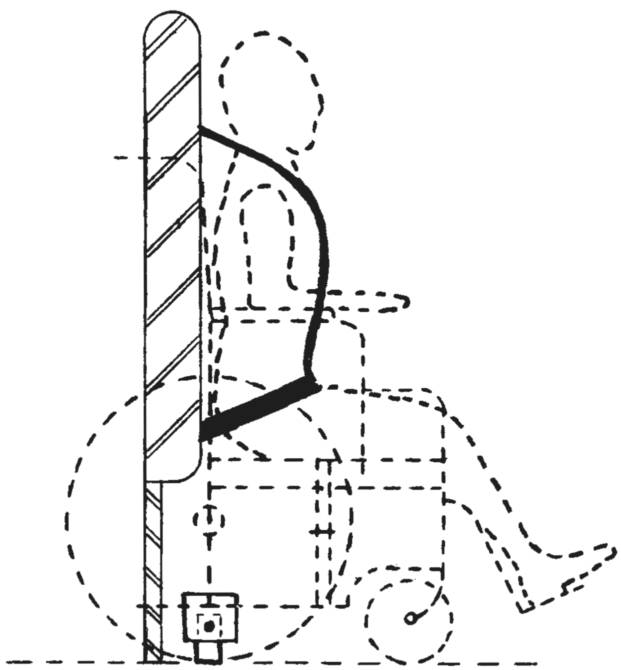
Two tests were conducted on this securement system, one with the dummy and chair facing rearward with respect to travel and the other facing forward. The sled speed in both tests was 20 mph. The sled deceleration was 9 g's for the rear facing test and 10 g's in the forward facing test. An electric powered chair was used in both tests.

In the rearward facing test, the wheelchair and dummy were restrained by the securement, but the dummy's head registered accelerations, producing a HIC of 144, which is low in the minor head injury range. The chair was undamaged.

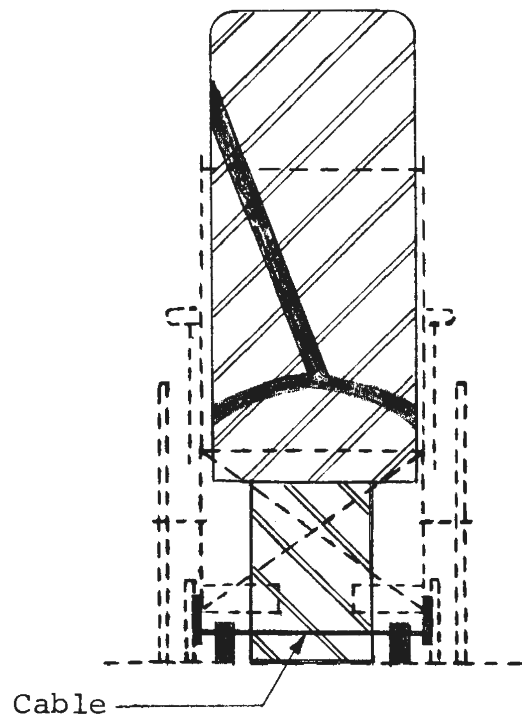
In the forward facing test, the cable broke and securement for both the chair and dummy was transferred to the dummy's lap and upper torso harness. The wheelchair was undamaged except for a slight bending of the seat back frame.



PLAN VIEW



SIDE VIEW



FRONT VIEW

WAYNE STATE

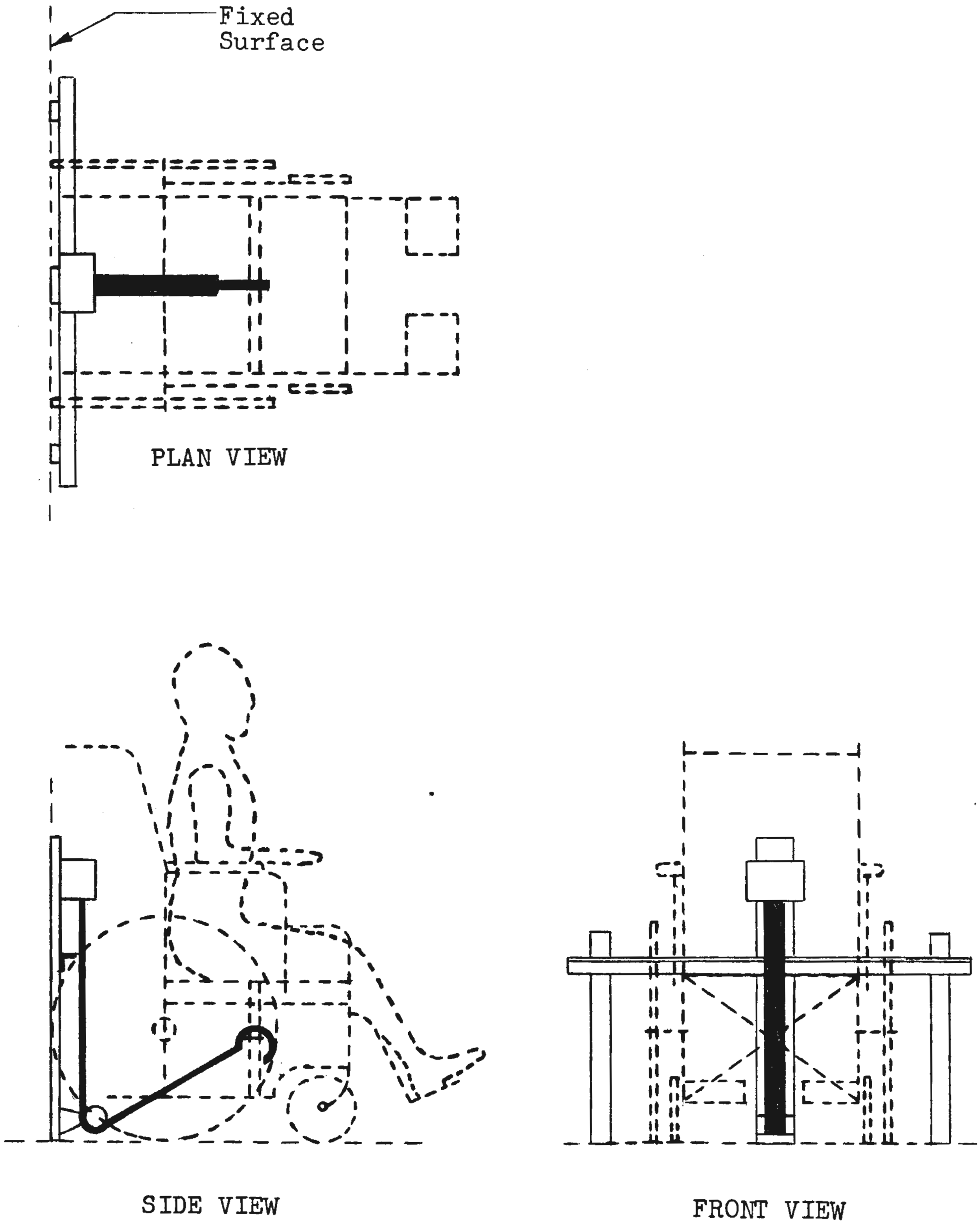
Figure 32

Cross Brace Belt

The cross brace belt securement system consists of a web belt that attaches to the wheelchair's cross brace. The belt is threaded through a roller that is mounted at the vehicle's side wall to floor intersection. From there the belt continues to a side wall mounted ratchet system that applies tension to the belt (Figure 33).

One side facing test was conducted with this securement system at a sled speed of approximately 20 mph and a deceleration rate of 10 g's. A manually propelled wheelchair was used.

Upon impact, the chair and dummy slid in a downrange arc about the wall anchor point. The chair tilted approximately 45 degrees in the direction of travel allowing the dummy to strike the simulated obstruction in the area of its elbow. The wheelchair sustained major damage.



CROSS BRACE BELT

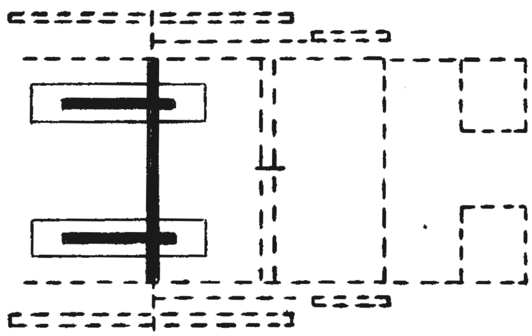
Figure 33

Frame Cable

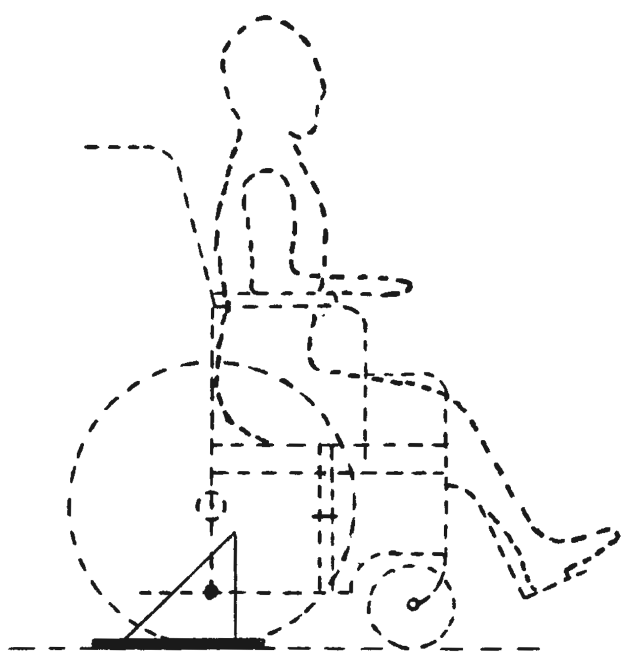
The frame cable securement system consists primarily of a cable stretched between the lower side members of the wheelchair frame. The cable engages two metal plates that are bolted to the floor and located at approximately the 1/3 points between the chair's rear wheels (Figure 34).

One forward facing test was conducted with this securement system, at a sled speed of 20 mph and a deceleration rate of 9 g's.

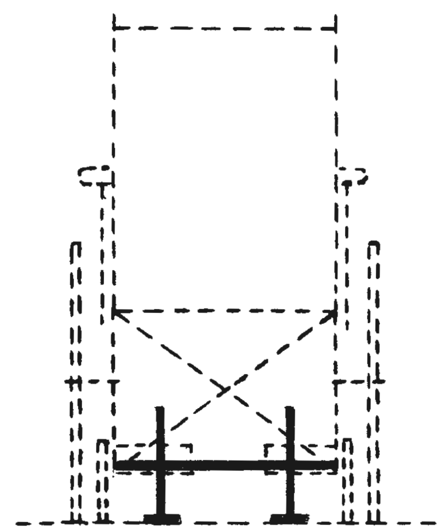
Shortly after impact the cable failed (presumably in shear), allowing the dummy and wheelchair to continue forward without restraint.



PLAN VIEW



SIDE VIEW



FRONT VIEW

FRAME CABLE

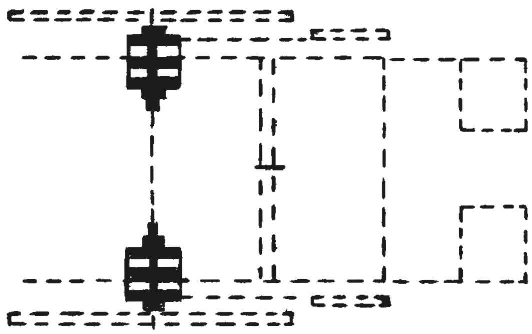
Figure 34

Frame Anchor

A frame anchor securement system consists of a plate attached to each side of the wheelchair frame at the junction of the bottom horizontal rail and the vertical back posts. The plates fit inside "U" shaped brackets that are bolted to the floor of the vehicle. A bolt secures each plate to each bracket (Figure 35).

One forward facing test was conducted with this securement system at a sled speed of 20 mph and a deceleration rate of 10 g's.

During the test, the dummy's hands and feet struck the simulated obstruction. Its head did not contact the obstruction but did strike its right leg. The measured head accelerations indicated it could have sustained a minor injury. The wheelchair sustained minor bending of the frame.



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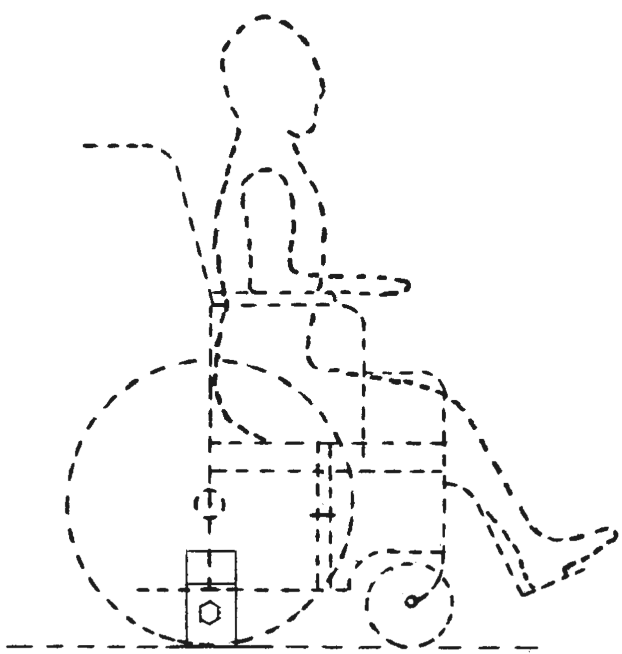

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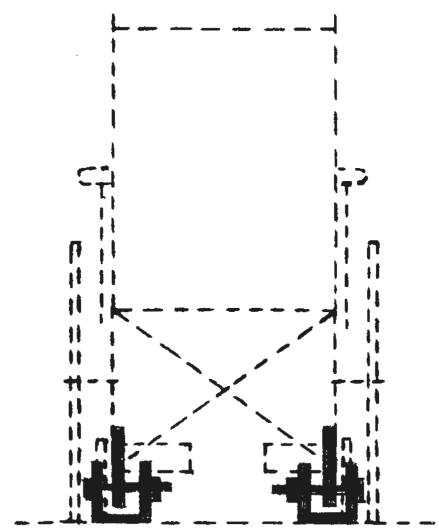


FRONT VIEW

FRAME ANCHOR

Figure 35

SYSTEMS TESTED/ FACING DIRECTION / TEST PARAMETERS	T-BAR (front position)								T-BAR (rear position)			WILL RIM PIN		
	FORWARD						SIDE		FORWARD		SIDE	FORWARD		
TEST NUMBER	1040	1045	1116	1117	1060	1095	1041	1074	1077	1118	1122	1063	1100	1101
SLED SPEED (mph)	9.0	20.3	5.7	11.7	19.3	19.7	7.7	17.2	19.9	20.0	19.3	19.3	23.2	23.1
SLED DECELERATION (g's)	6	12	10	10	12	12	5	12	12	12	12	12	12	12
CHAIR TYPE	Manual	Manual	Manual	Manual	Manual	Manual	Manual	Manual	Manual	Manual	Manual	Manual	Manual	Manual
FOOTREST TYPE	Rigid	Rigid	No footrest	No footrest	Rigid	No footrest	Rigid	Rigid	Rigid	No footrest	Rigid	Rigid	No footrest	Rigid
SEAT BELT	Loop to chair back	Loop to chair back	To axles	To axles	To axles	To axles	Loop to chair back	To axles	To axles	To axles	To axles	To axles	To axles	To axles
SEAT BELT LOAD (lbs)	NA	NA	NA	NA	900	700	NA	400	NA	1100	NA	1200	1100	NA
HEAD EXCURSION (inches) (1)	54	69	41	60	56	61	30	71	41	NR	54	45	43	44
DUMMY STRIKE	NE	NE	NE	NE	NE Head on legs	NE	NE	NE	NE Head on legs	NE	NE Head on arms	NE	NE	NE
H.I.C. (2)	0	NA	0	NA	172	106	2	54	250	138	310	172	322	190
C.S.I. (3)	0	22	0	NA	86	38	0	10	62	28	NA	40	76	60
CHAIR DAMAGE	Minor bending of front casters, footrest & back posts	Minor bending of front casters & footrest. Major bending in back posts	None	Minor caster bending	Minor bending in front casters & frame	Major damage to front casters. Bottom lt. rail bent	Minor bending in the leading caster fork stem	Major damage to leading caster. Minor damage to trailing bottom rail	Moderate damage to side frame, casters & footrests	NR	Major damage to leading side (wheels & frame)	Minor damage to rear wheel rims	Major caster & rim damage	Failure of the spokes led to major rear wheel rim damage
COMMENTS	T bar slid off caster arch	T bar slid off caster arch	T bar slid off caster arch	T bar slid off caster arch	T bar slid off caster arch	Chair tipped forward approx. 90°	Chair rotated approx. 10°	Chair tipped forward	Chair tipped forward slightly	Anchor bolt failed. Chair un-restrained	Violent impact of dummy & armrest	Rear wheels lifted off the floor several inches	Chair tipped forward approx. 90°	Same as Test 1063

(1) Forward, relative to pretest position; (2) Head Injury Criteria; (3) Chest Severity Index; NA = Not Available; NE = No Envelope provided; NR = Not Relevant (The securement failed, therefore, results are not applicable.)

SUMMARY OF DYNAMIC TEST RESULTS - PHASE I

TABLE 2

SYSTEMS TESTED/ FACING DIRECTION / TEST PARAMETERS	WALL RIM PIN		FLOOR RIM PIN					FENDER		USER AND CHAIR BELT				
	SIDE		FORWARD		SIDE			FORWARD	SIDE	FORWARD			SIDE	
TEST NUMBER	1073	1072	1054	1059	1055	1087	1070	1064	1071	1079	1086	1099	1078	1098
SLED SPEED (mph)	11.3	19.4	19.0	19.1	19.0	10.3	18.5	19.5	19.5	19.8	22.2	22.5	11.5	10.5
SLED DECELERATION (g's)	9	12	12	12	12	10	12	12	12	12	12	12	10	12
CHAIR TYPE	Manual	Manual	Manual	Manual	Manual	Manual	Manual	Manual	Manual	Manual	Manual	Manual	Manual	Manual
FOOTREST TYPE	Elevating leg rest	Rigid	Rigid	Rigid	Rigid	Elevating leg rest	Rigid	Rigid	Rigid	Elevating leg rest	Rigid	No footrest	Elevating leg rest	Rigid
SEAT BELT	To axles	To axles	Loop to chair back	To axles	Loop to chair back	To axles	To axles	To axles	To axles	To floor	To floor	To floor	To floor	To floor
SEAT BELT LOAD (lbs)	300	1000	450	1300	300	450	NA	1000	1300	2000 (failed)	2400	2400	650	900
HEAD EXCURSION (inches) (1)	44	61	53	44	56	38	56	48	39	64	NA	50	44	44
DUMMY STRIKE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE Head on legs	NE Head on legs	NE Head on legs	NE On testroom wall	NE
H.I.C. (2)	8	44	20	158	70	14	46	NA	186	500	424	1338	NA	8
C.S.I. (3)	2	24	10	40	18	2	16	NA	34	74	68	124	NA	4
CHAIR DAMAGE	Minor damage to a caster, a rear wheel & x-brace	All spokes failed on trailing wheel. Major damage to most parts	Major bending in back posts. Minor bending in frame & wheels	Major damage to wheels and casters	Major damage to wheels, casters and frame	Minor damage	Major damage to most parts	Severe bending in rear wheels. Casters bent aft 1"	Moderate damage	NA	Minor frame damage	Seat tore & cross frame bent	Minor bending in leading wheel and bottom frame	Leading wheel badly bent
COMMENTS		Violent impact between dummy & armrest	Belt in contact with upper abdomen		Securement did not confine dummy		Although the chair was destroyed, the dummy was held		Violent impact between dummy & armrest	Belt broke— dummy & chair unconfined			The usual wall behind the chair was not provided	Back wall provided

(1) Forward, relative to pretest position; (2) Head Injury Criteria; (3) Chest Severity Index; NA= Not Available; NE = No Envelope provided; NR = Not Relevant (The securement failed, therefore, results are not applicable.)

SUMMARY OF DYNAMIC TEST RESULTS - PHASE I

TABLE 2

SYSTEMS TESTED/ FACING DIRECTION — TEST PARAMETERS	THREE-POINT BELT		HORIZONTAL BARS		MODIFIED HORIZONTAL BARS		SINGLE RIM LATCH		MODIFIED SNGL RIM LATCH	WAYNE STATE		CROSS BRACE BELT	FRAME CABLE	FRAME ANCHOR
	FORWARD	SIDE	FORWARD	SIDE	FORWARD	SIDE	FORWARD		FORWARD	REAR	FORWARD	SIDE	FORWARD	FORWARD
TEST NUMBER	1183	1184	1185	1186	1191	1193	1187	1196	1197	1189	1190	1199	1201	1235
SLED SPEED (mph)	20.1	20.1	20.0	19.9	20.0	20.0	19.8	19.9	19.9	20.0	20.0	19.9	20.0	20
SLED DECELERATION (g's)	12	10	10	12	10	10	11	10	10	9	10	10	9	10
CHAIR TYPE	Manual	Manual	Manual	Manual	Electric power	Electric power	Manual	Electric power	Manual	Electric power	Electric power	Manual	Manual	Manual
FOOTREST TYPE	Rigid	Rigid	Rigid	No footrests	Rigid	Rigid	Rigid	Rigid	Rigid	Rigid	Rigid	Rigid	Rigid	Rigid
SEAT BELT	To axles	To axles	To axles	To axles	To axles	To axles	To axles	External lap & shoulder	To axles	External lap & shoulder	External lap & shoulder	To axles	To axles	To axles
SEAT BELT LOAD (lbs)	450	850	NR	NR	500	1200	NR	1400	180	50	460	1100	370	300
HEAD EXCURSION (inches) (1)	50	52	NR	NR	43	58	NR	34	54	14	24	54	NR	39
DUMMY STRIKE	Head on legs	Head on obstruction armrest	NR	Head & hand on obstruction	Lt. hand on stanchion. Rt. hand on obstruction armrest	Head on seat cushion. Hand on armrest, elbow on wall	NR	Head on right leg	Shoulder on stanchion. Knees on seat	Head on securement cushion	None	Rt. arm on obstruction armrest	Shoulder on stanchion. Legs on seat	Legs & hands on obstruction Head on arms & legs
H.I.C. (2)	306	1532	NR	NR	352	286	NR	622	128	144	72	130	70	306
C.S.I. (3)	60	158	NR	NR	56	90	NR	124	98	68	58	68	80	NA
CHAIR DAMAGE	Seat tore & cross frame bent	Major damage to side frames & right rear wheel. Seat tore	NR	NR	Moderate bending & crushing of armrest	Rt. armrest & wheel bent. Extensive bending & twisting in frame	NR	Back post bent aft. Seat separated from back	Right rear wheel destroyed	None	Back posts bent aft	Major damage to frame. Cross brace failed	Minor bending in back posts & cross braces	Seat attachment failed. Moderate bending in frame & rt. caster
COMMENTS		Head blow probably fatal	Securement released. Backup belt system restrained chair	Anchors slid sideway allowing backup belts to restrain chair	Securement bar held through impact, but dropped off on rebound	Extreme lateral torso rotation	Securement released. Backup belts restrained chair	Wheel lock unlatched. Shoulder belt ineffective. Improper retractors	Excursion limited by shoulder impact		Chair cable failed transferring load through dummy	Violent impact between dummy & obstruction armrest	Cable failed releasing chair & dummy	

(1) Forward, relative to pretest position; (2) Head Injury Criteria; (3) Chest Severity Index; NA = Not Available; NE = No Envelope Provided;
NR = Not Relevant (The securement failed, therefor, results are not applicable.)

SUMMARY OF DYNAMIC TEST RESULTS - PHASE II

TABLE 3

SYSTEM EVALUATION

Summary

Table 4 summarizes the performance of each securement concept tested with respect to selected evaluation parameters. In addition to identifying the securement concept (system) and chair's facing direction, Table 4 also lists the following:

- o estimated values of the dummy's head excursion
- o amount of damage the chair(s) sustained
- o the combined effectiveness of the securement system and chair in absorbing initial impact
- o the degree of effectiveness of the securement system in maintaining positive contact with the chair after the initial impact.

Chair damage, as defined in the beginning of this report, was ranked by the researchers as minor, moderate, or major, using the following definitions of the classifications:

Minor: Damaged parts still function with very little applied effort. The chair's rolling and maneuvering ability is only slightly impaired.

Moderate: A great amount of effort is required to move and maneuver the wheelchair. An inexperienced and able-bodied person seated in the damaged chair would find it very difficult to move or maneuver it.

Major: The wheelchair is so badly damaged that it cannot be rolled, is unusable.

The effectiveness of the securements was rated as either good or poor, according to the following definitions:

Good: The securement retained positive contact with its attachment point(s) on the chair throughout impact and prevented the chair from tipping over or from making an otherwise undesirable movement. The system is judged satisfactory under the conditions tested, it is acceptable.

Poor: The securement either lost contact with the chair, did not prevent it from tipping over during impact, or allowed it to make undersirable movements. The system is judged not satisfactory under the conditions tested, it is unacceptable.

Along with the research data listed in Table 4 is a subjective evaluation, by the authors, of the degree of difficulty a wheelchair user would have applying the securement system to his chair without assistance from another person. When making the rating, the authors assumed that the wheelchair user would have moderate use of his upper body, arms, and hands--for example, can rotate his trunk, move his arms, and grasp with his hands.

A low degree of difficulty means that a user, as described, would have little difficulty attaching the securement system. Conversely, a high degree of difficulty means that the user would have great difficulty attaching the securement system. It must be remembered that these ratings could become irrelevant in cases where drivers or attendants are present to assist the wheelchair user.

None of the securement systems tested was electrically operated. Some of them could be, and if they should become electrically operable, their degree of difficulty could be reduced.

SYSTEM EVALUATION

At Approximately 20 mph and 10 g's

System	Facing Direction	Head Excursion (in)	Degree of Difficulty to Self Secure (1)			Chair Damage (2)			Initial Impact Effectiveness (3)		Secondary Impact Effectiveness (4)	
			low	medium	high	minor	moderate	major	good	poor	good	poor
T-Bar Fwd	Fwd	60			X	X				X		X
T-Bar Fwd	Side	71			X			X		X		X
T-Bar Aft	Fwd	41			X		X		X		X	
T-Bar Aft	Side	54			X			X	X		X	
Wall Rim Pin	Fwd	44		X			X		X		X	
Wall Rim Pin	Side	61		X				X		X	X	
Single Rim Latch	Fwd	Excessive	X					X		X	X	
Floor Rim Pin	Fwd	44			X		X		X		X	
Floor Rim Pin	Side	56			X			X		X	X	

(1) Subjective evaluation of the degree of difficulty for a wheelchair user with moderate upper torso, arm and hand dexterity to secure the chair (personal securement not included) without assistance from another person.

(2) Relative levels of damage to the wheelchair relating to its useability after damage (see definition for levels).

(3) A measure of the combined effect of chair securement system (retaining contact with the chair) and chair (not overturning or falling apart) in absorbing initial impact.

(4) A measure of the securement system's ability to retain positive contact with the chair after initial impact rebound (regardless of the condition or position of the chair).

Table 4

SYSTEM EVALUATION

At Approximately 20 mph and 10 g's

System	Facing Direction	Head Excursion (in)	Degree of Difficulty to Self Secure (1)			Chair Damage (2)			Initial Impact Effectiveness (3)		Secondary Impact Effectiveness (4)	
			low	medium	high	minor	moderate	major	good	poor	good	poor
Fender	Fwd	48	X				X		X		X	
Fender	Side	39	X				X		X		X	
User & Chair Belt	Fwd	57		X		X			X		X	
User & Chair Belt	Side	44		X			X		X		X	
Three Point Belt	Fwd	50			X	X			X		X	
Three Point Belt	Side				X			X	X		X	
Horizontal Bars	Fwd	43	X			X			X			X
Horizontal Bars	Side	58	X					X	X		X	
Cross Brace Belt	Side	54			X			X	X		X	

(1) Subjective evaluation of the degree of difficulty for a wheelchair user with moderate upper torso, arm and hand dexterity to secure the chair (personal securement not included) without assistance from another person.

(2) Relative levels of damage to the wheelchair relating to its useability after damage (see definition for levels).

(3) A measure of the combined effect of chair securement system (retaining contact with the chair) and chair (not overturning or falling apart) in absorbing initial impact.

(4) A measure of the securement system's ability to retain positive contact with the chair after initial impact rebound (regardless of the condition or position of the chair).

Table 4 (cont'd)

SYSTEM EVALUATION

At Approximately 20 mph and 10 g's

System	Facing Direction	Head Excursion (in)	Degree of Difficulty to Self Secure (1)			Chair Damage (2)			Initial Impact Effectiveness (3)		Secondary Impact Effectiveness (4)	
			low	medium	high	minor	moderate	major	good	poor	good	poor
Wayne State	Rear	14	X			X			X		X	
Wayne State	Fwd	24	X			X				X		X
Frame Cable	Fwd	Excessive	X			X				X		X
Frame Anchor	Fwd	39			X		X		X		X	

(1) Subjective evaluation of the degree of difficulty for a wheelchair user with moderate upper torso, arm and hand dexterity to secure the chair (personal securement not included) without assistance from another person.

(2) Relative levels of damage to the wheelchair relating to its useability after damage (see definition for levels).

(3) A measure of the combined effect of chair securement system (retaining contact with the chair) and chair (not overturning or falling apart) in absorbing initial impact.

(4) A measure of the securement system's ability to retain positive contact with the chair after initial impact rebound (regardless of the condition or position of the chair).

Table 4 (cont'd)

Suggested Improvements

Crashes of the magnitude simulated in this research are severe, and it would be unrealistic to expect no injury to a passenger or no damage to a wheelchair in a real 20 mph, 10 g's crash of a transit vehicle. The test results--data measurements, observations of the films, and evaluation of chair damage--gave indications, however, of where protective improvements can be built into certain of the securement concepts and into the chair. Thus, suggestions for improvements are made in the paragraphs to follow.

The suggestions are restricted to minor changes which the authors believe can significantly improve a securement system's effectiveness in securing a chair and its occupant during a crash. Securement systems which either performed well as tested or showed no potential for improvement without extensive modification are not addressed. On the other hand, although the chair performed above expectations, a suggestion for its improvement is made.

Wheelchair. By and large, the wheelchairs tested were much stronger in some crash situations, for instance, forward facing during frontal impacts, than had been originally anticipated (29). Still, various parts of the chairs could be strengthened, at modest cost, to improve their crashworthiness in those situations. If interested in identifying where strengthening could be made, one can do so by examining the test results and commentary.

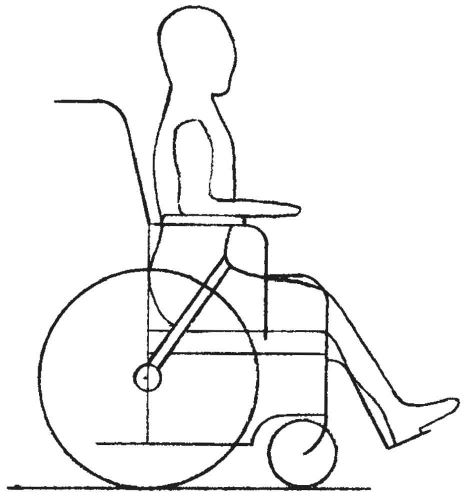
Several failures occurred in the seat fabric reinforcement. When the dummy was secured by a belt attached to the rear wheel axles, seat failure resulted in greater dummy excursion than would have occurred had the seat not failed.

How the additional excursion occurs is explained as follows: The angle of a hip belt which is attached to the wheel's axles is normally a little steeper than 45° to the horizontal before impact. Upon impact, the dummy slides forward on the seat until it takes all slack out of the belt and reduces the angle to 45° or a little less. If the seat does not fail, this angle is maintained throughout the rest of the crash. However, if the seat fails, the dummy continues forward and downward as the belt tries to assume a horizontal position, and further reduces the angle.

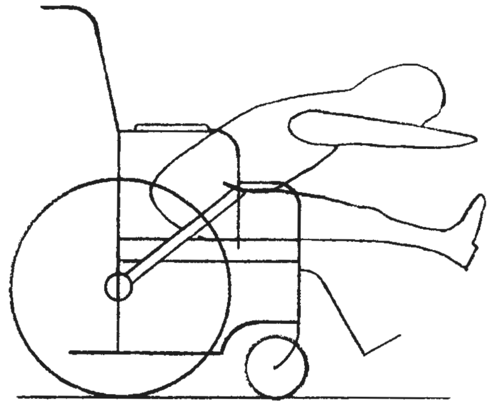
As an example of the effect of a seat failure (See Figure 36), suppose the apparent belt length is 16 inches (which is very close to what it was in these tests). The additional excursion then could be 16- (16xcos 45°) or 4.7 inches.

Hence, improvement in the reinforcement to prevent edge tear-out of the seat would greatly improve the chairs' performance with respect to protection for the occupant by minimizing his excursion; consequently, this improvement is suggested.

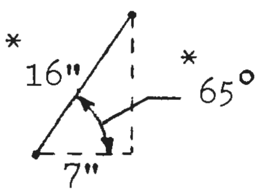
Comments are often made on strengthening the wheels as a means of improving the chair's crashworthiness. Strengthening the rear wheels would improve the overall performance of those securement systems which attach to the rear wheels. On the other hand, the wheels can not be strengthened significantly without excessive cost (7). As it were, securement systems which attached to both wheels performed satisfactorily in forward facing frontal impacts. From the excessive damage the wheels suffered in most crashes with the chair facing sideways, it appears that considerable strengthening would be required before the chair's resistance to lateral loading would be significantly improved. Therefore, wheel strengthening is not suggested.

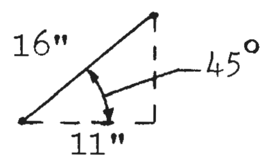


Before Impact

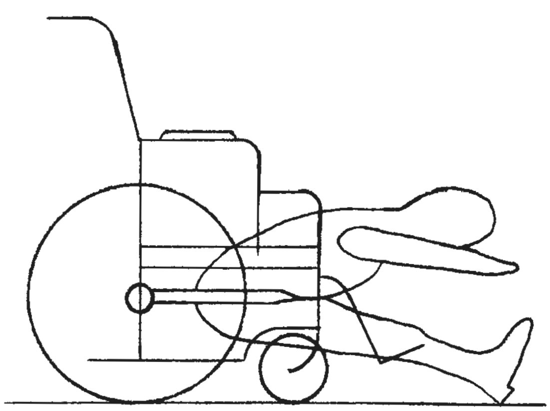


After Impact Excursion
Without Seat Failure





* Dimensions & Angles
Are Approximate



After Impact Excursion
With Total Seat Failure

DUMMY EXCURSION

Figure 36

T-Bar. Improvement in the T-bar system can be made by restricting its attachment to the lowest horizontal frame member either just forward the chair's cross brace or just forward of the chair's backpost (the backpost position provides the greatest protection during frontal crashes). It appears that further improvement can be made by providing generous-length, upside down U-shaped brackets (which are on the ends of the T-arms and fit over the bottom frame members). Generous lengths in bracket legs provide greater assurance of containing the chair during crash rebound or secondary crashes.

Wall Rim Pin. When the wall rim pin system is used for forward facing wheelchairs, it should include a means to restrict lifting and upward rotation of the rear wheels. The need for restriction of wheel movement is especially important when rigid footrests are not part of the wheelchair being secured.

User and Chair Belt. For best performance during a crash, the chair should be backed up to a wall when the user and chair belt system is used, as opposed to just providing "stops" for the rear wheels.

Horizontal Bars. The attachment hooks of the horizontal bars system can be attached any place along the chair's forward vertical frame members, or the forward part of the armrests. If they are placed below the axles of the chair's big wheels, there will be a tendency for the chair to overturn. Therefore, the hooks should be attached above the axles, preferably above the combined center of gravity of wheelchair and user. Likewise, the anchoring mechanism for the horizontal bars should be also located above the axles.

The attachment hooks need to be sufficiently strong to prevent them from straightening during impact, and need to be designed so that they maintain attachment during post-crash action.

The anchor mechanism for the bars requires a "stop" attachment to prevent undesirable sliding of the bars along the mechanism when the wheelchair is facing sideways in a frontal impact.

User Belt System. Belts attached to the vehicle should have locking type retractors. Non-locking spring reel retractors do not provide proper securement without careful adjustment and should, therefore, be avoided. Inertial type locking retractors may provide securement during high-speed-sudden stops and during crashes, but they are ineffective for restraining movement of a wheelchair during normal stopping and turning activities of a vehicle. It is therefore recommended that inertial type locking retractors not be used for wheelchair securement. If shoulder belts are provided, they should be coupled with the hip belts in a manner that positions the belt diagonally across the upper torso of the user.

Securement Design Loads

Load cells were attached to the belts securing the anthropomorphic dummy for two purposes, to measure loading on the dummy as a part of injury assessment and to provide information necessary in determining design loads needed for the various securement systems. Developing accurate securement design loads from the test data is arduous for a number of reasons: the geometry of the system is variable during the crash event as the chair and dummy move about and the chair deforms; belt angles are difficult to measure from the high speed films because the armrests, etc., tend to obscure them; the highly decoupled nature of the dummy, chair and securement combination makes it difficult to calculate loads caused by the chair based on either belt measurements or sled pulses.

Notwithstanding the above complications, design loads and reactions were determined by analyzing test data and films for eight of the twelve systems tested. Design loads were not developed for the Cross Brace Belt, Single Rim Latch and Frame Cable systems since they were concluded to be unacceptable at the level tested. Because of the engineering and testing that has already gone into the development of the Wayne State system, emphasis was not placed on the acquisition of data sufficient to develop design loads for it.

Only the forward facing position was considered in the development of the design loads. Many of the side facing tests on the various systems were not acceptable at higher (20 mph, 10 g's) test levels and insufficient data were acquired to determine design loads on those that were successful at the higher level.

The loads are not being proposed as standards. Rather, they are included as a first step in making this kind of guidance available to designers and manufacturers of securement systems. It is recognized that additional research will be needed before design standards can be proposed.

Except for the T-bar and the User and Chair Belt systems, which were provided with load cells for direct measurement of securement loading, dummy load (P) and chair load (W) were combined to calculate the securement design loads ($R_{X\&Y}$, M). Orientations of these loads are shown in Figure 37.

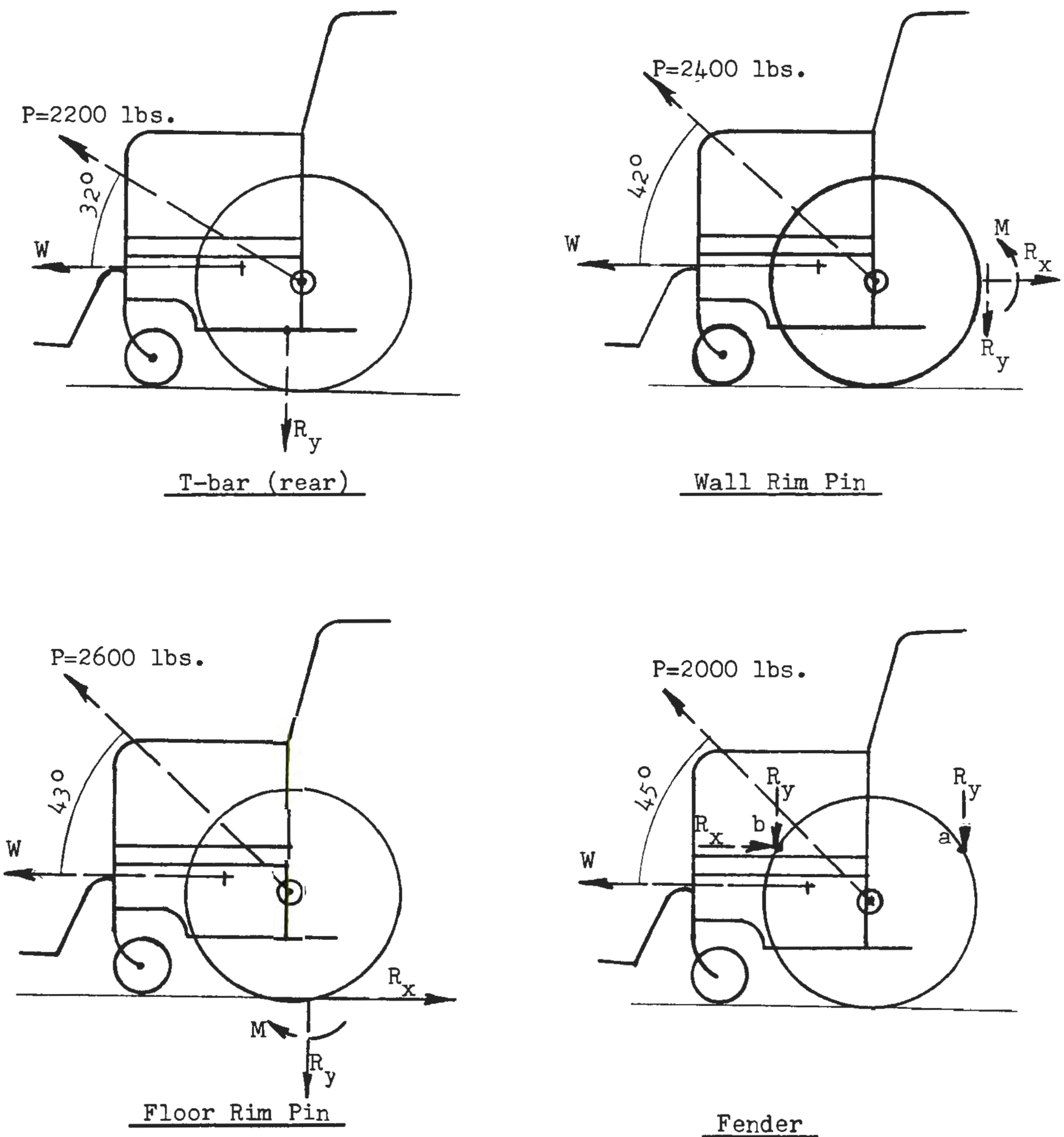
Table 5 lists the calculated design loads for a 20 mph 10g crash level, a 50 percentile male occupant and the manual type wheelchair for the following systems: T-bar (rear), Wall Rim Pin, Floor Rim Pin, Fender, User and Chair Belt, Three Point Belt, Horizontal Bars, and the Frame Anchor.

Securement Design Loads (20 mph, 10g's)

System	Design Loads*		
(Forward Facing)	Ry (lbs)	Rx (lbs)	M (ft-lbs)
T-bar (rear	3200		
Wall Rim Pin	1600	2200	1600
Floor Rim Pin	1800	2300	2300
Fender	1400(a), 200(b)	2000	
User & Chair Belt	3400	3400	
Three Point Belt	700	1100	
Horizontal Bars	300	1500(a), 400(b)	
Frame Anchor	900	500	

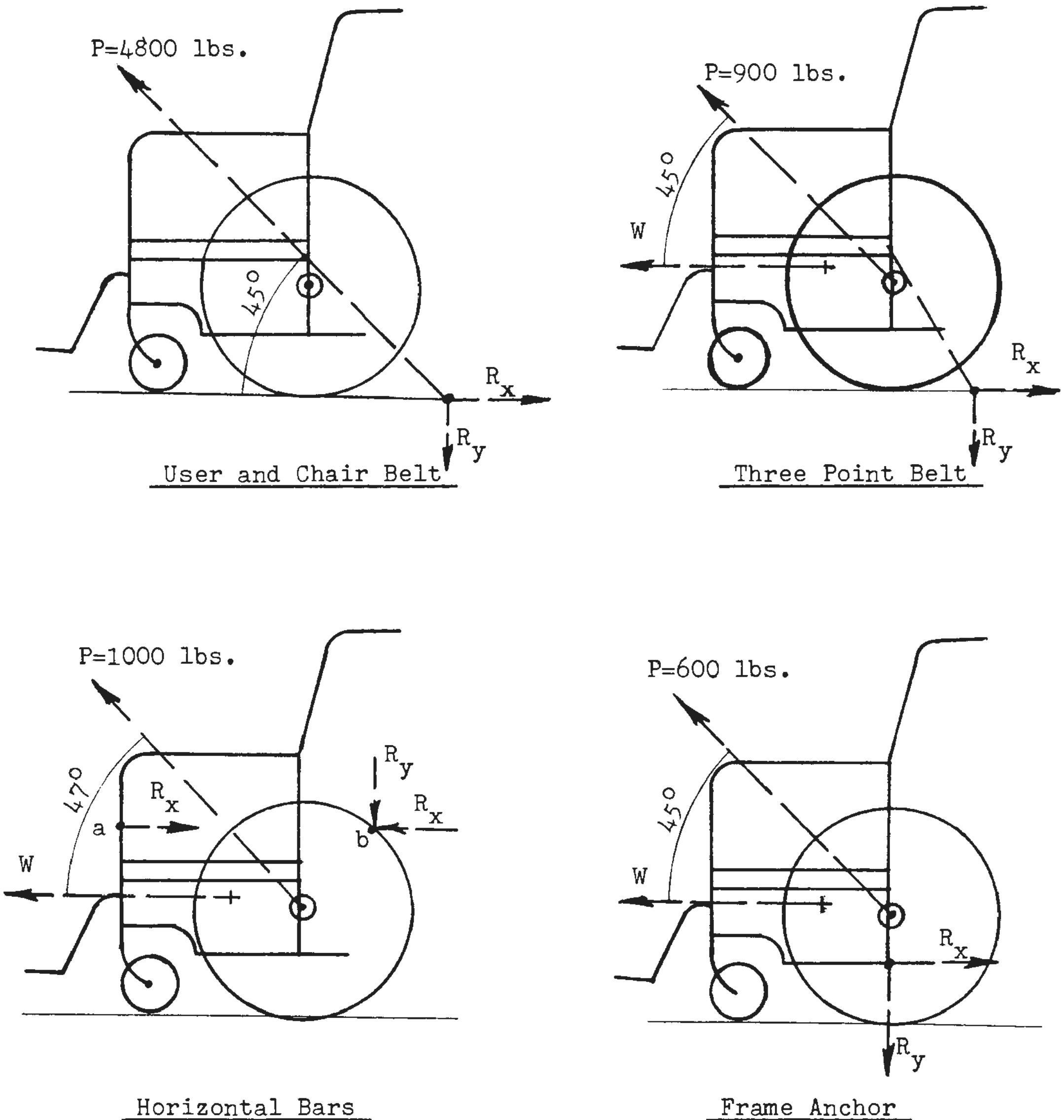
*Design load = total design reaction, i.e., $R_Y/2$ per wheel where appropriate. For design load locations see Figure 37.

Table 5



SECUREMENT DESIGN LOADS

Figure 37



SECUREMENT DESIGN LOADS

Figure 37 (cont'd)

SELECTED TECHNICAL AND POLICY ISSUES

The following discussions are included to help those who are interested in the various subjects included in this report better understand the behavior of wheelchairs and occupants during a crash. The discussions also identify wheelchair transportation issues on fixed route transportation that need solutions. The discussions are directed specifically to wheelchair users and those who are interested in either developing a wheelchair securement system, initiating transportation of wheelchair users, upgrading existing transportation, or planning wheelchair crashworthiness tests.

Deceleration

For the benefit of those of us who do not normally work with deceleration forces, perhaps it would be helpful to review what happens during a dynamic event; i.e., a crash.

During a change in velocity of a body, the body is subjected to either a push or a pull (force) depending on whether it is being slowed down or speeded up. This force results from the momentum of a body resisting a change in velocity. It is the product of the body's weight and deceleration, or rate of change in velocity (the change in velocity per unit of time). In general terms, this force is called g force, and is expressed in gravitational equivalents. The effect on the body is an increase in its "apparent" weight, which is proportional to the deceleration in g's.

As an example of the g effect on a person secured with a seat belt, suppose the person when traveling in a forward direction slows down at a rate equal to 10 times that of gravity [10 g's, i.e., 10x32.2 (or 322) feet per second per second]. Unless the person hits something, the load placed on him through his restraining belt will be 10 times his at-rest weight.

The Significance of Velocity and Decoupling

The original plan for this project was to investigate damage to a wheelchair and injury to its occupant at crashes of 30 mph and 10 g deceleration. The test study design plan called for the deceleration of the crashes to start at 5 g's and then, depending on the results of the 5 g test, to increase the g's in increments to the desirable 10 g's, or decrease in increments to a lower limit. No provision was made in the plan to vary the test speed from the 30 mph level.

After testing started, it was realized that speed, or velocity, at the time of impact is also a very important variable when determining the ability of an occupant-wheelchair securement system to withstand a crash.

A system's crashworthiness is determined by a comparison of the energy it absorbs and the damage it suffers. From a purely mathematical point of view, the kinetic energy of a system just before impact is measured by $1/2\ mV^2$ (where m is the mass of the system and V is its impact velocity). The deceleration force exerted on the system is proportional to the average deceleration of the system after impact. The average deceleration (a) is equal to $\frac{V-Vo}{t}$ (where V is the impact velocity, Vo is the final velocity, and t is the time). Consequently, whereas the deceleration force varies with the first power of the impact velocity, energy varies with the second power of this velocity.

When it is desirous to maintain a constant deceleration force on a rigidly connected system, regardless of the velocity, the time over which deceleration occurs and the distance over which it occurs are changed ($V = \frac{2d}{t}$, where V is the impact volocity, d is the distance, and t is the time).

However, a wheelchair secured to a sled, or a vehicle, is not a rigidly connected system. Consequently, the purely mathematical point of view is not totally applicable to the overall system (load and vehicle).

To better understand the difference, let's look at what happens to a secured wheelchair in a crash situation. The results would be approximately the same whether the chair was secured to a crashing vehicle or to a sled simulating a vehicular crash; hence, we will look at a chair-sled system during a typical forward facing test at approximately 20 mph.

When the sled starts decelerating, there is continued, practically unrestricted, movement of the chair; free movement lasts until slack in the securement system has been taken up; after the slack is removed, the chair continues to move as it deforms; only after resistance to further deformation takes over does the chair begin to decelerate significantly. When the dummy is attached to the chair, it is only after the chair begins a significant deceleration that the slack in the dummy's belt is taken up and the dummy starts decelerating. By the time these events take place, it is not uncommon for the sled to have come to a complete stop. Consequently, the actual deceleration rate of any load--payload--attached to the sled in a manner similar to a wheelchair securement system is somewhat dependent on the deceleration of the sled, but is primarily dependent on the impact velocity, looseness of the attachment, and the flexibility of and kinetic energy of the attached load (16).

The delayed action of the payload caused by looseness in its attachment and its internal flexibility is called the "decoupling effect". It is possible for the decoupling effect to cause a level of g's on the payload much higher than that which the transporting vehicle experiences.

As an example of how the decoupling effect can influence crash results, suppose that when traveling at 20 mph a sled is decelerated at a 10 g rate. Under these conditions, the sled is controlled to slow to a stop in a given time and distance. Before the deceleration started, the sled had a certain kinetic energy. This energy is dissipated (converted into work) through stopping the sled's mass over the stopping distance.

Now suppose that a payload on the sled is attached with a very elastic band which requires little force to stretch it a considerable length, but upon reaching a certain length becomes very stiff (requires a large force to stretch it further).

During deceleration of the sled, the payload will continue forward with very little deceleration until it stretches the attachment to its "holding" length. At this time the payload will start its significant deceleration and will be stopped over a very short distance and time (assuming that by then the sled will have come to a stop). Under these conditions, the payload's g will be greater than that of the sled.

As with the sled, the kinetic energy of the payload is dissipated through stopping its mass over the stopping distance.

Now suppose the sled's velocity at the moment of impact is doubled. The g of the sled can be made to remain the same by increasing both the time over which it stops and its stopping distance. The new kinetic energy of the sled is increased four times (the change in velocity squared--2 x 2). Despite the increase in the sled's kinetic energy, by maintaining the same deceleration rate (g), the energy will be dissipated at the same rate it was at the lower velocity; consequently, the change in velocity has no effect on forces the sled has to resist.*

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*It should be noted that the example given is an idealized situation. In the real world the following factors, which are not included in the example given, influence the results: because of the limited "soft" area in the front of a vehicle, the stopping distance of the vehicle after impact cannot necessarily be lengthened; slack in the system could come into play at different time histories during the two speed conditions; and the normal belt material behaves differently at various energy levels. Including these factors in the velocity examples given should not change the results appreciably, just refine them.

On the other hand, because of the independence given the payload by the decoupling effect, under the doubled velocity the payload's g will be higher (the stopping distance allowed by the band is independent of all other factors). The payload's kinetic energy will be increased by the same factor of four as the sled's; however, since the payload's kinetic energy will be dissipated over approximately the same distance as the kinetic energy was at the lower velocity, because of the decoupling effect, its rate of dissipation will be greater. A higher rate of dissipation increases the force on the payload system. Hence, the change in velocity does affect the forces acting on a decoupled payload.

A logical question at this point is, "Since the deceleration rate of the chair and dummy could be different from that of the sled, then why the importance of setting specific sled g requirements?" Remember that the decoupling effect will occur for all systems (with different degrees for each) in both the real-world situation of a bus crash and in the test sled simulations. Remember, also that the crash parameters selected for this project (against which a securement system was to be evaluated) represent what happens when a full-size bus hits a solid object head-on at 30 mph. Test results of such an event have shown that with this speed the deceleration experienced (g) at the floor level where a wheelchair station is likely to be is very close to 10 g's (11,12,13,14,15). Consequently, to stay as close to the real-world situation as possible, the support for the chair (sled) during testing should closely approximate the measured deceleration of the floor of a bus during a crash, 10 g's for these tests.

Strengthening the Wheelchair

Before this research began, a remark the authors often heard was that the currently used wheelchair would fall apart when subjected to a force of more than about 2 g's. The tests have shown the chair to have much more energy absorbing capacity than originally assumed.

Although the current wheelchair was not designed to serve as a seat on transit vehicles, the chair's energy capacity could be improved in future models if there were a standard method of securing chairs on transit vehicles. Knowing the point of securement, the designer could restructure specific elements of the chair to make it stiffer and stronger during vehicle-crash imposed stresses.

Use of Energy Absorbers

Incorporating energy absorbers within the securement system has been proposed as a method of reducing the energy the occupant or chair has to absorb. Normally, an energy absorber either smooths out the deceleration rate or extends the time of deceleration. The elasticity of the occupant's seat belt and the current compliant structure of the wheelchair tend to act as energy absorbers. The space needed for these two actions to take place, plus that needed to offset the slack in the securement system, closely approaches that which has been assumed to be an acceptable amount for wheelchair stations in transit buses, which are already faced with limited space. Consequently, other changes probably are needed, rather than incorporating an energy absorber, to produce an ideal securement system. This is not to say, however, that energy absorbers should be completely ruled out for future consideration.

An ideal securement system with respect to crashworthiness and space limitation is one that reduces the overall decoupling effect between the wheelchair user and the vehicle, i.e., comes into action immediately after the vehicle starts decelerating and is attached to the chair in a manner to fully utilize the stiffest elements of the chair. This reduction of decoupling takes advantage of more of the time over which the vehicle decelerates and thereby reduces the g's felt by the wheelchair user.

Transit Issues

Many factors complicate the ability of the transit operator to provide safe and practical securement for travelers in wheelchairs. While conducting this research, the authors recognized some of these factors and believe it to be appropriate to bring forward 3 of them at this time. They are:

- o Self securement of the wheelchair user.
- o Wheelchair facing direction.
- o Standardizing securements.

Self Securement of the Wheelchair User. There are two issues of major importance which must be considered in the design of securement systems that will be applied by the wheelchair user without assistance when using public transportation. They are: user disabilities and user dexterity. More specifically, what percentage of the potential wheelchair passengers have disabilities which require special equipment such as an extra wide or overly padded belt, and what percentage of these passengers will have the ability (even though hampered by a disability or limited dexterity) to secure themselves with the equipment provided for public use on the bus? The authors could not find data for either of these two factors. However, from observation, the authors have noted a wide diversity of disabilities and dexterities amoung wheelchair users in California. In fact after having worked with wheelchair user groups for over 5 years, the authors believe that because of either one or the other of those two issues (or both), over 50 percent of the wheelchair users in California do not have the ability to secure themselves with most of the systems available on public transportation in mid-1979. These systems predominantly use belts to secure the wheelchair user.

A major problem with belts heretofore provided on transit buses is that they are located in a position that forces persons in wheelchairs to stretch far to their side and back to reach them. Some wheelchair users who have the ability to reach the belts either do not have sufficient strength in their arms to pull the belts forward or lack sufficient control of their fingers or hands to latch the belt ends together. A repositioning of the belt ends that are attached to the vehicle would make applying the belt easier for a few, but would fall extremely short of solving the belt problem for the majority. The problem is made worse by the fact that since inertial retractors do not provide restraint during normal operating conditions, ratchet-type locking retractors are commonly used. Ratchet locking retractors are difficult to use even by many able-bodied persons.

To be effective, user belts must be properly located on the person and adjusted. As previously mentioned, lap belts should be located at angles between 20 and 75 degrees and positioned so that they apply stresses to the hip area rather than the stomach area during loading.

Three of the systems tested--user and chair belt, single rim latch (with external lap and shoulder belts) and Wayne State--employed user belts attached to the vehicle. A vehicle attached system means that the belts must be fastened by the user or an attendant after the user has positioned his chair in the vehicle. In the tests, these belts were purposely secured at the optimum position. In practice, however, the quickest and most convenient position is usually used. Because of the problems encountered in feeding a belt and latching buckle between the seat, back, and armrest of an occupied chair, common practice is to pass the belts over the armrests and buckle them near the upper stomach area. The test movies show that when the belt is originally placed across the upper stomach area, it tends to remain in that area and the dummy tends to jackknife around this area, which is undesirable.

Another problem for the wheelchair user with some types of combined user and chair securement systems is that when the wheelchair is facing forward during a frontal crash, the user is loaded by not only his own weight but also by the weight of the chair.

An alternate method of user securement would be for the users to provide their own securement to their chairs before boarding the bus. By doing so, the users can take into consideration their own disabilities and select the securement to fit their particular needs, and also have it placed in the most effective location.

It can be argued that securement of the occupant to the chair causes more damage to the chair than that which would occur if the occupant were secured to the vehicle and independently of the chair. Furthermore, the securing mechanism for the chair would not need to be as strong for a system using an independent occupant securement as it would for a system which secures both the chair and the occupant through the chair. Both arguments have value, but of more importance to wheelchair users are the already discussed questions of disabilities and dexterity (the potential for an inappropriate type of securement to be furnished and the possible inability to apply it). If proper personal securement is provided by the user to his or her chair and adequate chair securement is furnished by the transit operator, the end result after a vehicular accident probably will be a more damaged chair but a less injured user when compared to an independent user type securement furnished by the transit operator.

Wheelchair Facing Direction. Rearward facing orientation to the impact direction, when the head and body are fully supported, has been shown (5,6,8) to offer the most protection of the various possible orientations. The rearward facing securement equipment tested provided a much greater surface area for the body to impact into, which resulted in less load per unit area. Consequently, from the point of view of personal safety, wheelchair users should be transported while facing rearward. [The authors feel comfortable in drawing this conclusion in spite of the 144 HIC experienced by the dummy's head in the one "facing backwards" test (#1189). A 144 HIC is not considered injurious].

There are, however, other points of view with respect to riding on public transportation which must be weighed with the safety aspect. For instance, it is easier for people to anticipate where they desire to leave the transit vehicle while facing forward. Also, the rearward facing securement equipment designed to-date is much larger than are the regular seats; therefore, except for a station just behind the driver, the equipment could interfere with the line of sight of other passengers. Moreover, people in general dislike riding backwards, and give as the reason that they get motion sickness while riding backwards.

Further, it should be remembered that securement for the chair is still needed even for a backwards facing system.

Tests conducted by others (8) with live persons have shown that the tolerance to impact is considerably lower for persons facing sideways relative to the direction of impact as compared to forward or rearward facing. These tests (8), however, were conducted only to the voluntary tolerance level of the test subjects; hence, they say nothing quantitatively about tolerances in the side facing position during severe crashes. It appears reasonable to assume that the injury producing tolerance would also be less (to an unknown level) for side facing occupants in the more severe crashes.

With a few exceptions, sidefacing impacts with the securement systems tested resulted in more damage to the chair than that resulting from forward facing impacts.

During side impacts, it appears that damage to the chair can be lessened by providing side support for the chair. Also, padded side supports could be provided to distribute forces on the occupant, initiate early deceleration and reduce violent lateral trunk rotation (9). However, there is no indication that a side support will improve the tolerance limit of the passenger.

Standardizing Securements. An ideal securement system for wheelchairs on standard size transit buses is one that fits a high percent of chairs in use and requires minimum effort to activate. The wide difference in design of chairs makes it difficult to find a "common" point of attachment, but one solution to serving a high percent of chairs seems to be the adoption of a standard fixture which could be easily and inexpensively retrofitted to all chairs.

At this stage of the project, it appears that the bottom frame anchor developed during this study comes closest to fitting the ideal system. During the remainder of this project, the study team intends to perform additional testing of this system and evaluate the reaction of users to furnishing an attachment to their chairs.

The idea of each chair's having a mating fixture has raised questions when the subject has been discussed: Who is to pay for the wheelchair attachment? If a person does not have an attachment, will he or she be prevented from boarding the bus? Since such equipment would have to be somewhat sophisticated, would it have a reliability problem?

A response to the "who is to pay" question could be that there are many ways the retrofit cost could be handled. For one, the Department of Health and Human Resources could sponsor a retrofit project. For another, the local transit provider, with support from UMTA, could sponsor retrofitting. Then there are such organizations as the Veterans Administration, State Rehabilitation Departments, private nonprofit groups, handicapped associations, and others who could be expected to help.

At this time it appears that the cost for a single retrofit should be less than $15, assuming a standard has been adopted and the equipment can be mass produced; so, the cost should not be a major factor.

To satisfy the question of "What if the chair is not equipped with the standard attachment?," a backup seat belt system could be provided at each wheelchair station. While some users would require assistance in applying the backup belt system, every wheelchair user could be assured of a securement system.

Regarding the reliability question, the backup belt could also be used if the standard system should malfunction. To prevent prolonged use of the standby belt system after a malfunction, and to prevent excessive down time to repair the malfunction, the vehicle-attached portion of the standard system could be designed for quick and easy replacement. Replacement units could, therefore, be stored to minimize down time and eliminate removing the bus from regular service while repairing the malfunction.

Another advantage of a standard wheelchair securement system on public transit is that once a user is acquainted with the system, he or she can go from one type of transit to another (even in different cities) with confidence in their ability to use the equipment.

CONCLUSIONS

These are interim or "indicated" conclusions, arrived at by the authors from the study's test data, including test films, and from discussions with others -- researchers, wheelchair users, transit providers, and wheelchair and securement manufacturers.

It is to be understood that the performance of the various securement concepts tested resulted from test conditions used, and that the performance may be different under different conditions.

1. The wheelchair, in general, is capable of absorbing higher impact energy than that originally thought by most people involved in the transportation for handicapped persons.

2. The direction the chair is facing with respect to the direction of impact, and the point of attachment of a securement system to a wheelchair are primary variables affecting the crashworthiness of the chair.

    a. The backward facing (with respect to the direction of travel) system tested provided the best securement with respect to chair damage and "apparent" injury to the dummy. The primary reason for the good showing was the well-padded support provided from the chair seat to the top of the dummy's head. With the chair backed up to this support, the chair experienced little of the dummy's mass, as it was transferred directly into the support, and the size of the support resulted in less load per unit area on the dummy.

b. The next best facing direction was forward, or in the direction of travel. Successful tests (as measured by the degree of chair damage, apparent injury, and containment of the chair and dummy) were conducted at impacts up to speeds of 23 mph and 12 g's.

c. The low resistance of the wheels to side thrust and the designed-in ability of the chair to fold caused the chair to have its least resistance to damage, and thereby the least ability to contain the dummy when it was facing perpendicular to the direction of travel. Most successful side facing tests were at an impact speed of <u>less</u> than 11 mph and a deceleration of 10 g's.

3. It appears that a side support--wall or seat back--would increase the ability of side facing chairs to withstand frontal impacts. (It is possible that a sufficiently padded side support could also minimize the potential injury to the occupant).

4. At 20 mph and 10 g's, the large rear wheels of wheelchairs are strong enough to restrain a forward facing chair and occupant (attached to the chair) in a frontal impact when both wheels are held by the securement system. The wheels are not strong enough to restrain the chair when only one wheel is being held.

5. When the large rear wheels of a chair are secured to the bottom of a fold-up seat, there is a tendency for the seat to fold down during crashes occurring in the same direction as the chair is facing, thereby adding a vertical component to the securement system.

6. When the large rear wheels of a forward facing chair are secured with a wall rim pin device, the wheels tend to roll upward during a frontal impact. When rollup occurs, load is transferred to the footrests. Chairs without footrests, or with non rigid footrests, tend to tip over forward during the rollup.

7. Systems tested that rely on tension for attachment (i.e., T-bar, horizontal bar, etc.) tend to become free when the chair deforms and the system rebounds. Consequently, to be effective throughout the entire crash event, such systems must have supplemental methods of maintaining contact with the chair.

8. The forward placed T-bar is an ineffective securement system during frontal crashes over 10 mph and 10 g's for two reasons. They are: The T slips off the caster arch, which allows the chair to tip forward and place the T in a poor position for retaining the chair during subsequent impacts; and the short distance between the T and casters (or footrests) causes high vertical loading to occur in the casters (or footrests) during tipping actions.

9. Heavy "Bungee" tie-downs are effective in securing batteries to the frame of an electric-powered chair during crashes of the magnitude used in this study.

10. Securement by a belt around the user's waist and the back of the chair is unsatisfactory for high speed impacts because of the high potential for internal injury and disengagement as the chair back bends. Improved securement can be obtained by use of a lap type belt secured to the chair near the axles of the

rear wheels and passed over the hip area of the user.

11. Because of the multiplicity of disabilities and limited dexterity of a large percentage of wheelchair users, there are benefits to be gained from the wheelchair user's providing his or her own securement to his or her chair. A user would be assured of having equipment that best fits his needs and that can be applied with assistance, if assistance is needed, prior to his entering the transit vehicle.

12. Occupant excursion varied widely with the systems tested. Therefore, the available clear envelope and removal or padding of obstructions should be major concerns in the selection and placement of the securement in a transit vehicle.

13. The space (envelope) needed for a forward facing wheelchair station is dependent on the size of chairs used and the type of wheelchair/user securement system used; consequently, the space needed varies considerably. A minimum clear space of 30 inches wide by 53 inches long appears to meet the needs of the average size of chairs on those systems where the users position themselves.

14. Loads on the various securement systems during the tests, as calculated from recorded data, differed considerably, with some being surprisingly low. To ensure that too low a design standard is not set, the low values should not be accepted until confirmed by additional tests.

PROPOSED FUTURE TESTS

There are still many unanswered questions on the wheelchair securement issue. Answers to some of these questions can be pursued through physical testing. On the other hand, answers to some must be pursued through subjective reasoning and compromise. With the belief that the solution to the wheelchair securement problem on public transit vehicles requires input from both the testing and subjective sides, it is planned to pursue answers to the securement problem through both methods as this project continues.

During testing, it is proposed to address the following:

- A more thorough "look" at the performance of the "frame anchor" system.
- The performance, at a speed of 20 mph and 5 g's, of some of the systems that performed poorly at the 20 mph and 10 g's level.
- The performance of new concepts as they are identified.

Table 6 lists some of the systems planned to be tested. It is proposed to include the same 53-inch longitudinal (with respect to the axis of the bus) envelope for the chair that was used in the Phase II tests.

In the introduction section on "Securement Problems", the authors concluded that wheelchair users should be given the same protection during a vehicle accident as that provided to ambulatory passengers. Protection of the ambulatory passenger is achieved through containment between the transverse seats. As explained in the Study Design section, the crash pulse (20 mph/10 g's) chosen for the dynamic tests represented a severe crash of the bus at 20-30 mph into a solid barrier. During the course of testing, questions were raised about the severity of this crash and the need to perform testing at a level closer to the seat standard for Transbus (30). The Transbus seat requirements relate to a sinusoidal shaped deceleration curve peaking at 5 g's and with a 1/2 frequency of 0.10 seconds. Although vehicle velocity is not specified, the pulse was based on crashes of a car into a bus at a closing speed of 56 mph. The car speed was chosen to develop impact energy comparable to a bus traveling at 20 mph (31).

At the request of UMTA, the authors have proposed a portion of future tests to be conducted at 20 mph and 5 g's. Due to the decoupling effect between the wheelchair and the test sled (refer to Selected Technical and Policy

Issues section on the Significance of Velocity and Decoupling), tests at 20 mph and 5 g's may not produce results significantly different from those performed at 20 mph and 10 g's. If initial future tests indicate this to be true, a decision will be made as to further need for 20 mph/5 g's tests.

During the subjective method it is proposed to address the following:

- The acceptability of the concept that the wheelchair users will be responsible for providing their personal securement to their chair, and that the transit providers will be responsible for providing securement for the chair.
- The level of speed and deceleration which the wheelchair securement should resist.

PROPOSED FUTURE TESTS

Securement System	Facing Direction	Speed/Deceleration		Chair Type		User Belt	Comments
		20mph/5g	20mph/10g	Manual	Elect		
Frame Anchor	Forward		X		X	Axle	Strain Gauge
Frame Anchor	Forward		X		X	Frame Anchor	Strain Gauge
Frame Anchor	Side		X		X	Axle	
Single Rim Latch	Forward	X		X		Axle	
Single Rim Latch	Forward	X			X	Axle	
Single Rim Latch	Forward	X		X		3-Point	
T-Bar (Rear)	Forward		X	X		Axle	Without Foot Rest
T-Bar (Rear)	Side	X		X		Axle	
Wall Rim Pin	Forward	X		X		Axle	W/o Footrest Block Wheels

Table 6

PROPOSED FUTURE TESTS

Securement System	Facing Direction	Speed/Deceleration		Chair Type		User Belt	Comments
		20mph/5g	20mph/10g	Manual	Elect		
Wall Rim Pin	Side	X		X		Axle	
Floor Rim Pin	Side	X		X		Axle	
User Chair Belt	Side	X		X			User Belt Included
Three Point Belt	Forward		X		X	Axle	
Three Point Belt	Side	X		X		Axle	
Horizontal Bars	Side	X		X		Axle	
Belt Around Armrest	Forward		X	X		Axle	
*Automatic Rim Pin	Forward		X	X		Axle	

*Floor rim pins which engage each wheel from the inside but are not fully closed around the rim.

Table 6

REFERENCES

1. Carl F. Stewart and Herbert G. Reinl, Student Wheelchair Transportation - Loading and Securement, Caltrans, Division of Mass Transportation, August 1974.

2. Movie, "Unsecured Wheelchairs on Transit Buses," Caltrans, Division of Mass Transportation, October 1978.

3. Highway Accident Report - Greyhound Bus Collision with Concrete Overpass Support Column...November 3, 1973, National Transportation Safety Board, Report No.: NTSB-HAR-74-5.

4. Bertil Aldman, Sven-olof Brattgård and Sören Hansson, Safety in Special Public Transportation, Division for Handicapped Research, Göteborg University, Göteborg, Sweden, March 1974.

5. D. Orne, E. Barak and R. F. Fisch, "Design, Test, and Development of a Wheelchair Restraint System for use in Buses," Twentieth Stapp Car Crash Conference, 1976.

6. Unpublished report by Southwest Research Institute on a study for the Veterans Administration.

7. Correspondence and discussions with Everest and Jennings Co. representives.

8. R. G. Snyder, <u>State-of-the-Art - Human Impact Tolerance</u>, SAE, 1970.

9. Unpublished study by Minicars.

10. Society for Automotive Engineers Standards (1978).
    - J128 - Occupant Restraint System Evaluation-Passenger Cars
    - J211b - Instrumentation For Impact Tests
    - J383 - Motor Vehicle Seat Belt Anchorages-Design Recommendations
    - J885a - Human Tolerance To Impact Conditions as Related to Motor Vehicle Design

11. D. M. Severy, H. M. Brink and J. D. Baird, "School Bus Passenger Protection," <u>SAE Transactions</u>, Vol. 76.

12. Unpublished report by British Leyland Truck and Bus Division, Preston England.

13. Donald J. La Belle, "Barrier Collision and Related Impact Sled Tests on Buses in Intercity Services," The Seventh Stapp Car Crash Conference, Proceedings, 1973.

14. J. A. Mateyka, "Safety Considerations in Design of New Transit Bus Seats," Eighteenth Stapp Car Crash Conference, 1974.

15. L. L. Hoag and S. K. Adams, "Human Factors in Urban Transportation Systems," Human Factors, Vol. 17, April, 1975.

16. G. Grims, "Effect of Seat Harness on Movement of Car Occupant in a Head-On Collision," Highway Research Record No. 4, 1963, pages 76-90.

17. Unpublished material from Booz Allen on Transbus tests.

18. National Highway Traffic Safety Administration, Department of Transportation, CFR, Title 49 - Transportation, Chapter 5, Standard No. 208 (Occupant Crash Protection).

19. (Backward Facing) "The Limits of Man," Trends in Technology/Biomechanics, January, 1963.

20. R. H. Fredericks, "Barrier Collision Investigation of Harness Restraining Systems," The Seventh Stapp Car Crash Conference, proceedings, 1973.

21. Louis C. Lundstrom, Alonzo H. Kelly, Jr. and Donald J. LaBelle, "Impact Sled Testing and Related Barrier Tests,". The Seventh Stapp Car Crash Conference, Proceedings, 1973.

22. D. M. Severy, "Correlates of 30 MPH Intersection Collisions," Highway Research Record, Number 4, 1963.

23. C. W. Gadd, "Criteria for Injury Potential," National Academy of Science, National Research Council Publication No. 977, 1962.

24. W. L. Garrard, R. J. Candill, T. L. Rushfeldt, Crashworthiness and Crash Survivability for Personal Rapid Transit Vehicles, International conference on PRT, Denver, CO. Sept. 1975.

25. A Study of Wheelchair Access to the Current Transit Bus Design, prepared for the Department of Transportation, Urban Mass Transportation Administration, by AM General Corp., April 1977.

26. T. J. McGean, N. W. Lutkefedder, Application of Automotive Crash Survivability Research to Close Headway PRT Systems, ASME Paper 73-ICT-52, Sept. 1973.

27. Lawrence W. Schneider, John W. Melvin, Sled Test Evaluation of a Wheelchair Restraint System for use by Handicapped Drivers, a special report prepared for the University of Michigan Rehabilitation Engineering Center, November, 1978.

28. U.S. Department of Transportation, "Baseline Advanced Design Transit Coach Specifications".

29. Allen E. Kelvin, "Human Factors in Rehabilitation and Health Care-Transportation for the Handicapped," Proceedings of the 17th Annual Meeting of the Human Factors Society, October 16-18, 1973.

30. U.S. Department of Transportation, "Transbus Procurement Requirements".

31. Discussions with Booz, Allen Applied Research representatives.

32. Conversation with Rolf Eppinger, Ph.D., Biomechanics Group, Research and Development, Office of Vehicle Systems Research, National Highway Traffic Safety Administration, January 1981.

APPENDIX

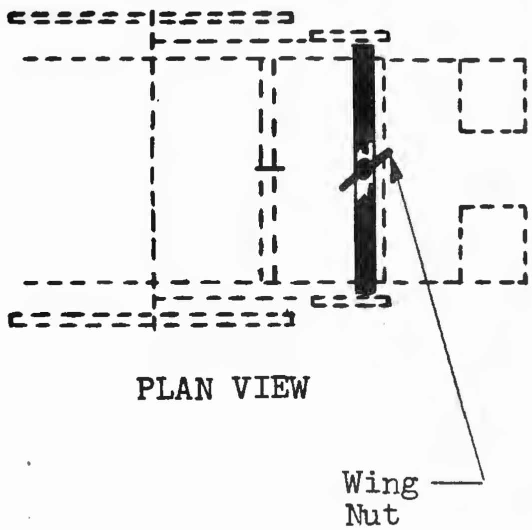
DYNAMIC TEST RESULTS

Following are descriptions, results, and photographs of the forty two dynamic tests conducted thus far in this project. For the purpose of minimizing space in this interim report, only a few representive samples of printout test data on accelerations and loads are given. All data collected will be presented in the final report.

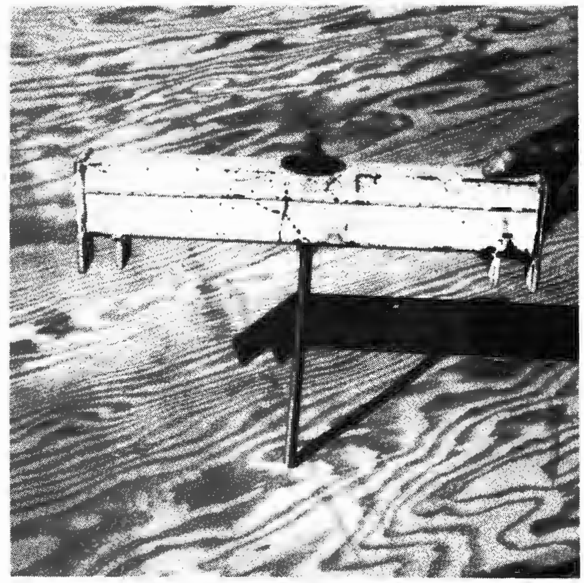
Rather than being in the order in which they were run, the tests are grouped by type of securement.

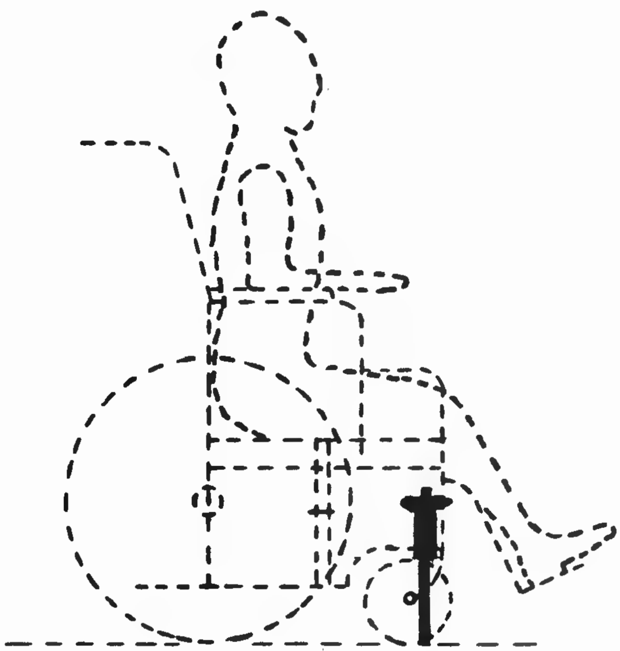
T-Bar

The T-bar system consists of a horizontal bar with end flanges and a center adjustable anchor rod that is attached to the floor. The bar, or top portion of the T, spans between the bottom rails of the chair with the end flanges straddling the rails. Its points of engagement on the bottom rails are either in front of the chair's cross brace (Figure A-1) or to the rear of it (Figure A-2), depending upon the preference of transit providers. It was tested in each location. For chairs with offsets in the bottom rail (caster arch) to facilitate turning of the front casters, the forward positioned T-bar usually has to be placed on the top portion of the arch because of insufficient room for it between the cross brace and the beginning of the arch. During all T-bar tests, the T was cinched down with a pre-load of 600 pounds. This load is easily obtained by hand tightening the wing nut which is usually provided with T-bar systems.

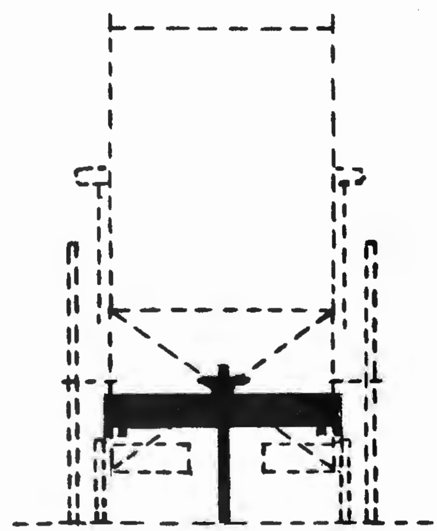


PLAN VIEW





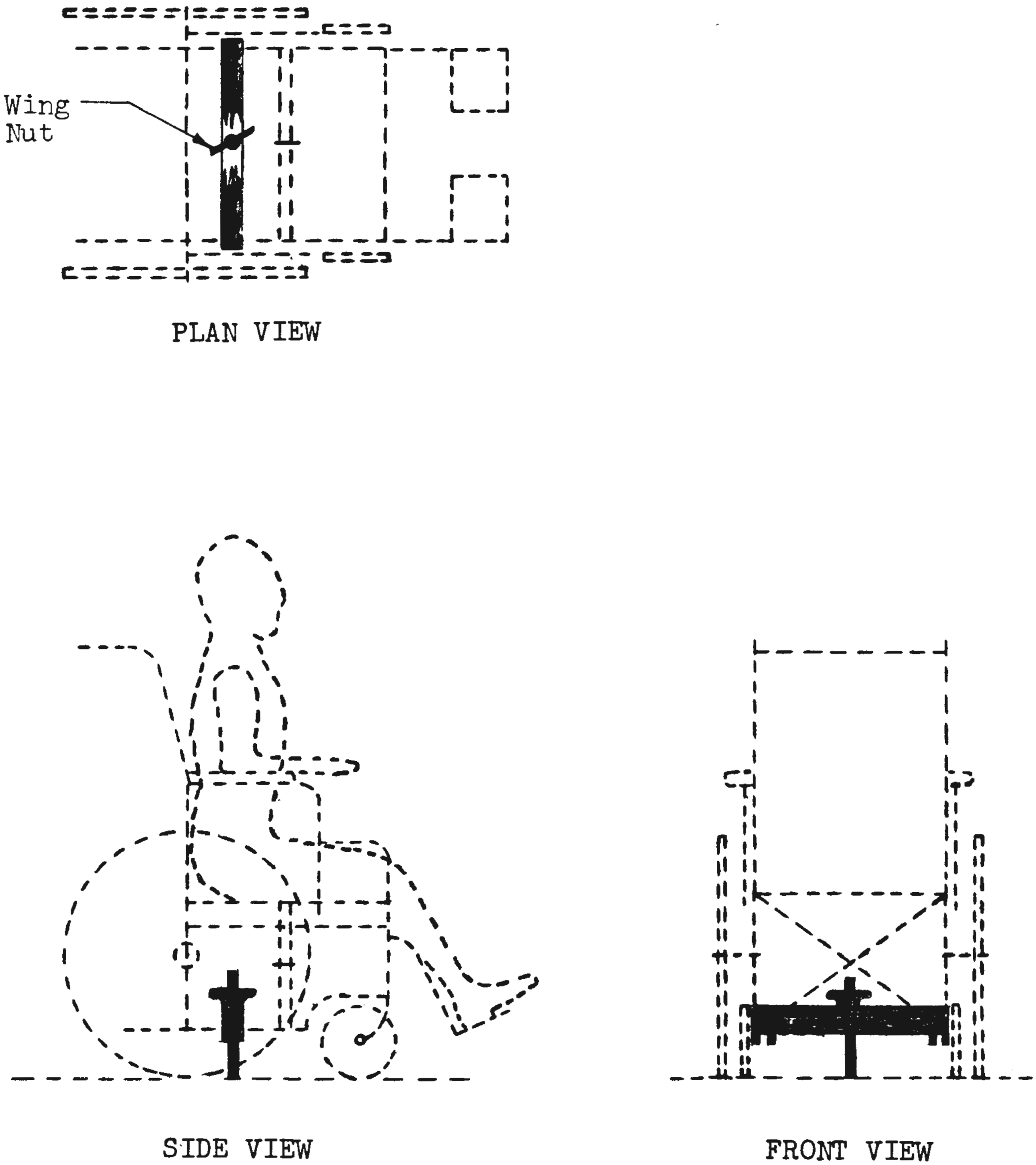
SIDE VIEW



FRONT VIEW

T-BAR/FORWARD POSITION

Figure A-1



T-BAR/REAR POSITION

Figure A-2

Eleven tests were made on the T-bar system:

- o Six with the T in the front position and the chair facing forward.
- o Two with the T in the front position and the chair facing sideways.
- o Two with the T in the rear position and the chair facing forward.
- o One with the T in the rear position and the chair facing sideways.

TEST NUMBER: 1040 SLED SPEED: 9.0 mph

FACING DIRECTION: Forward CRASH PULSE: 6 g's

CHAIR TYPE: Manual

SECUREMENT

WHEELCHAIR: T-bar - front position

DUMMY: Waist belt around chair back

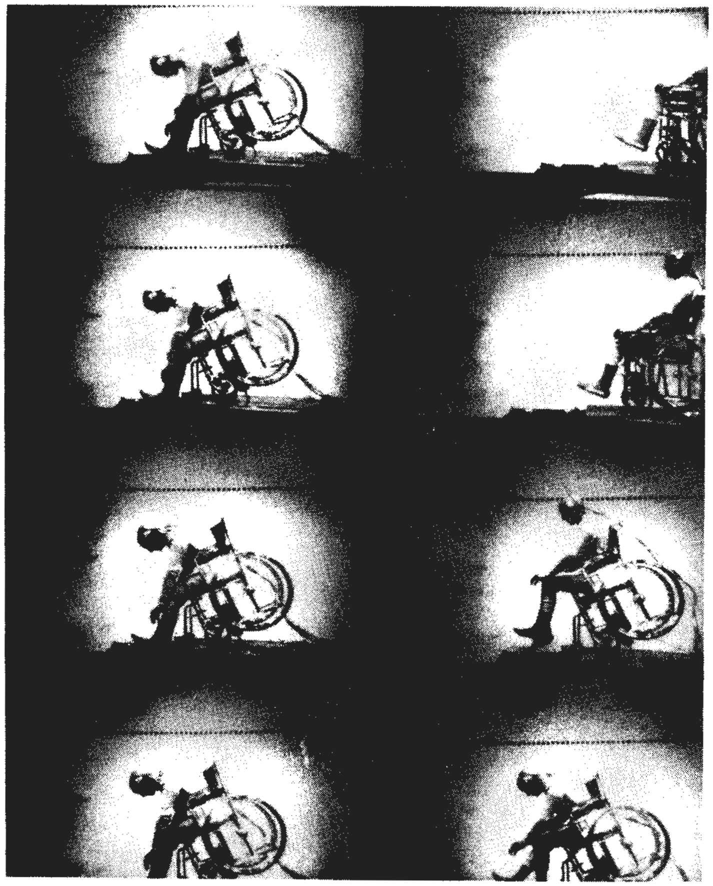
TEST ACTION

The T-bar immediately slid off the caster arch and engaged the bottom rail just forward of the cross brace. The chair then tipped forward placing load on the rigid type footrests. While this was happening, the dummy slipped forward in the seat placing load on the waist belt. The load in the waist belt was taken by the backposts of the chair causing the chair to rotate forward off of the back wheels and onto the footrests. The waist belt load caused the backposts to deflect inward and forward a small amount. Both feet of the dummy came off the footrests, but the dummy did not go into a jackknife position (Figure A-3).

TEST RESULTS

WHEELCHAIR: There was minor bending of the front casters, footrests and backposts. Maximum tension in the T-bar anchor bolt was recorded as 1300 lbs. (Figure A-4).

DUMMY: The dummy remained in the chair. Forward excursion of the head relative to its initial position on the sled was 54 inches.



5 1

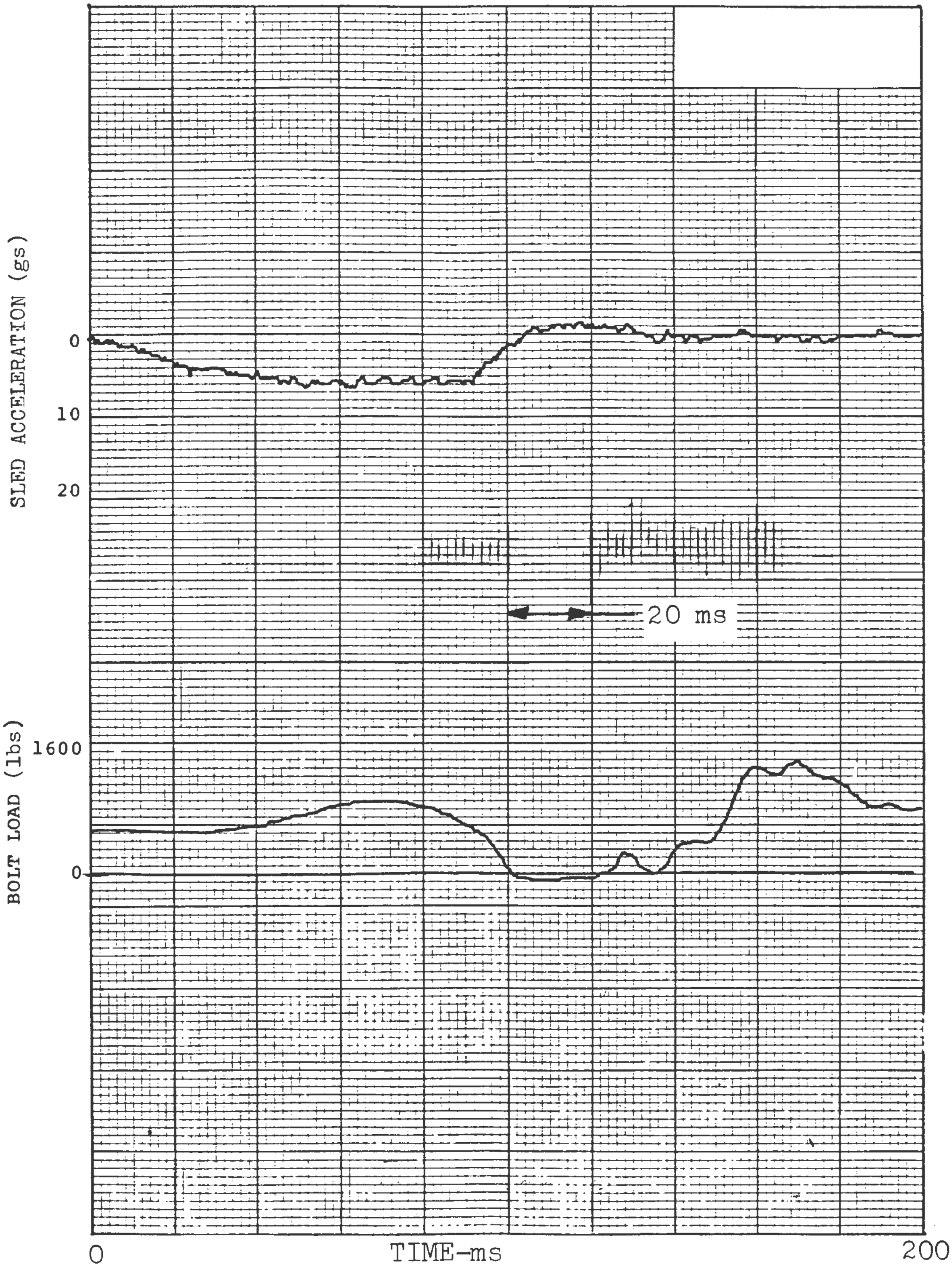
6 2

7 3

8 4

Test 1040--Sequence

Figure A-3



Bolt Load and Sled Acceleration

Test 1040

Figure A-4

TEST NUMBER: 1045 SLED SPEED: 20.3 mph

FACING DIRECTION: Forward CRASH PULSE: 12 g's

CHAIR TYPE: Manual

SECUREMENT

WHEELCHAIR: T-bar - front position

DUMMY: Waist belt around chair back

TEST ACTION

As in test 1040, the T-bar slid off the caster arch and engaged the bottom rail just forward of the cross brace. The chair again tipped forward loading the rigid type footrests. For the first 100 milliseconds (ms), little or no force was applied to the chair. At this point, when the sled was effectively stopped, the seat belt load and anchor bolt tension increased to stop the occupant. During this period, behavior of the chair was independent (decoupled) from the manner in which the sled stopped. (The decoupling effect is addressed in the DISCUSSION section).

At 140 ms into the event, the waist belt rose up the back rest supports tearing out wires to the belt, head and chest transducers. The waist belt came very close to slipping off the backrest supports. The dummy lifted off the chair seat as the belt rose up the backrest supports.

TEST RESULTS

WHEELCHAIR: The backposts were severely bent forward and inward. The front casters and footrest were slightly bent.

DUMMY: Forward excursion of the head was 69 inches. Because of this large excursion and imminent loss of waist belt attachment to the chair, securement of the dummy was judged inadequate.

TEST NUMBER: 1060 SLED SPEED: 19.3 mph

FACING DIRECTION: Forward CRASH PULSE: 12 g's

CHAIR TYPE: Manual

SECUREMENT

WHEELCHAIR: T-bar - front position

DUMMY: Lap belt to axle

TEST ACTION

As in tests 1040 and 1045, the T-bar slid off the caster arch and engaged the bottom rail just forward of the cross brace. This allowed the chair to tip forward onto the rigid type footrests. The dummy's upper torso rotated forward about the hips into a jackknife position with hands and feet extended. At about 260 ms, the dummy's head appeared to have struck its legs (Figure A-5).

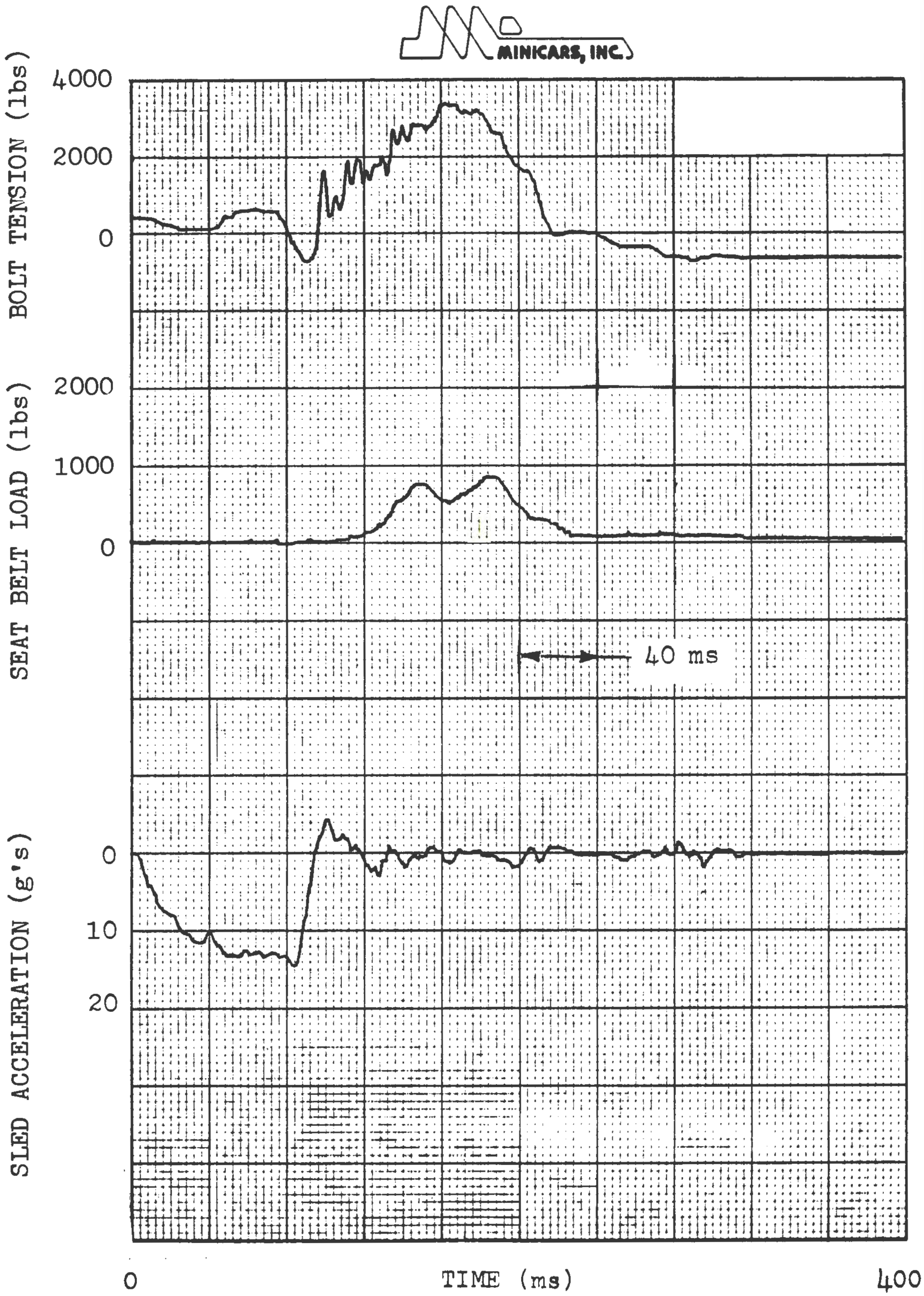
TEST RESULTS

WHEELCHAIR: The crash pulse, belt load, and T-bar tension bolt load histories are shown in Figure A-6. Minor damage to the front casters and frame were observed.

DUMMY: The dummy head and chest accelerations are shown in Figures A-7 and A-8. The spikes in the head plots were caused by the dummy's head hitting the legs. The acceleration of the head striking the legs was judged to be minor from an injury standpoint. The head injury criteria (HIC) was calculated as 172, T = 167 ms, T_2 = 218 ms. Head excursion was 56 inches.

Test 1060--Post Test Conditions

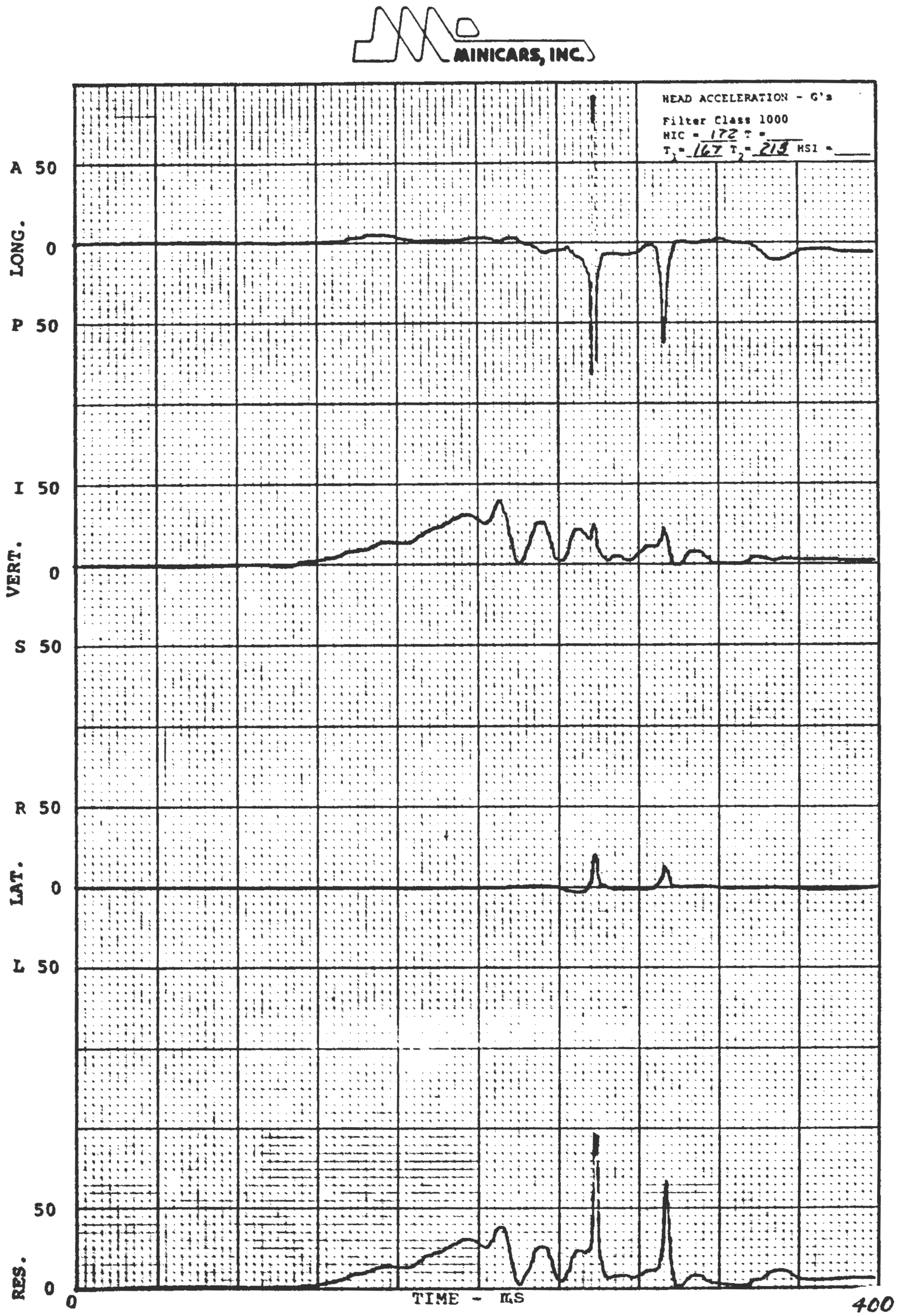
Figure A-5



Sled Acceleration, Seat Belt Load and Belt Tension

Test 1060

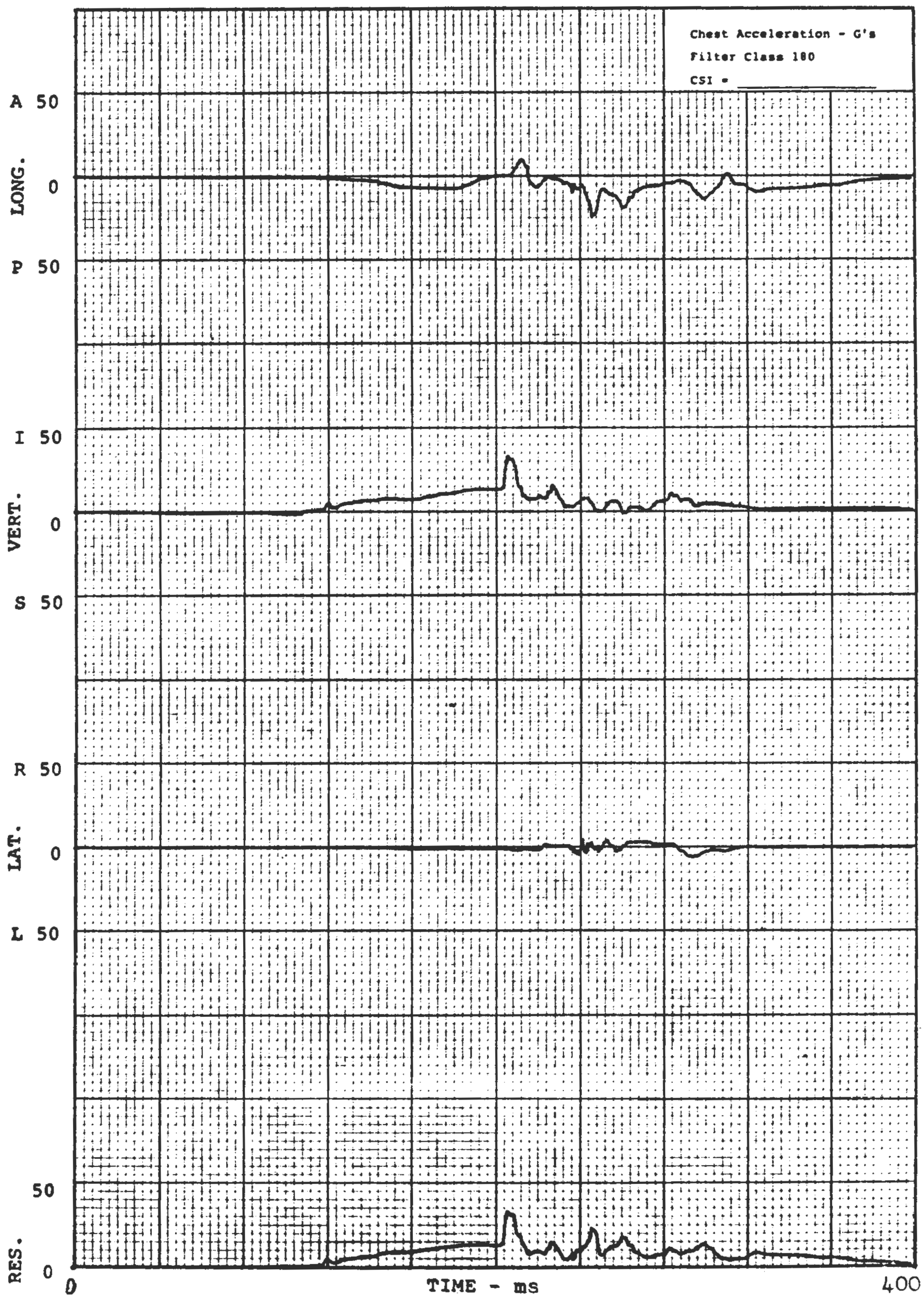
Figure A-6



Head Acceleration Graphs

Test 1060

Figure A-7



Chest Acceleration Graphs

Test 1060

Figure A-8

TEST NUMBER: 1095 | SLED SPEED: 19.7 mph

FACING DIRECTION: Forward | CRASH PULSE: 12 g's

CHAIR TYPE: Manual

SECUREMENT

WHEELCHAIR: T-bar - front position

DUMMY: Lap belt to axle

TEST ACTION

This was a retest of test 1060 with respect to velocity and deceleration; however, in this test the footrests were removed. The purpose of the retest was to determine the effect of rigid type footrests used in test 1060.

The T-bar slid off the caster arch and engaged the bottom rails just forward of the cross brace. With the absence of footrests, the tip forward was extreme compared to that in Test 1060. The chair rotated forward over the casters lifting the rear wheels off the platform and forcing the dummy onto the floor (Figure A-9).

TEST RESULTS

WHEELCHAIR: Chair damage was limited to caster crush back and some down bending of the bottom rail in the left side frame. Maximum load in the T-bar tension bolt was recorded as 2200 lbs.

DUMMY: Maximum tension in the seat belt was 700 lbs. Recorded head accelerations indicated a minor head injury criteria (HIC) of 106, T_1 = 152ms, T_2 = 397ms. Maximum head excursion was 61 inches.

Test 1095--
Sequence

Test 1095--
Post Test
Conditions

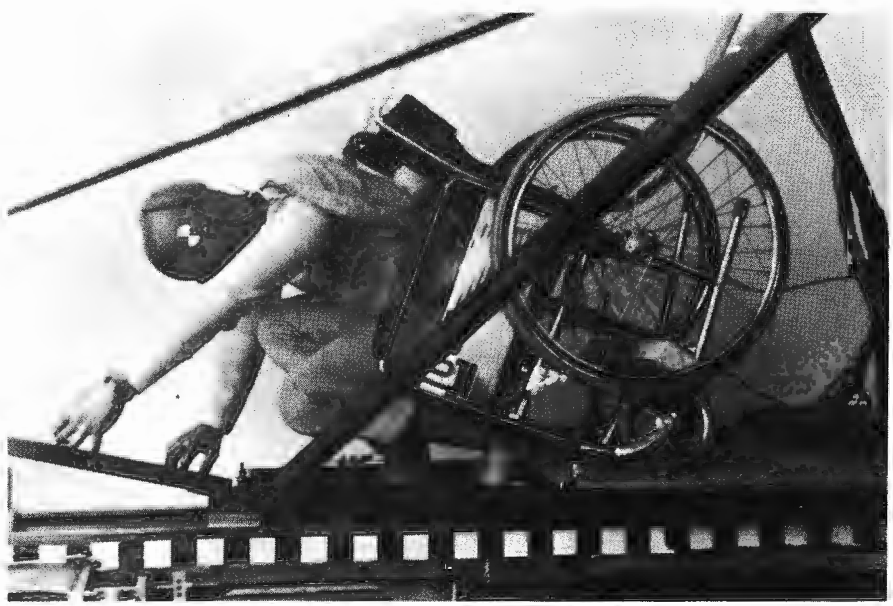


Figure A-9

TEST NUMBER: 1116 | SLED SPEED: 5.7 mph

FACING DIRECTION: Forward | CRASH PULSE: 10 g's

CHAIR TYPE: Manual

SECUREMENT

WHEELCHAIR: T-bar - front position

DUMMY: Lap belt to axle

TEST ACTION

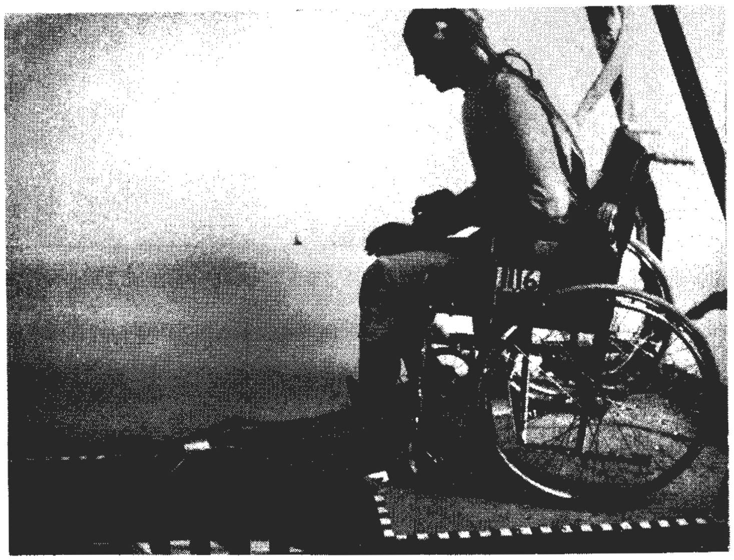
Due to the violent overturning reaction of this securement system without footrests demonstrated at an impact speed of 19.7 mph in Test 1095, the system was again tested without footrests, but at the lower speed of 5.7 mph. The system proved effective for initial impact at this speed.

Upon impact, the T-bar slid off the caster arch and engaged the bottom rails just forward of the cross brace (hence would not be effective for secondary impacts). The chair then tipped forward onto the casters approximately 25 degrees, lifting the rear wheels off the platform. The dummy remained in the seated position, leaning forward approximately 65 degrees from the vertical. The dummy's arms and legs remained in their original relative position with respect to the chair (Figure A-10).

TEST RESULTS

WHEELCHAIR: The wheelchair was undamaged.

DUMMY: Forward excursion of the head relative to its initial position on the sled was 41 inches.



Test 1116--Post Test Conditions

Figure A-10

TEST NUMBER: 1117 SLED SPEED: 11.7 mph

FACING DIRECTION: Forward CRASH PULSE: 10 g's

CHAIR TYPE: Manual

SECUREMENT

WHEELCHAIR: T-bar - front position

DUMMY: Lap belt to axle

TEST ACTION

The purpose of this test was to obtain reaction data for a sled impact speed between the 19.7 mph of Test 1095 (chair tipped over) and 5.7 mph of Test 116 (chair remained upright); consequently, as in Test 1116, footrests were not used on the wheelchair in this test.

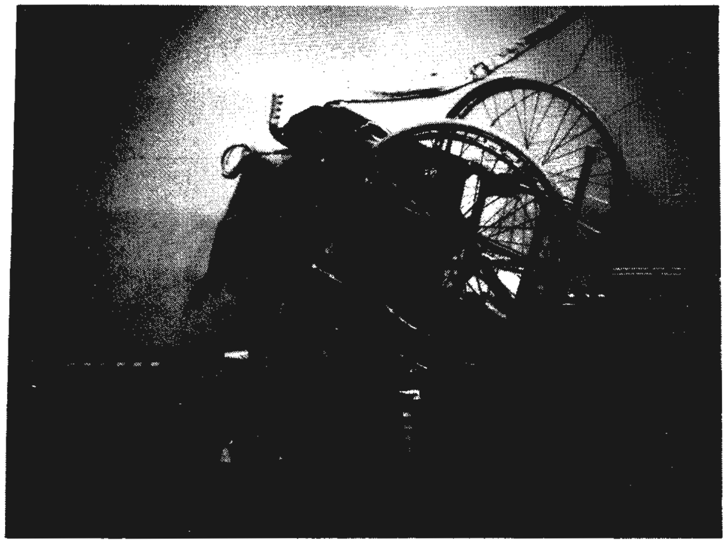
Upon impact, the T-bar slid off the caster arch and engaged the bottom rails just forward of the cross brace. The chair then rotated forward almost 90 degrees about the casters, lifting the rear wheels off the platform.

The dummy's legs did not jackknife outward, but remained in their initial position. As a result, the dummy rotated forward face down onto the sled (Figure A-11).

TEST RESULTS

WHEELCHAIR: The only damage was slight bending of the forward casters.

DUMMY: Forward head excursion was 60 inches.



Test 1117--Post Test Conditions

Figure A-11

TEST NUMBER: 1041

FACING DIRECTION: Side

SLED SPEED: 7.7 mph

CRASH PULSE: 5 g's

CHAIR TYPE: Manual

SECUREMENT

WHEELCHAIR: T-bar - front position

DUMMY: Waist belt around chair back

TEST ACTION

Since the center of gravity of the chair and occupant is behind the T-bar anchor bolt, upon impact the rear wheels of the chair slid in the direction of initial sled travel rotating the chair approximately 10 degrees about the anchorage point. The dummy leaned in a very mild manner toward the direction of travel.

TEST RESULTS

WHEELCHAIR: Minor collapse of the leading caster fork stem was observed. Maximum tension in the T-bar anchor bolt was 1600 lbs.

DUMMY: The dummy remained in the chair. Forward (in the direction of travel) excursion of the head relative to its initial position on the sled was 30 inches.

TEST NUMBER: 1074

FACING DIRECTION: Side

SLED SPEED: 17.2 mph

CRASH PULSE: 12 g's

CHAIR TYPE: Manual

SECUREMENT

WHEELCHAIR: T-bar - front position

DUMMY: Lap belt to axle

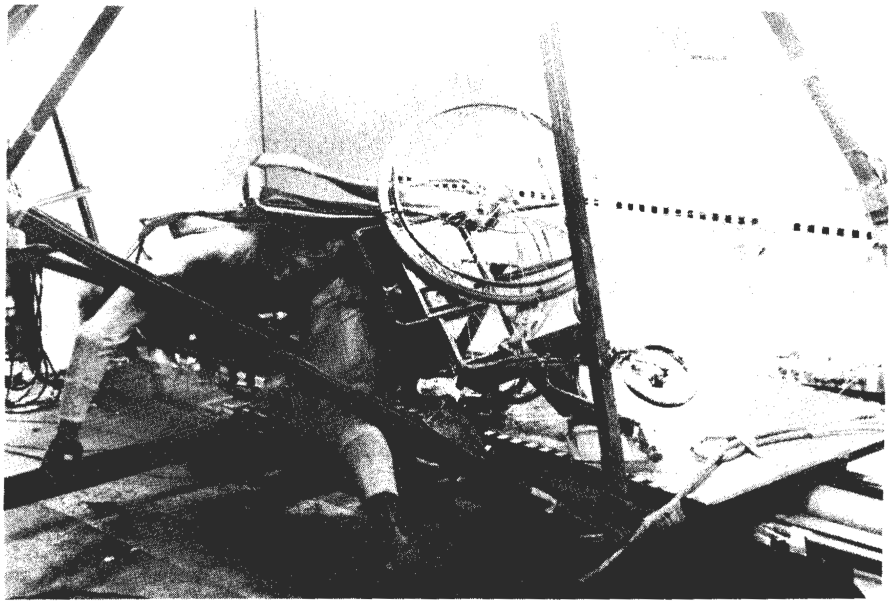
TEST ACTION

Observations of test films and wheelchair damage indicate that the dummy hit the leading armrest with appreciable force. The dummy and chair then pitched forward in the direction of travel.

TEST RESULTS

WHEELCHAIR: The right front footrest rotated about the lower bracket allowing the right (leading) caster to collapse. This resulted in the chair tipping forward (Figure A-12). The T-bar remained on the caster arch and caused a small bend in the left (trailing) caster arch. Maximum tension in the T-bar anchor bolt was 2000 lbs.

DUMMY: Seat belt load was low with a maximum of 400 lbs. A relatively high forward head excursion of 71 inches was recorded. Head and chest accelerations were relatively low. A minor head injury criteria of 54, T_1 = 156 ms, T_2 = 284 ms was calculated.



Test 1074--Post Test Conditions

Figure A-12

TEST NUMBER: 1077

FACING DIRECTION: Forward

SLED SPEED: 19.9 mph

CRASH PULSE: 12 g's

CHAIR TYPE: Manual

SECUREMENT

WHEELCHAIR: **T-bar - rear position**

DUMMY: **Lap belt to axle**

TEST ACTION

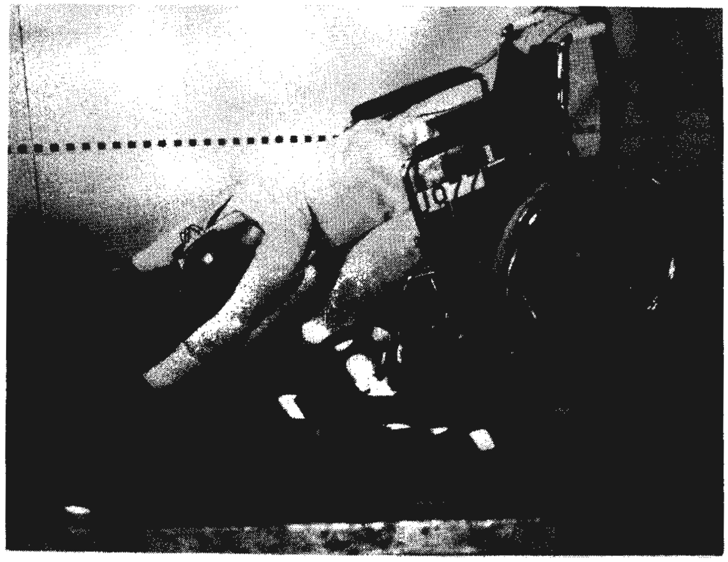
The bolt tension load cell was omitted due to insufficient space between the bar and sled. Immediately upon impact the dummy slid forward and engaged the lap belt. The upper torso then rotated forward and down into a complete jackknife position with arms and legs extended and head between the dummy's legs.

The chair moved forward a few inches until contact was made between the T-bar and the backpost just below the rear wheel axles. As load increased in the lap belt, the front casters failed, transferring load to the footrests and allowing the chair to tip forward slightly (Figure A-13).

TEST RESULTS

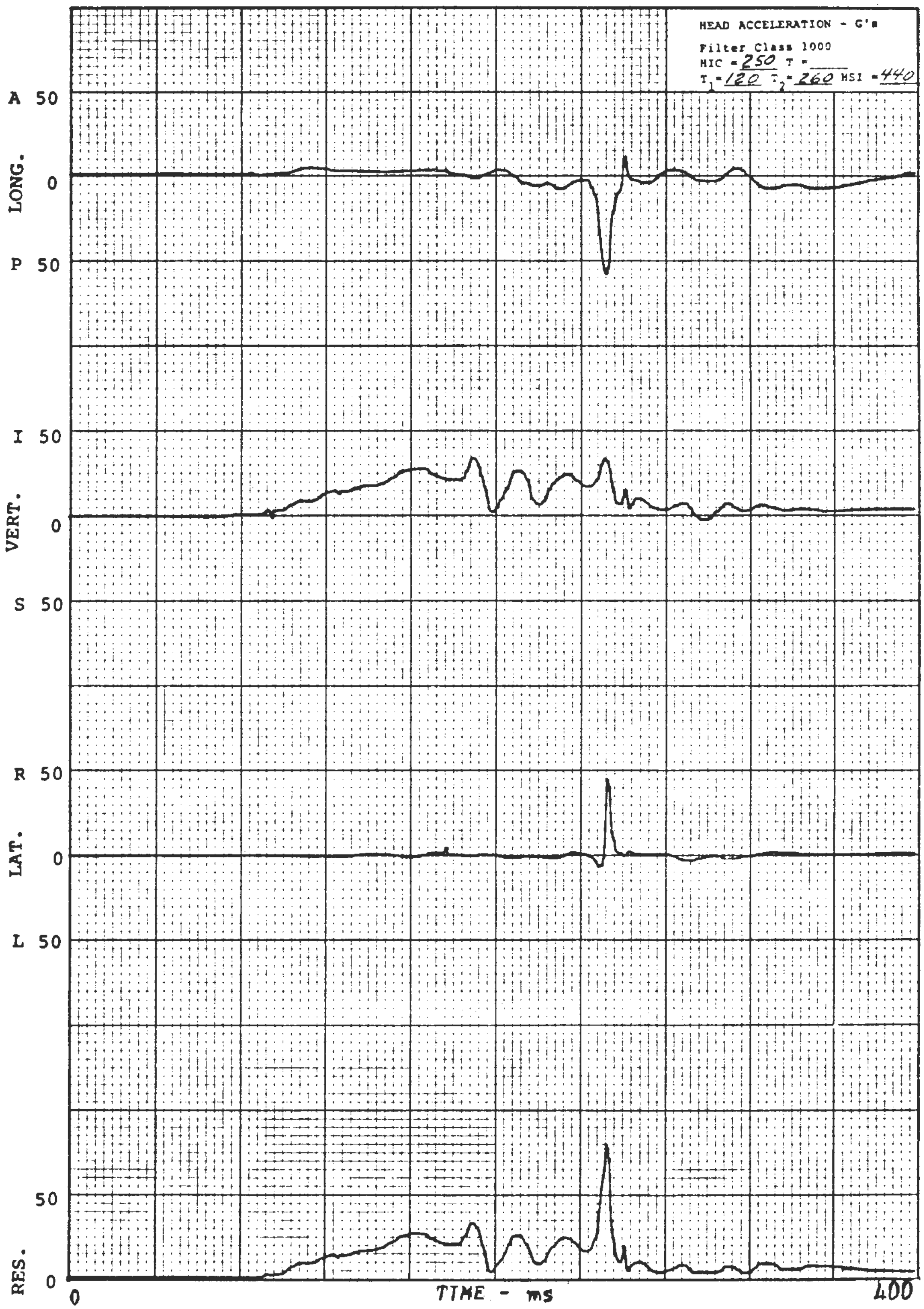
WHEELCHAIR: Both the right and left side frames were severely distorted in a parallelgram shape (almost 1 1/2 inches). The front casters were bent towards the rear almost 2 inches and the footrests pushed upwards until their brackets jammed into the armrest support sockets.

DUMMY: Head acceleration data (Figure A-14) indicated a minor head strike at 250 ms which was probably caused by the head striking the dummy's legs. The maximum head injury criteria (HIC) was calculated as 246 (T_1 = 120 ms, T_2 = 259 ms). Head excursion was 41 inches.



Test 1077--Post Test Conditions

Figure A-13



Head Acceleration Graphs

Test 1077

Figure A-14

TEST NUMBER: 1118

SLED SPEED: 20.0 mph

FACING DIRECTION: Forward

CRASH PULSE: 12 g's

CHAIR TYPE: Manual

SECUREMENT

WHEELCHAIR: T-bar - rear position

DUMMY: Lap belt to axle

TEST ACTION

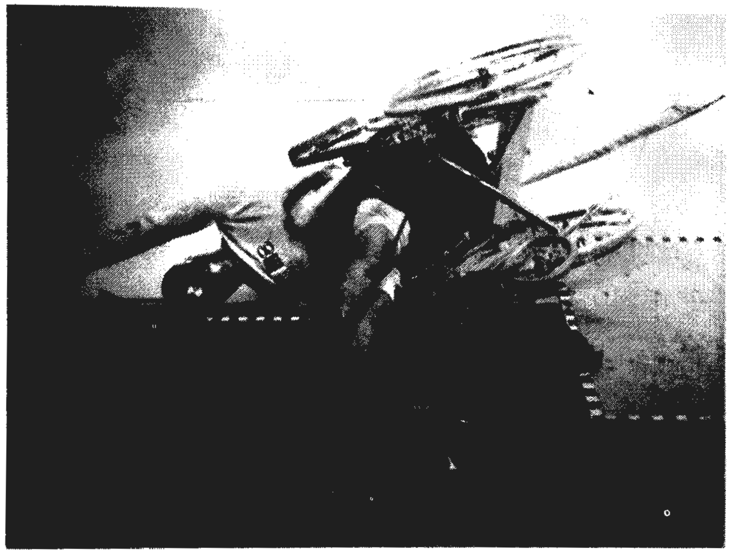
This test was designed to be a retest of Test 1077 with respect to speed and crash pulse, but without a footrest. The purpose being to determine the effect of the footrest.

The securement systems used in Phase I testing were over designed to preclude their failure during testing. However, at 124 ms into the event, the tension bolt securing the T-bar to the test sled failed just above the load cell. Failure was attributed to fatigue of the bolt from repeated use; repeated use was not allowed for during design. Upon failure of the anchor bolt, the chair and dummy were free to tumble downrange. At the time of failure, relative motion of the sled and dummy was low as evidenced by the fairly short distance traveled downrange (Figure A-15).

TEST RESULTS

WHEELCHAIR: Anchor bolt failure was recorded at a tension of 1600 lbs.

DUMMY: Maximum seat belt tension at the time of anchor bolt failure was 1100 lbs. Head and chest accelerations were nominal at bolt failure. A minor head injury criteria of 138, T_1 = 91 ms, T_2 = 210 ms was calculated.



Test 1118--Post Test Conditions

Figure A-15

TEST NUMBER: 1122

FACING DIRECTION: Side

SLED SPEED: 19.3 mph

CRASH PULSE: 12 g's

CHAIR TYPE: Manual

SECUREMENT

WHEELCHAIR: T-bar - rear position

DUMMY: Lap belt to axle

TEST ACTION

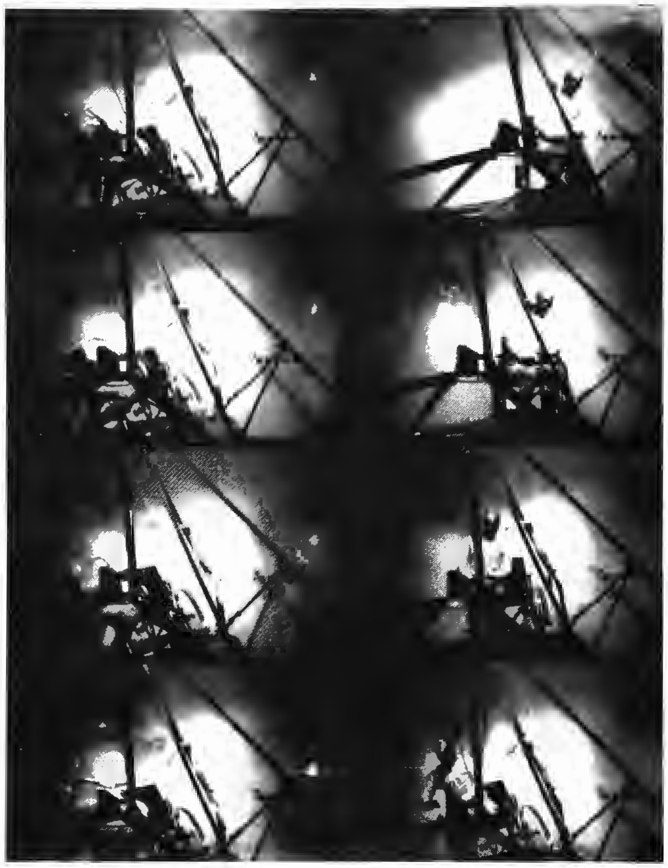
Upon impact the dummy slid sideways in the seat against the leading armrest. The dummy's upper torso then rotated violently downrange about the leading armrest.

The trailing rear wheel raised a few inches off of the sled as the casters slid downrange. The sequence of events is shown in Figure A-16, and the post test conditions are shown in Figure A-17.

TEST RESULTS

WHEELCHAIR: The load cell would not fit under the T-bar in this position, therefore, anchor bolt tension was not measured. The left (trailing) side frame and wheels were undamaged. The right wheel folded under the bottom rail. The right bottom rail was bent inwards at the axle. The right armrest was bent outwards and over the top of the wheel. The upper right portion of the cross brace was bent downwards.

DUMMY: Seat belt load was not recorded. Head and chest data indicate a moderate head strike (HIC = 310, T_1 = 124, T_2 = 244). Maximum head excursion was 54 inches.



Test 1122--Sequence

Figure A-16

Test 1122--Post Test Conditions

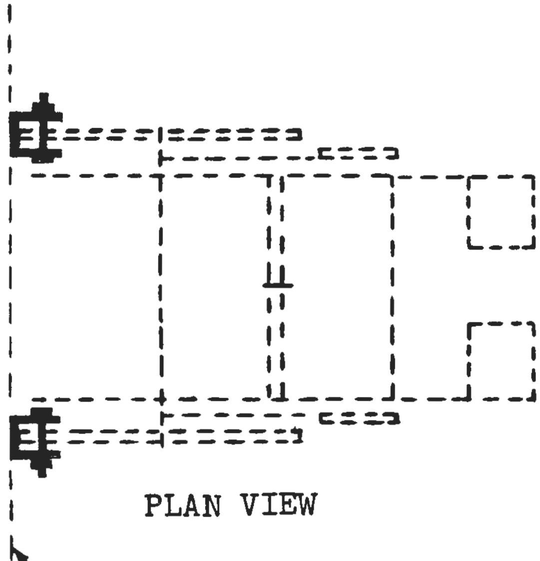
Figure A-17

Wall Rim Pin

The wall rim pin securement system consists of two U-shaped brackets mounted to a vertical surface or support at the axle level of the chair's large wheels (approximately 13 inches above the floor). Securement is obtained by placing the large wheels in the U's and trapping them in place by passing a bolt through the legs of the U's and over the rims of the wheels (Figure A-18).

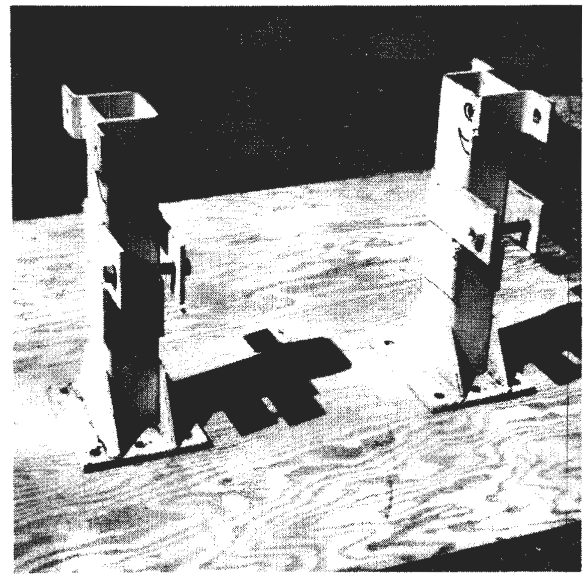
Five tests were conducted with the wall rim pin system:

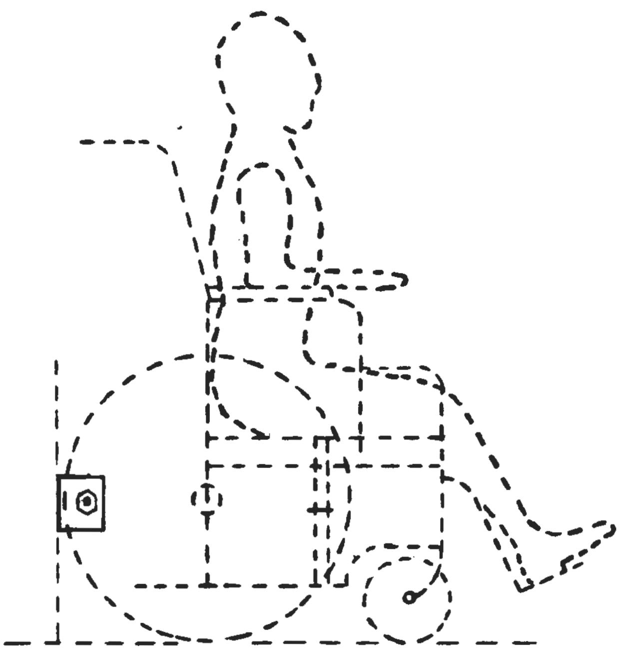
- Three tests with forward facing chairs.
- Two tests with side facing chairs.



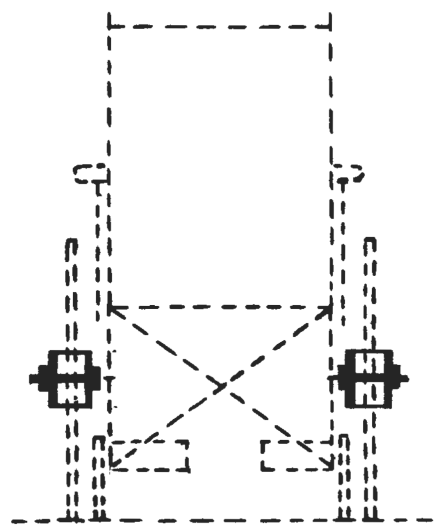
PLAN VIEW

Fixed Surface





SIDE VIEW



FRONT VIEW

WALL RIM PIN

Figure A-18

TEST NUMBER: 1063

FACING DIRECTION: Forward

SLED SPEED: 19.3 mph

CRASH PULSE: 12 g's

CHAIR TYPE: Manual

SECUREMENT

WHEELCHAIR: Wall rim pin

DUMMY: Lap belt to axle

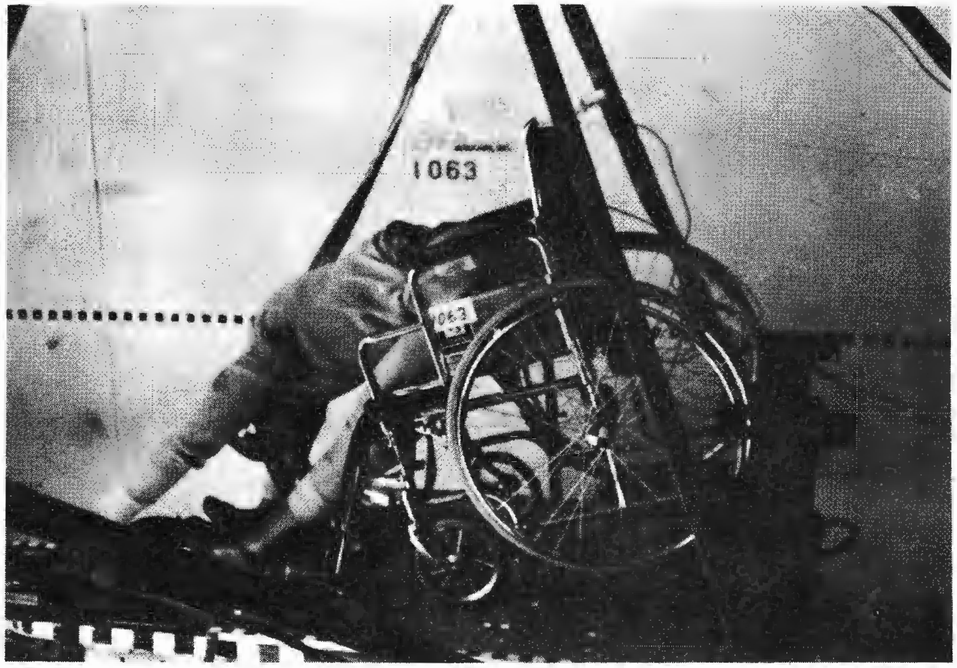
TEST ACTION

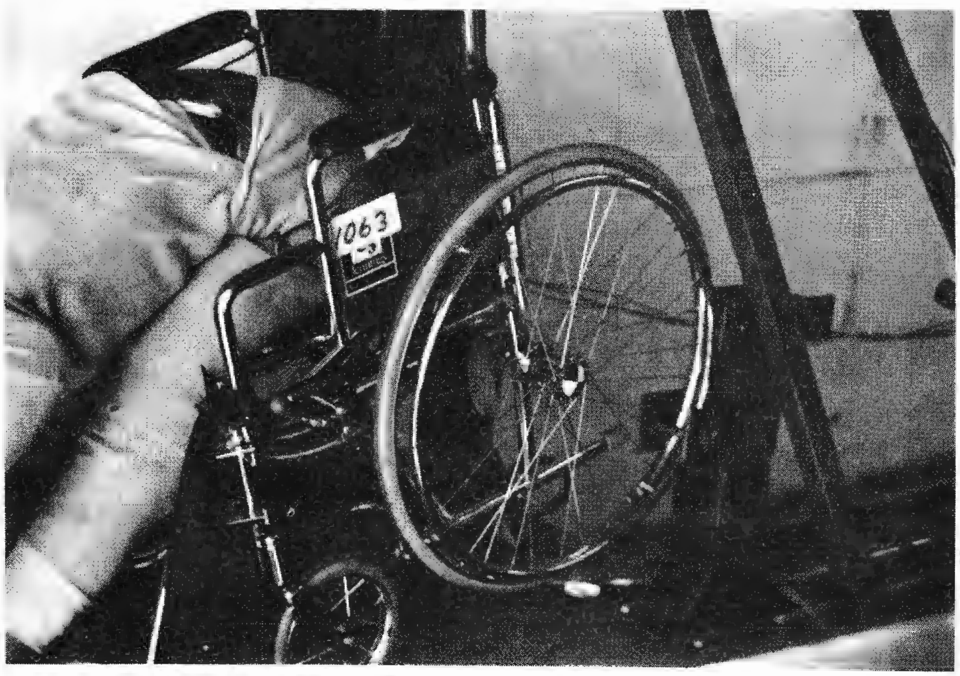
Upon impact, the chair momentarily stopped. The dummy continued to slide forward taking up slack in the lap belt. As the lap belt loaded, the dummy jackknifed forward with hands and legs extended. The dummy's upper torso rotated forward and down with its head between its legs. The high center of gravity of the dummy caused the chair to rotate forward lifting the rear wheels off the sled. The rear wheels rotated up the securement support until the footrests contacted the sled (Figure A-19).

TEST RESULTS

WHEELCHAIR: There was little frame and caster damage. The left footrest tube was bent forward slightly. Very minor damage was noted on the rear wheel rims.

DUMMY: Recorded data showed an early onset of lap belt load at about 50 ms and a peak load of 1200 lbs. in the belt (approximately 2400 lbs on the dummy). Head excursion was 45 inches. Head and chest accelerations were nominal (HIC = 172, T_1 = 108 ms, T_2 = 274 ms).





Test 1063--Post Test Conditions

Figure A-19

TEST NUMBER: 1100 SLED SPEED: 23.2 mph

FACING DIRECTION: Forward CRASH PULSE: 12 g's

CHAIR TYPE: Manual

SECUREMENT

WHEELCHAIR: Wall rim pin

DUMMY: Lap belt to axle

TEST ACTION

This test was run after work done during the static testing phase showed that the chair secured by the wall rim pin method could absorb the energy from a 22.2 mph impact without suffering severe damage; and that the footrests would play a minor roll in the chair's performance. After this test was conducted, Test 1101 was run with the same test parameters as this one except footrests were provided.

There is no attempt in the report to compare the static and dynamic tests for this securement system. The comparisons will be made on all of the applicable systems in the final report.

As in Test 1063, the high center of gravity of the dummy caused the chair to rotate forward lifting the rear wheels off the sled. The rear wheels rotated up the securement support as the casters moved in a rearward direction toward the securement. Tip forward was much more severe than in Test 1063, with the chair coming to rest on its forward surface (Figure A-20).

The dummy jackknifed forward and down, landing on the floor of the test sled.

TEST RESULTS

WHEELCHAIR: Both rear wheels had distorted rims with one broken spoke on each (Figure A-21). The left caster was not deformed, but the right caster was bent aft and inwards as it rolled back and contacted the securement support.

DUMMY: The seat belt load was low in comparison with Test 1063. Maximum belt tension was 1100 lbs. In spite of the final dummy position, the recorded head and chest accelerations appeared to be nominal (HIC = 322, T_1 = 95 ms, T_2 = 197 ms) and were similar to those in Test 1063. Head excursion was 43 inches.

Test 1100--Post Test Conditions

Figure A-20

Test 1100--Wheel Damage

Figure A-21

TEST NUMBER: 1101 SLED SPEED: 23.1 mph

FACING DIRECTION: Forward CRASH PULSE: 12 g's

CHAIR TYPE: Manual

SECUREMENT

WHEELCHAIR: Wall rim pin

DUMMY: Lap belt to axle

TEST ACTION

The test setup repeated Test 1100 except the footrests were installed on the chair. the importance of the footrests was demonstrated by the behavior of the chair in Test 1100. Target speed was chosen to verify latent energy calculations based on the static test data. (The static and dynamic test comparisons will be discussed in the final report.)

Test action was similar to that in Test 1063. The dummy and chair rotated forward lifting the rear wheels off the sled. The rear wheels rotated up the securement support until the footrests contacted the sled. The dummy's upper torso jackknifed forward with arms and legs extended (Figure A-22).

TEST RESULTS

WHEELCHAIR: Both rear wheels suffered severe damage. Their rims were badly deformed with 9 broken spokes in the left wheel and 4 broken in the right (Figure A-23).

DUMMY: The belt load transducer failed at 93 ms into the event. However, the belt load closely follows the load of Test 1063 up to the point of data loss. Head and chest accelerations appeared to be nominal (HIC = 190, T_1 = 124 ms, T_2 = 184 ms) and were similar with those in Test 1063. Head excursion was 44 inches.

5 1

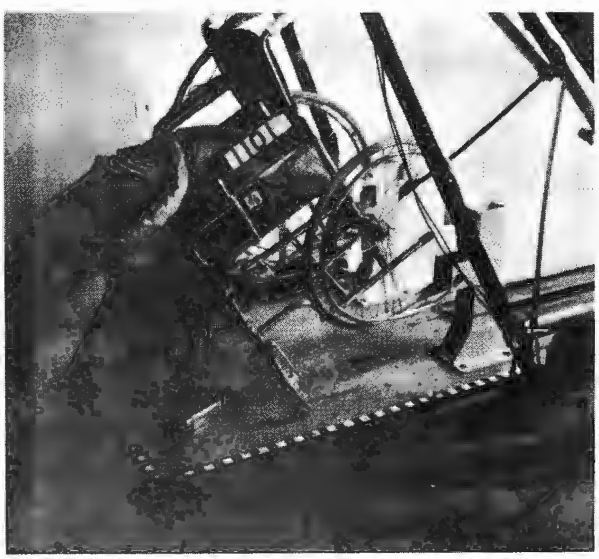
6 2

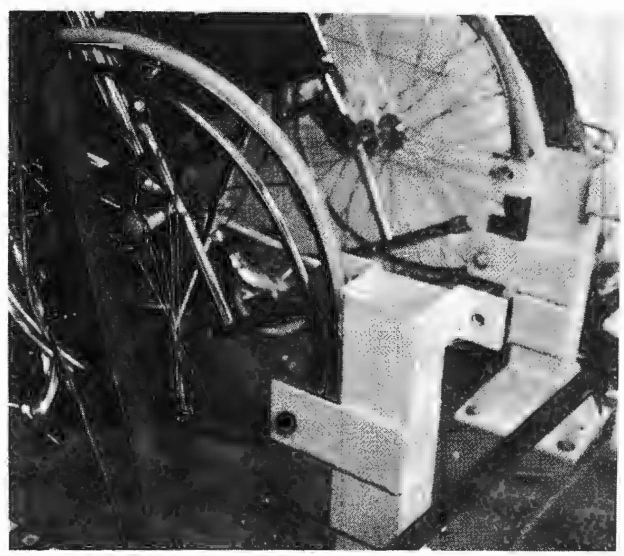
7 3

8 4

Test 1101--Sequence

Figure A-22





Test 1101

Post Test Conditions

Wheel Damage

Figure A-23

TEST NUMBER: 1073 SLED SPEED: 11.3 mph

FACING DIRECTION: Side CRASH PULSE: 10 g's

CHAIR TYPE: Manual

SECUREMENT

WHEELCHAIR: Wall rim pin

DUMMY: Lap belt to axle

TEST ACTION

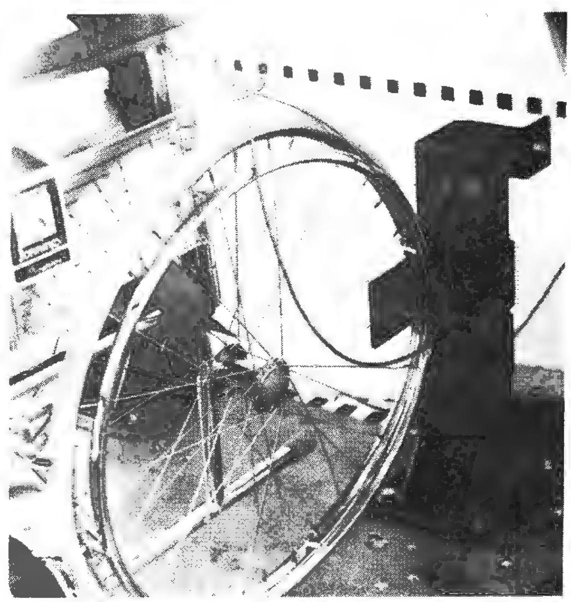
Upon impact, the chair rotated slightly in the direction of travel. The dummy leaned in the direction of travel striking the armrest. The model 774 elevating legrests--hinged to allow the legs to be elevated--on this chair swung up and then down during deceleration.

TEST RESULTS

WHEELCHAIR: There was no visable damage to the chair frame, armrests and leading wheel. The left (trailing) wheel suffered one broken spoke and the cross brace had suffered some distortion (Figure A-24). There was minor damage to the leading (right) caster.

DUMMY: Seat belt load was low with a maximum of 300 lbs. Head and chest accelerometer traces were essentially flat. Excursion of the head in the direction of travel relative to its initial position on the sled was 44 inches.

Frontal
View



Left Wheel

Right Wheel

Test 1073--Post Test Conditions

Figure A-24

TEST NUMBER: 1072

FACING DIRECTION: Side

SLED SPEED: 19.4 mph

CRASH PULSE: 12 g's

CHAIR TYPE: Manual

SECUREMENT

WHEELCHAIR: Wall rim pin

DUMMY: Lap belt to axle

TEST ACTION

Virtually all of the spokes failed in the trailing wheel allowing the chair to rotate downrange over the leading securement. At the same time, the chair tipped up on the right front (leading) caster. At about 180 ms into the event, the right front caster swung forward off the test sled allowing an almost complete forward rotation of the chair.

The dummy struck the leading armrest violently. It attempted to roll over the armrest but came to rest in the chair seat.

TEST RESULTS

WHEELCHAIR: Full securement of the chair was not maintained during the test. The trailing wheel was completely destroyed (Figure A-25). All of the spokes were broken and the rim, tire and hand rim were separated. The left (trailing) side frame was intact except for a slight inward bend of the backpost at the axle. The right (leading) bottom rail was bent inwards. The right armrest was bent outwards almost 10 degrees and almost lifted from the rear socket.

DUMMY: Recorded head and chest accelerations were nominal with no particular indication of injury (HIC = 44, T_1 = 127 ms, T_2 = 308 ms). However, impact of the dummy against the armrest raises the possibility of injury. Excursion of the head in the direction of travel relative to its initial position on the sled was 61 inches. Maximum seat belt load was 1000 lbs.

Test 1072--Post Test Conditions

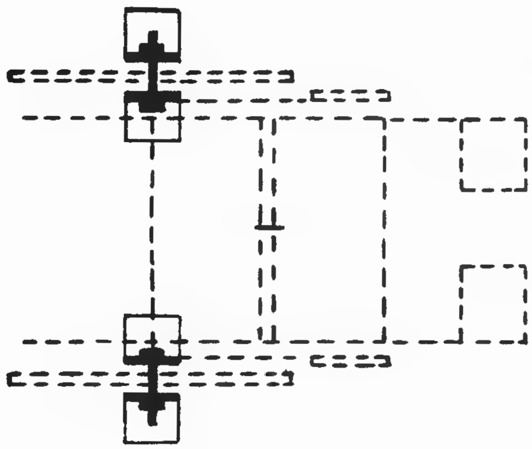
Figure A-25

Floor Rim Pin

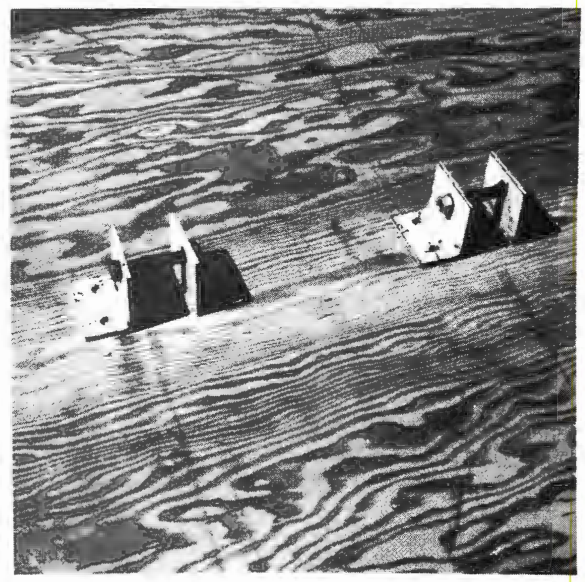
The floor rim pin consist of two U-shaped brackets mounted to the floor with a bolt through the legs of the U. Securement is obtained by placing both large rear wheels of the chair in the U's and trapping them in place by passing the bolts through the legs of the U's and over the rims of the wheels (Figure A-26).

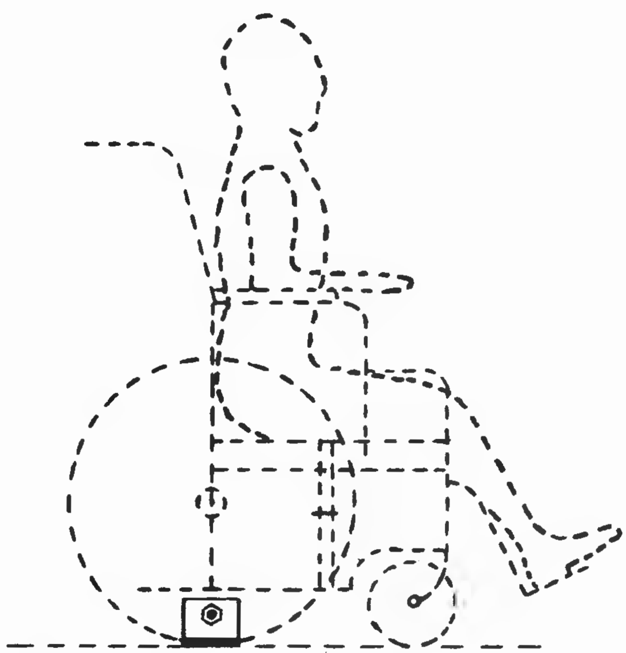
Five tests were conducted with the floor rim pin system:

- Two with foward facing chairs.
- Three with side facing chairs.

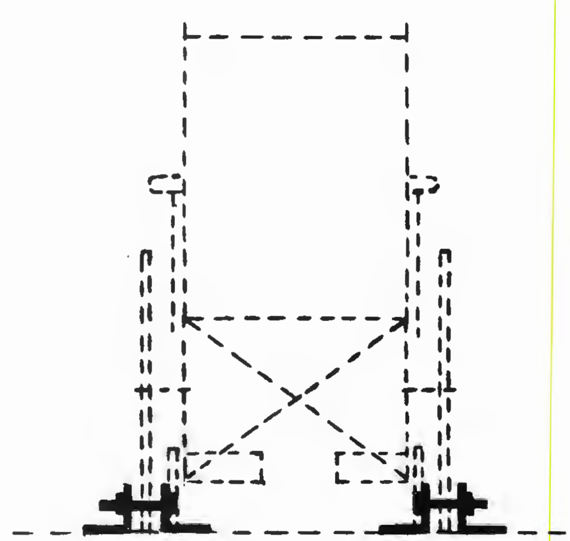


PLAN VIEW





SIDE VIEW



FRONT VIEW

FLOOR RIM PIN

Figure A-26

TEST NUMBER: 1054 SLED SPEED: 19.0 mph

FACING DIRECTION: Forward CRASH PULSE: 12 g's

CHAIR TYPE: Manual

SECUREMENT

WHEELCHAIR: Floor rim pin

DUMMY: Waist belt around chair back

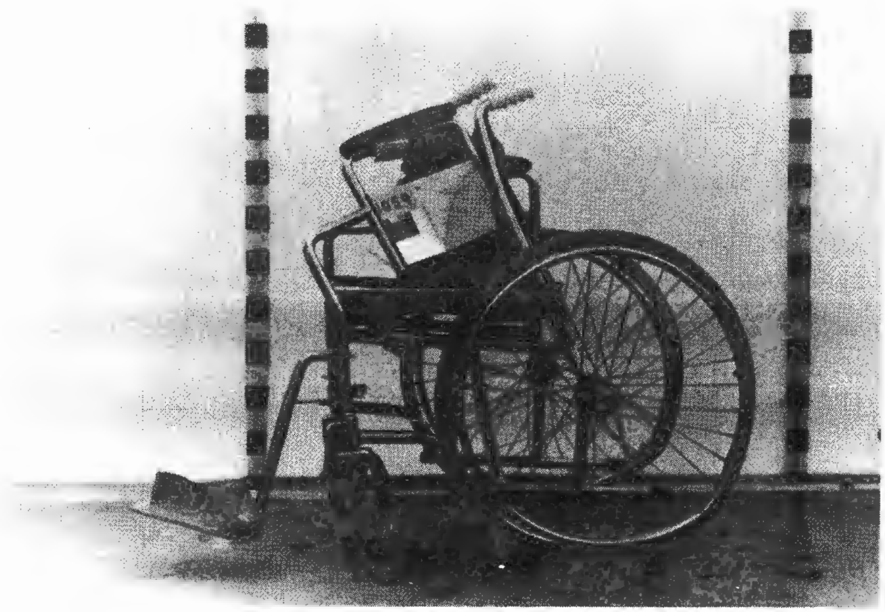
TEST ACTION

Upon impact, the waist belt started riding up the backrest supports. It continued to do so until it reached the handholds at the top of the supports. The waist belt load caused the backposts to bend inward and forward. Play between the rear wheel rim and the rim pins allowed the chair to move forward until load was picked up by contact of the pin on the rim. The dummy slid forward on the chair seat as the backposts deflected.

TEST RESULTS

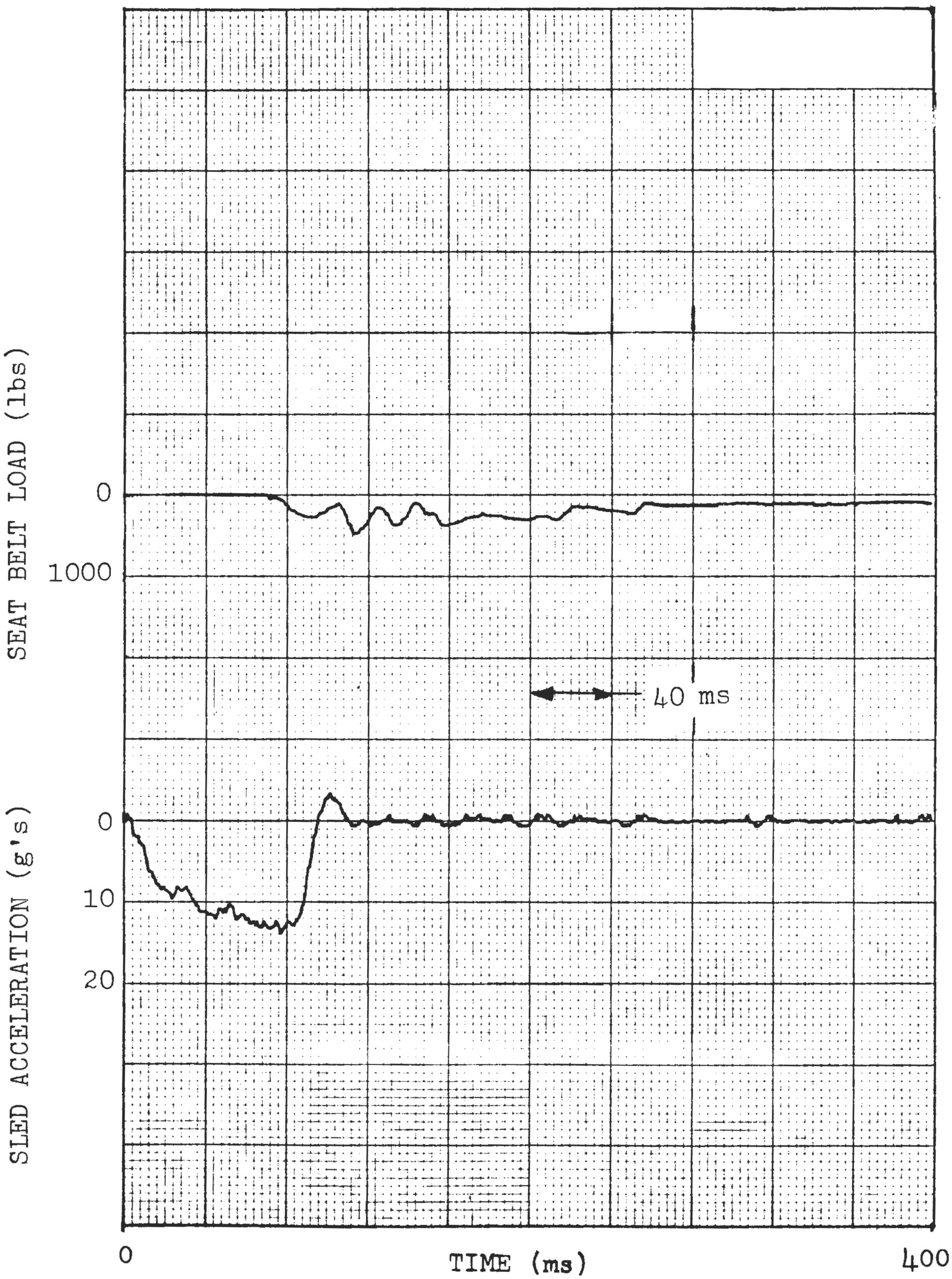
WHEELCHAIR: Major damage was done to the chair backposts (Figure A-27). Both posts were bent forward and inward; the left post failed just above the axle mount. Most frame members of the chair were bent. Minor bending occurred in the rear wheel rims; one spoke was broken.

DUMMY: Belt force on the abdominal area of the dummy (Figure A-28) was 900 lbs (twice belt load). Forward excursion of the head was 53 inches. Securement of the dummy was judged inadequate due to the imminent loss of the waist belt attachment to the chair.



Test 1054--Post Test Conditions

Figure A-27



Sled Acceleration and Seat Belt Load

Test 1054

Figure A-28

TEST NUMBER: 1059 SLED SPEED: 19.1 mph

FACING DIRECTION: Forward CRASH PULSE: 12 g's

CHAIR TYPE: Manual

SECUREMENT

WHEELCHAIR: Floor rim pin

DUMMY: Lap belt to axle

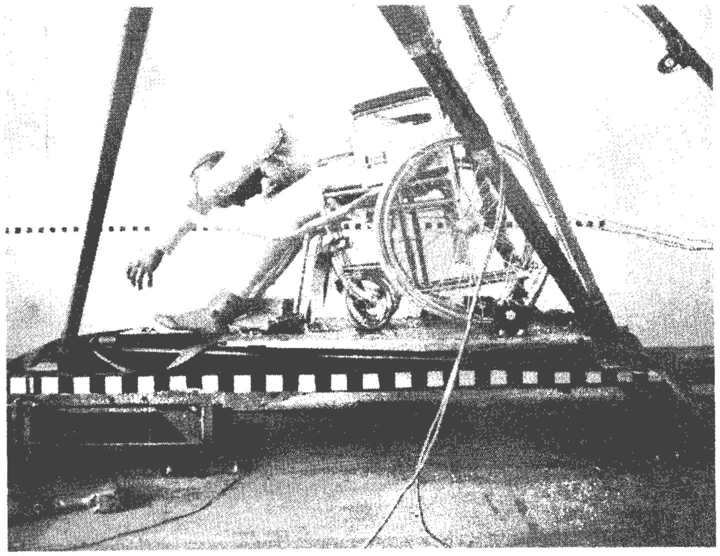
TEST ACTION

This was essentially a repeat of Test 1054, but with the dummy securement changed to a lap belt secured to the axles of the rear wheels. Upon impact, the chair moved forward until load was picked up by contact between the rim pins and the wheel rims. The dummy remained in the seat with only limited excursion. The dummy's upper torso rotated forward about the hips with arms extended (Figure A-29).

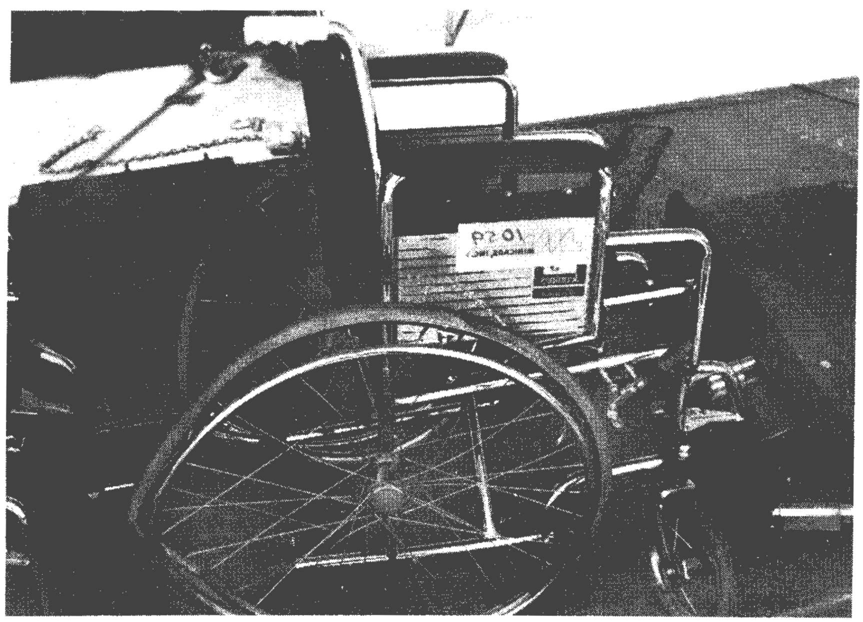
TEST RESULTS

WHEELCHAIR: Each rear wheel suffered three broken spokes and major distortion of their rims (Figure A-30). The casters were bent toward the rear about 3/4 inch.

DUMMY: Forward head excursion was 44 inches. Very low head and chest decelerations were recorded (Figures A-31 and A-32). HIC = 158, T_1 = 112 ms, T_2 = 248 ms.

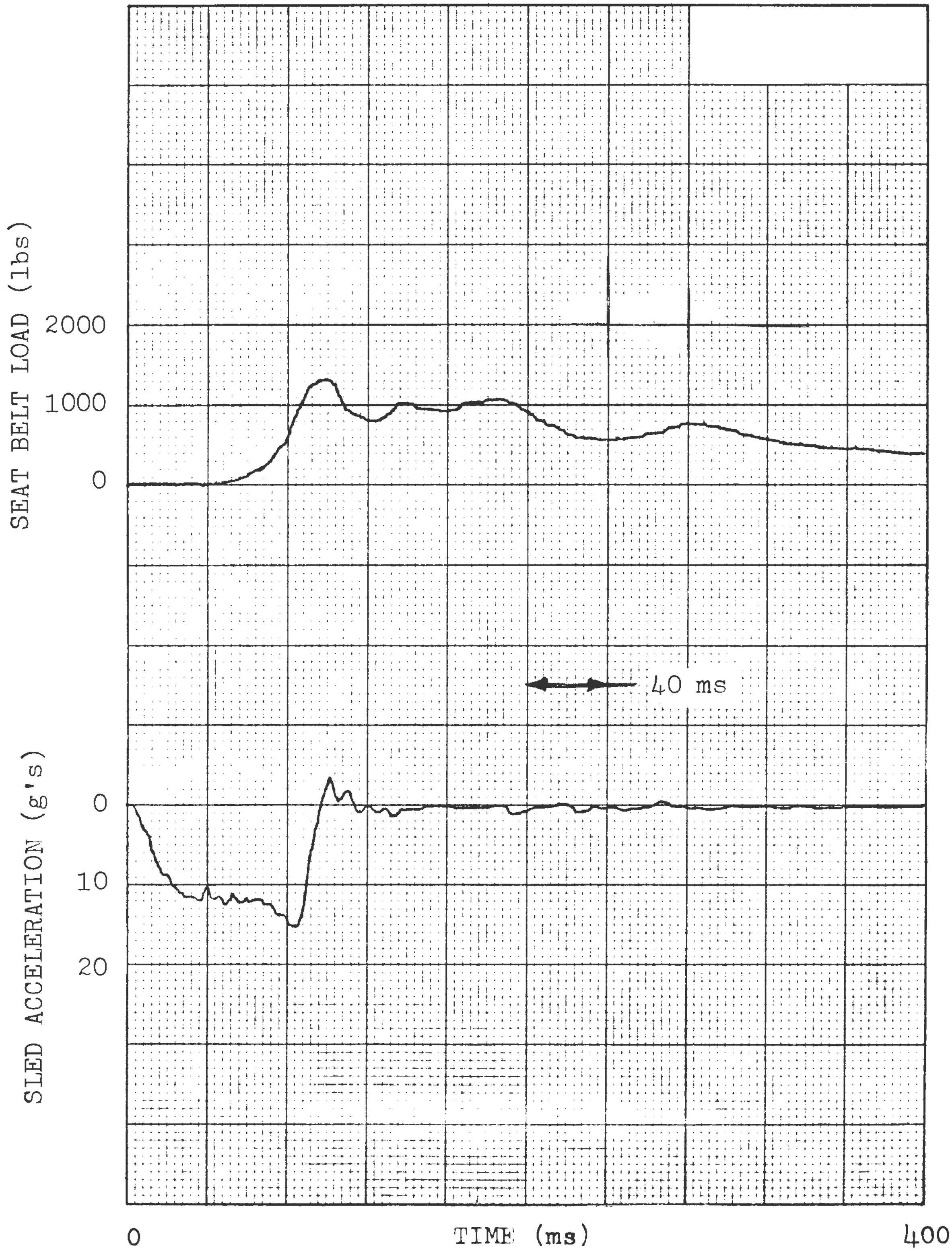


Test 1059--Post Test Conditions



Test 1059--Wheel Damage

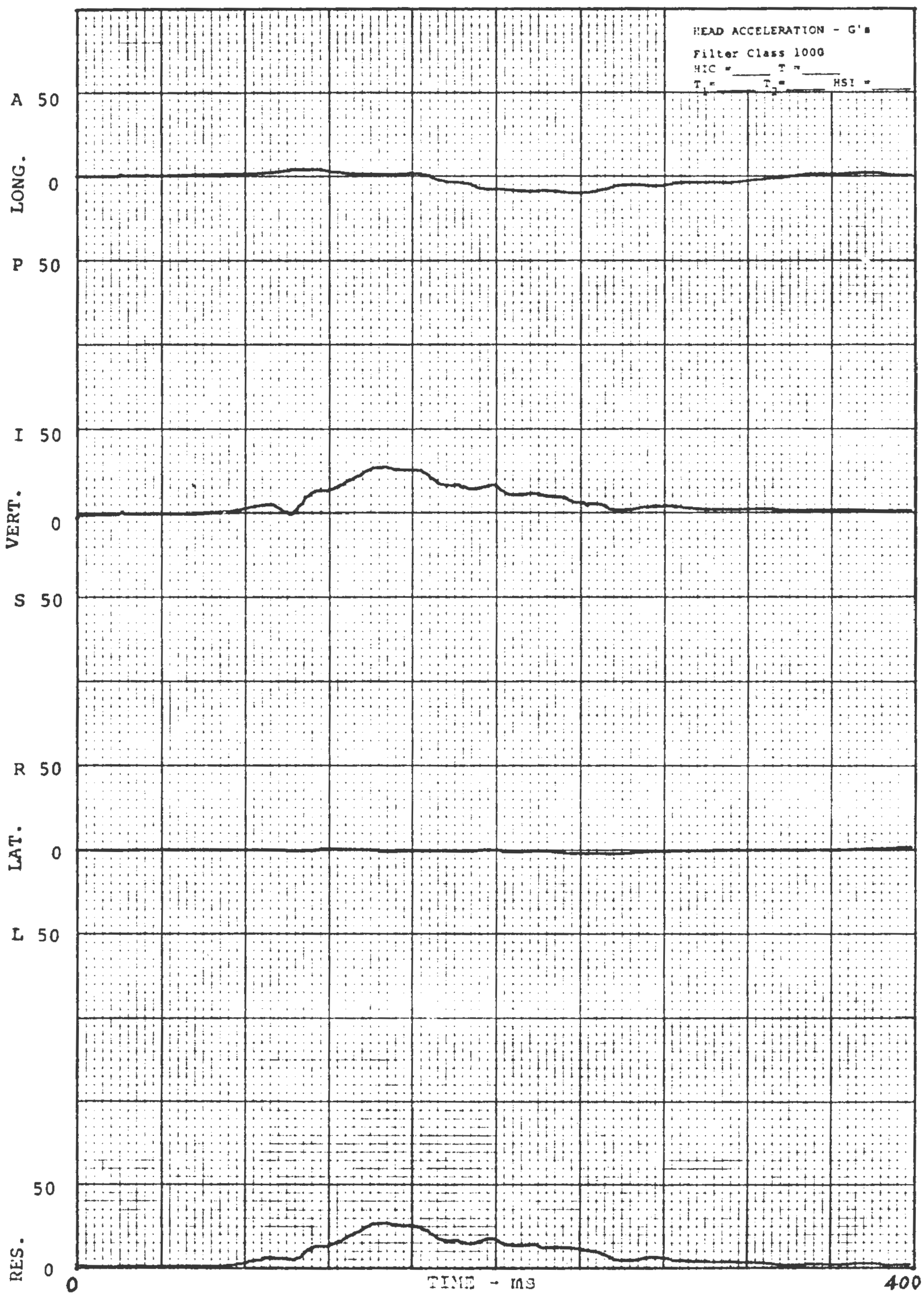
Figure A-29



Sled Acceleration and Seat Belt Load

Test 1059

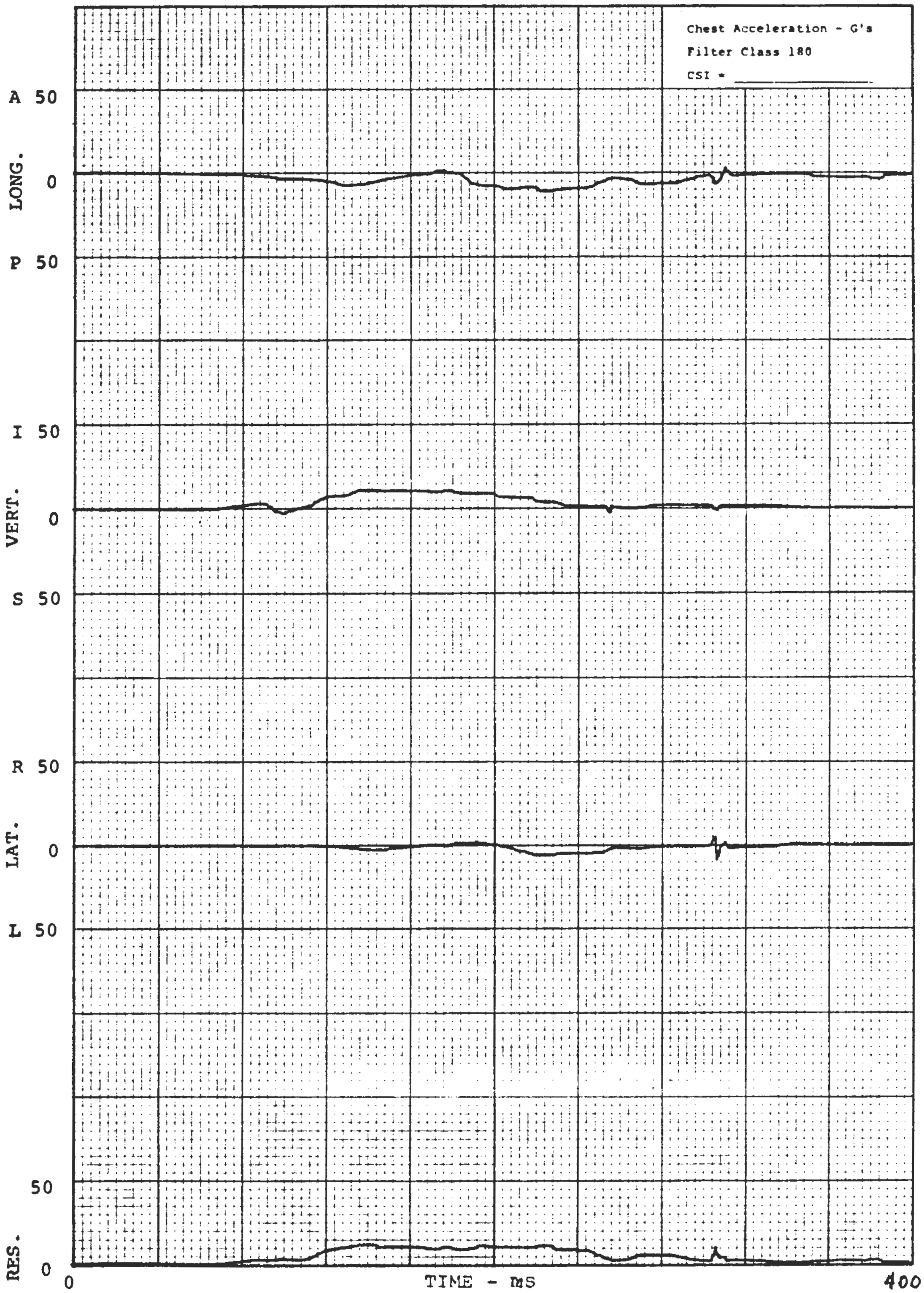
Figure A-30



Head Acceleration Graphs

Test 1059

Figure A-31



Chest Acceleration Graphs

Test 1059

Figure A-32

TEST NUMBER: 1055 SLED SPEED: 19.0 mph

FACING DIRECTION: Side CRASH PULSE: 12 g's

CHAIR TYPE: Manual

SECUREMENT

WHEELCHAIR: Floor rim pin

DUMMY: Waist belt around chair back

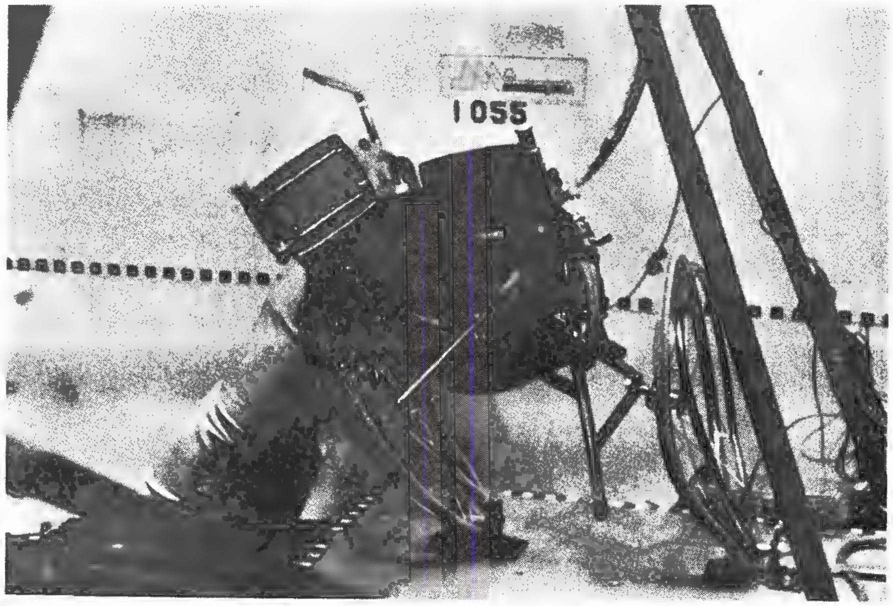
TEST ACTION

The waist belt rode up the left (trailing) backpost causing a large deflection of the chair back. The dummy rotated over the right (leading) armrest as the chair tipped backwards. At the end of the event, the dummy was out of the chair on its head with its feet slightly behind and downrange of the chair. The chair was tilted back with its front casters elevated about 45 degrees.

TEST RESULTS

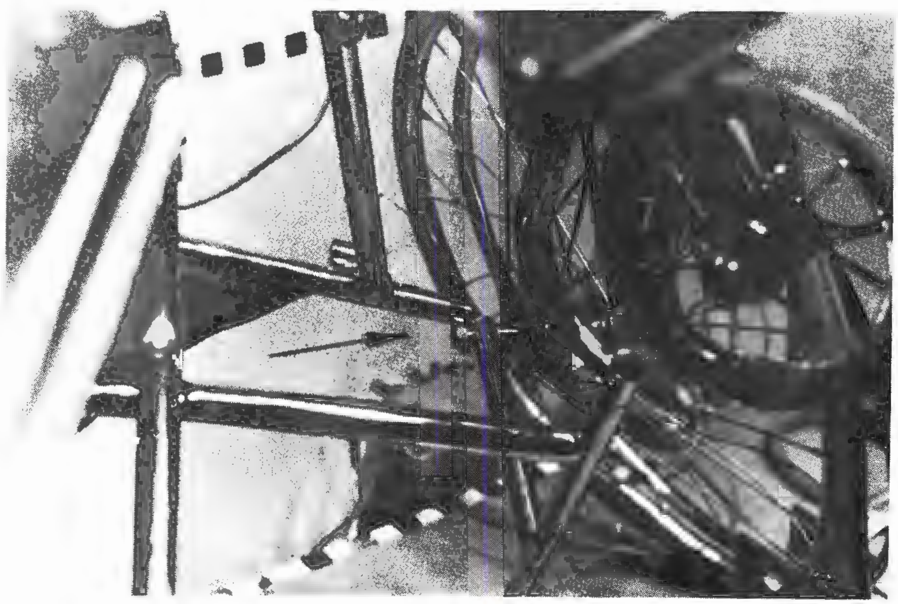
WHEELCHAIR: High belt loads caused the left (trailing) backpost to fail just above the axle (Figure A-33). The leading lower side frame was bent towards the rear. Both rear wheels were severely bent with several spokes broken (Figure A-34).

DUMMY: Seat belt load was 300 lbs. Forward head excursion was 56 inches. The dummy was not confined by the securement provided.



Test 1055--Post Test Conditions

Figure A-33



Test 1055--Back Post Failure

Figure A-34

TEST NUMBER: 1087

FACING DIRECTION: Side

SLED SPEED: 10.3 mph

CRASH PULSE: 10 g's

CHAIR TYPE: Manual

SECUREMENT

WHEELCHAIR: Floor rim pin

DUMMY: Lap belt to axle

TEST ACTION

At this velocity, the chair was able to absorb the impact energy and remained in place throughout the incident. The dummy leaned sideways--downrange--(Figure A-35) against the leading armrest with its left arm raised and extended downrange.

TEST RESULTS

WHEELCHAIR: Minor damage was observed in the right (leading) armrest and hand rim (Figure A-36). The left (trailing) wheel suffered a dented rim and one broken spoke.

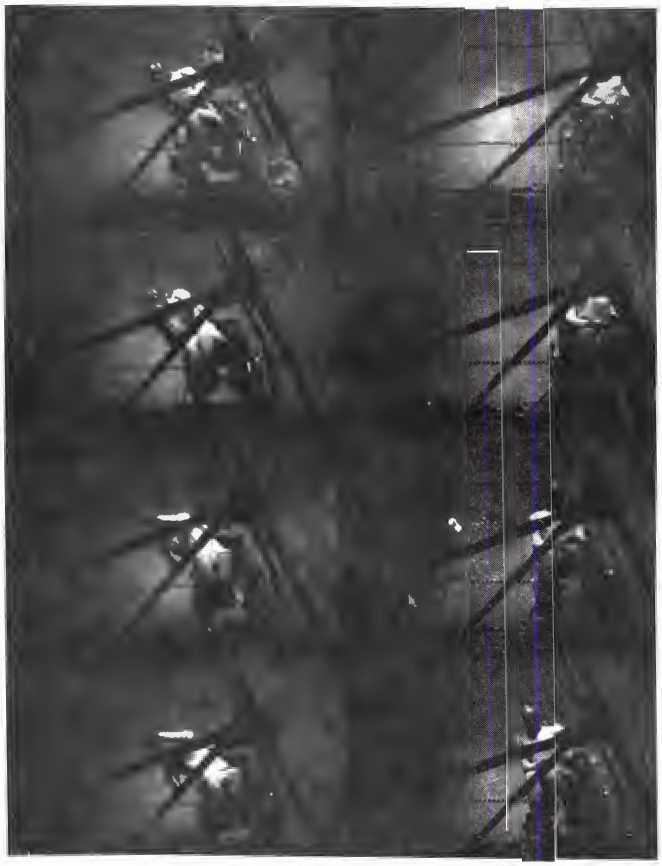
DUMMY: Maximum tension in the seat belt was 450 lbs. Head and chest accelerations were nominal (HIC = 14, T_1 = 157 ms, T_2 = 220 ms). Maximum head excursion measured downrange from its initial position was 38 inches.

5 1

6 2

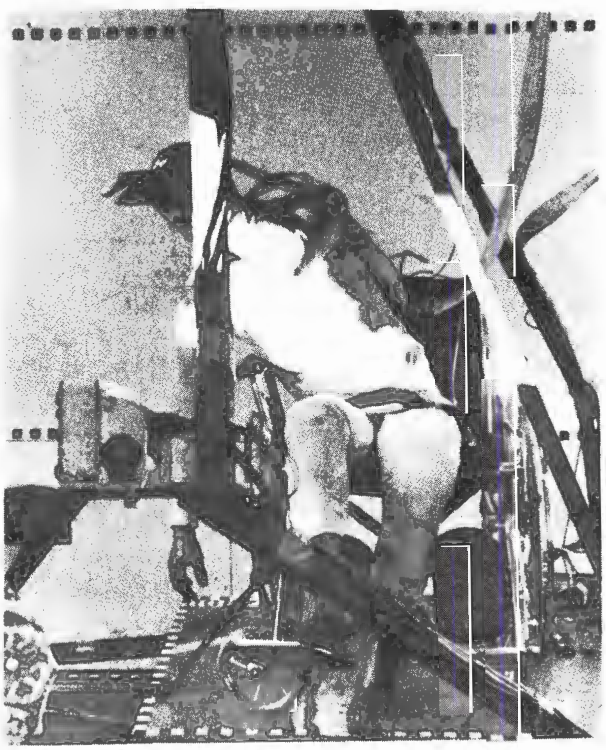
7 3

8 4



Test 1087--Sequence

Figure A-35



Test 1087--Post
Test Conditions

Figure A-36

TEST NUMBER: 1070

FACING DIRECTION: Side

SLED SPEED: 18.5 mph

CRASH PULSE: 12 g's

CHAIR TYPE: Manual

SECUREMENT

WHEELCHAIR: Floor rim pin

DUMMY: Lap belt to axle

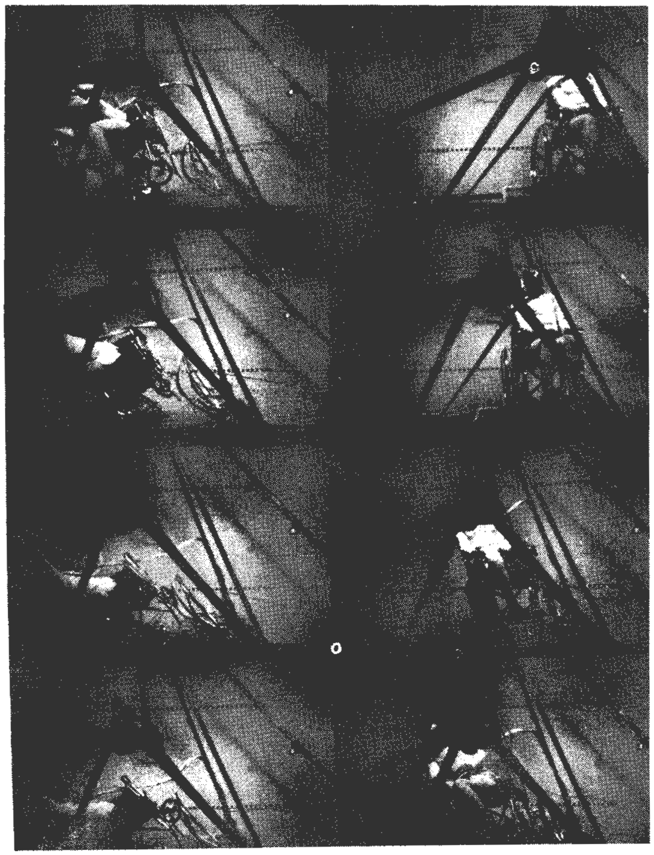
TEST ACTION

As suspected, the chair could not absorb the energy from an onset speed of 18.5 mph. The trailing wheel spokes failed, allowing the chair to rotate downrange over the leading wheel and caster (Figure A-37). The dummy attempted to roll over the forward armrest coming to rest essentially at the sled floor level but still secured to the chair.

TEST RESULTS

WHEELCHAIR: "Retention" of the chair was not maintained during the test. The trailing wheel was completely destroyed; most of the spokes failed. The tire, rim, and hand rim separated. The leading wheel bent inwards under the chair. The cross bracing and side frames of the chair were twisted and bent (Figure A-38).

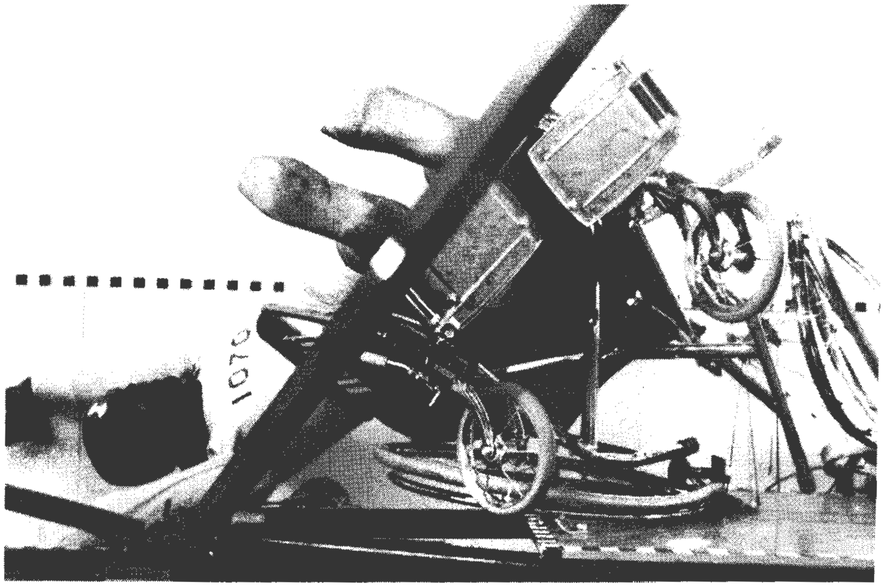
DUMMY: Seat belt data was invalidated due to the fouling of a transducer. Head and chest accelerations were relatively low (HIC = 46, T_1 = 115 ms, T_2 = 243 ms). Head excursion was 56 inches.



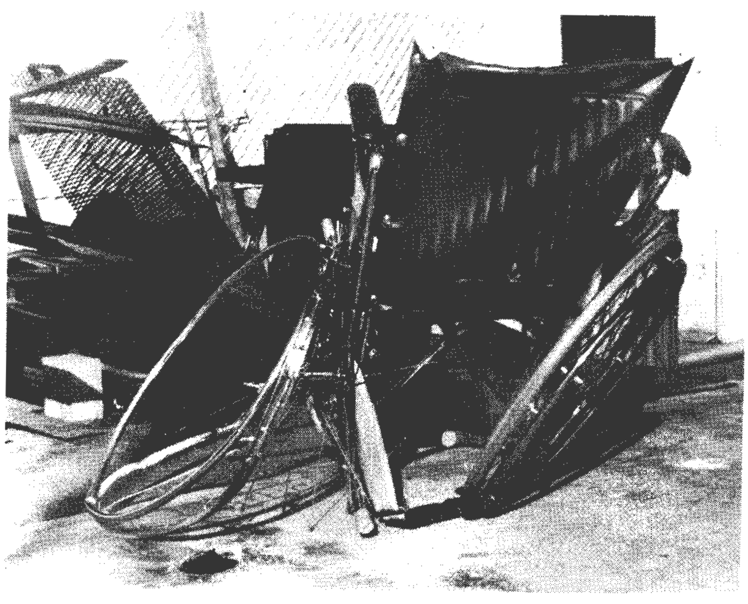
5 1
6 2
7 3
8 4

Test 1070--Sequence

Figure A-37



Test 1070--Post Test Conditions



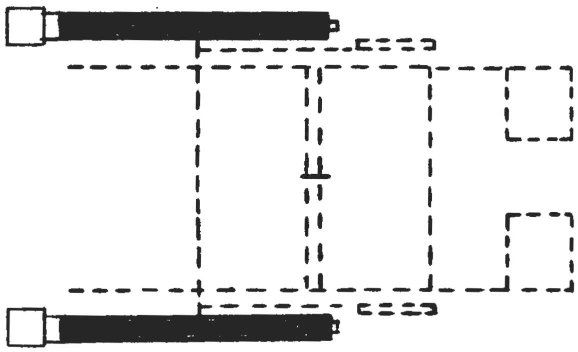
Test 1070--Chair Damage

Figure A-38

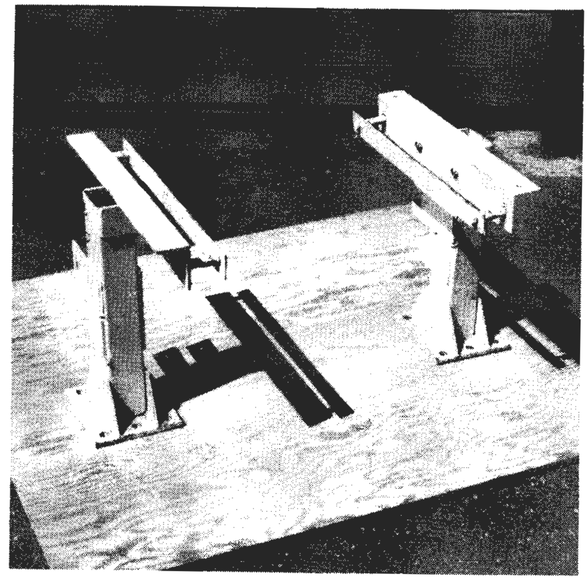
Fender

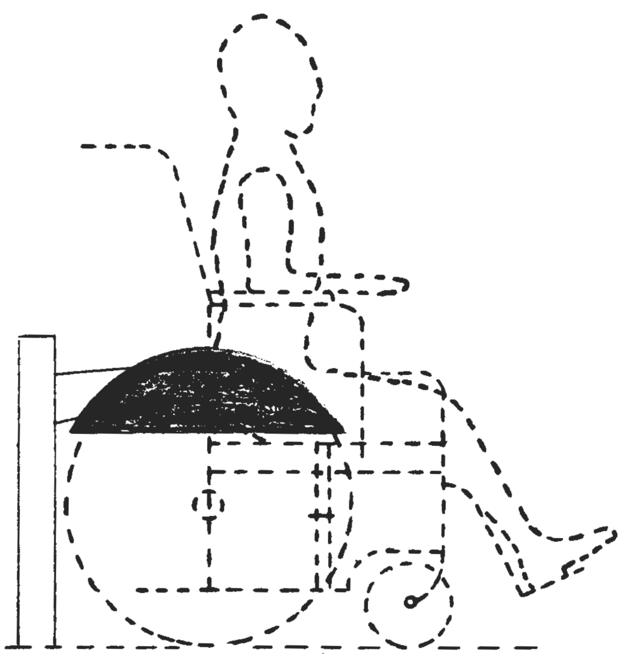
The fender system consists of upside down trough shapes (similar to bicycle fenders) that fit over the large diameter wheels. Inasmuch as the wheels of a forward facing chair will tend to slide or be forced from under fenders during a frontal impact, thereby contacting only the lower edge of the frontal portion of the fenders, only the lower edges of the front and rear portion of the fenders were constructed. The sides of the fenders were either wide straps or the three-inch leg of an angle shape. In either case, what was provided closely represented the actual insides of the lower portion of a fender (Figure A-39).

Two tests--both a forward and side facing chair-- were conducted with the fender system.

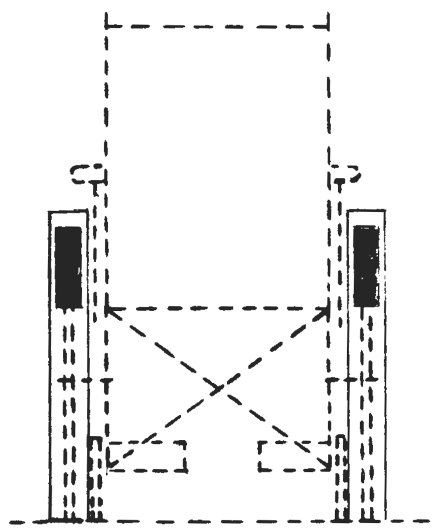


PLAN VIEW





SIDE VIEW



FRONT VIEW

FENDER

Figure A-39

TEST NUMBER: 1064 SLED SPEED: 19.5 mph

FACING DIRECTION: Forward CRASH PULSE: 12 g's

CHAIR TYPE: Manual

SECUREMENT

WHEELCHAIR: Fender

DUMMY: Lap belt to axle

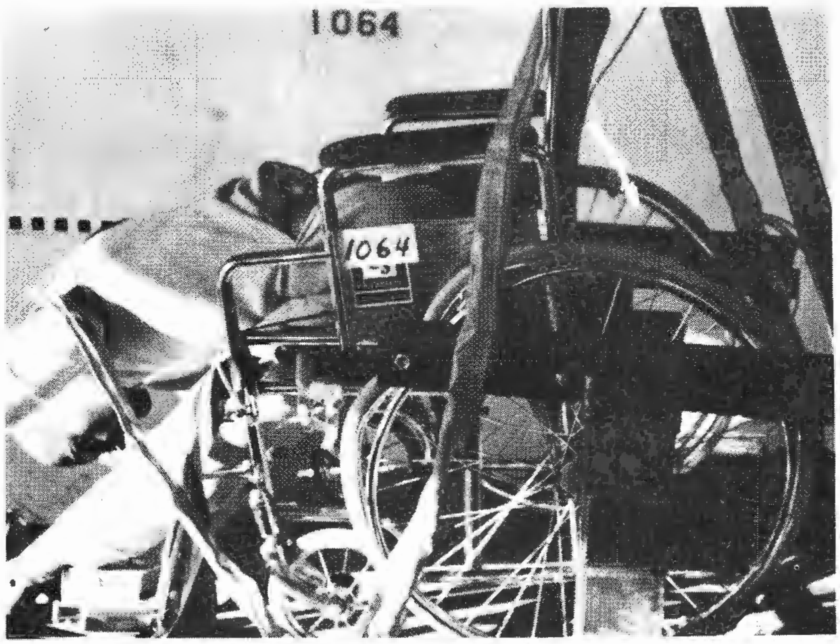
TEST ACTION

Upon impact, the chair moved forward slightly to firmly engage the forward edge of the fenders. The chair remained stationary while the dummy slid forward in the seat, solidly engaging the lap belt. The dummy jackknifed to a position slightly below the horizontal with its head between its legs.

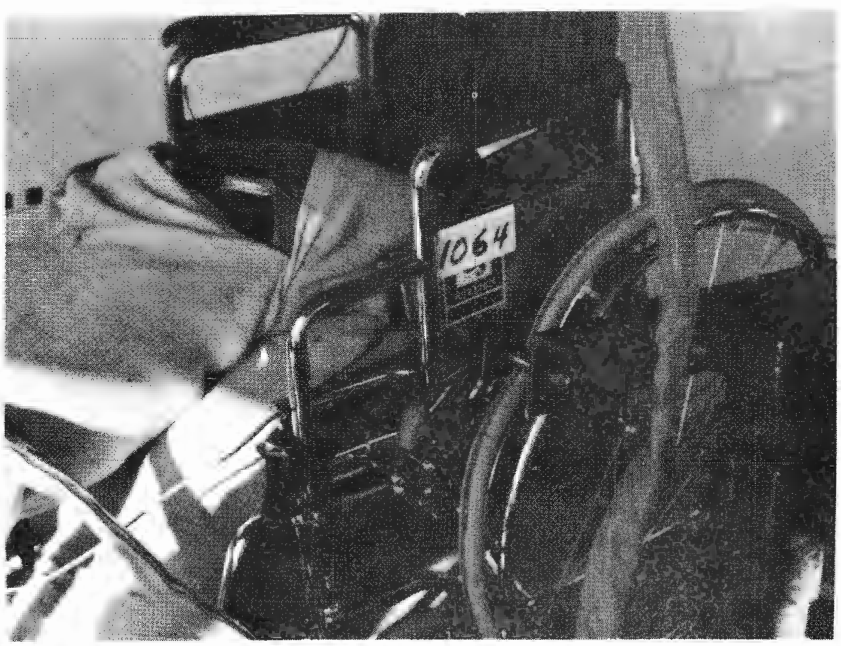
TEST RESULTS

WHEELCHAIR: Severe bending of the rear wheel rims was observed (Figure A-40). The front casters were bent aft about 1 inch. Bending of the casters combined with slight uplift of the rear wheels, allowed the footrests to contact the sled and take some loading.

DUMMY: Head and chest accelerations were nominal. An early onset of lap belt load was recorded at 50 ms peaking at 2000 lbs. Head excursion was 48 inches.



Post Test
Conditions



Wheel
Damage

Test 1064

Figure A-40

TEST NUMBER: 1071

FACING DIRECTION: Side

SLED SPEED: 19.5 mph

CRASH PULSE: 12 g's

CHAIR TYPE: Manual

SECUREMENT

WHEELCHAIR: Fender

DUMMY: Lap belt to axle

TEST ACTION

The restraint system was very effective in retaining the chair and occupant with little excursion relative to the sled. The dummy's upper torso leaned sideways (in the direction of travel) striking the leading armrest with what appeared from the test movies to be considerable force.

TEST RESULTS

WHEELCHAIR: Damage to the chair was relatively minor. There was minor damage to the leading wheel and trailing side frame which was bent at the axle joint (Figure A-41).

DUMMY: The data traces indicate a relatively high lap belt load of 1300 lbs with early onset at 60 ms into the event. Although head and chest data traces show only nominal accelerations with no particular indication of injury (HIC = 186, T_1 = 114 ms, T_2 = 172 ms), sideways bending of the torso and impact of the ribs on the armrest could have resulted in severe injuries. Head excursion in the direction of travel was 39 inches.

Post Test Conditions

Trailing Side Damage

Test 1071

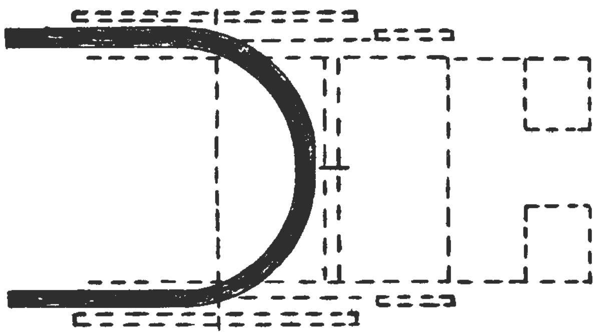
Figure A-41

User and Chair Belt

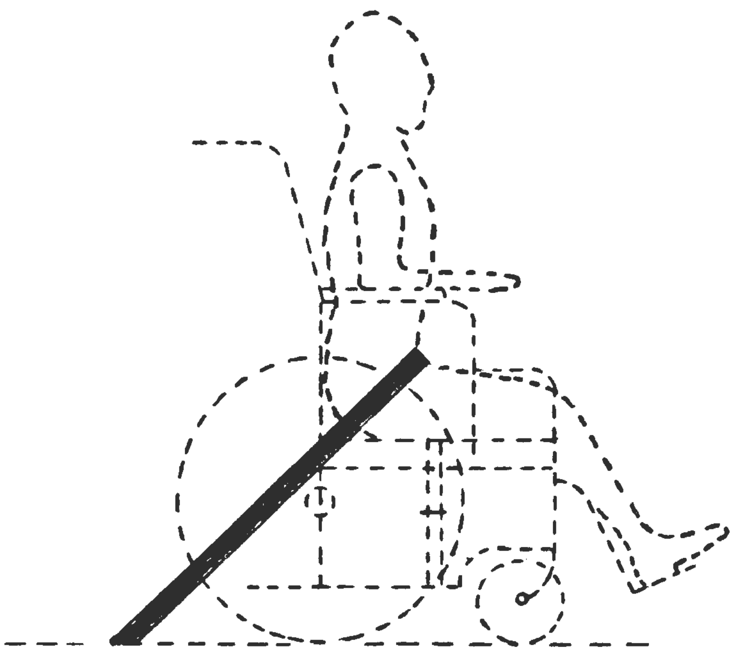
The user and chair belt consists of a regular automotive type seat belt anchored to the floor at an angle of approximately 45°. The free ends pass around the chair (passing between the arm assembly and backrest) and user, and latch in the lap area of the user. As the name implies, the single belt secures both the chair and the user (Figure A-42).

Five tests were conducted with the user and chair belt system:

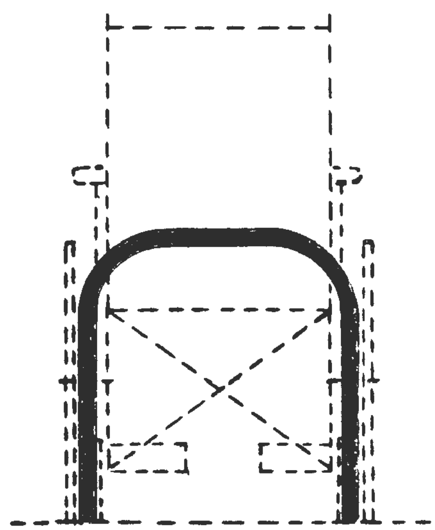
- o Three with a forward facing chair.
- o Two with a side facing chair.



PLAN VIEW



SIDE VIEW



FRONT VIEW

USER AND CHAIR BELT

Figure A-42

TEST NUMBER: 1079 | SLED SPEED: 19.8 mph

FACING DIRECTION: Forward | CRASH PULSE: 12 g's

CHAIR TYPE: Manual

SECUREMENT

WHEELCHAIR: User and chair belt

DUMMY: Same belt as chair securement

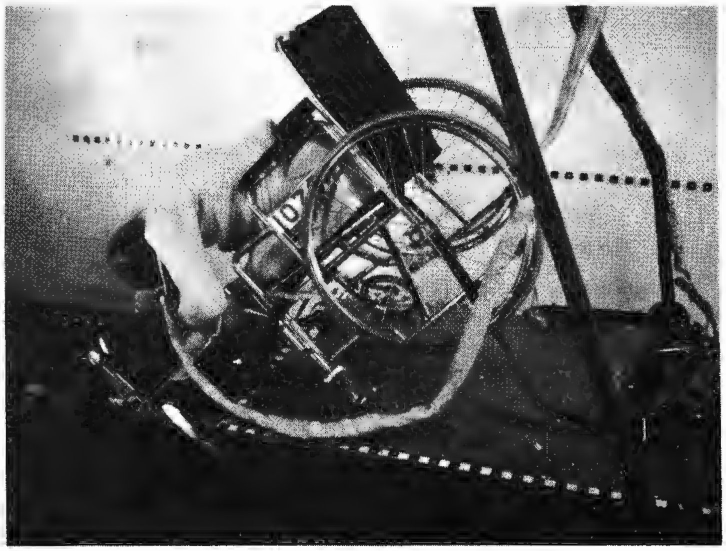
TEST ACTION

Model 774 elevating legrests were used on this chair as compared to the rigid type 770 used in most other tests. Upon impact, the legrests raised upward in the same manner as the dummy's legs. As the restraining belt load increased, the dummy's upper torso rotated forward into a jackknife position. The chair remained relatively motionless until the right end of the belt failed at the floor D-ring allowing the chair to rotate forward (Figure A-43).

TEST RESULTS

WHEELCHAIR: The draw bolt at the center of the cross brace bent into an S-shape allowing the side frames to splay out at the bottom. No other damage to the chair was noted.

DUMMY: Maximum floor belt load was measured at approximately 2000 lbs. The horizontal component of the approximately 45° belt (2 x 2000 x .707 = 2830 lbs) agrees well with the observed 15 g occupant chest acceleration [2830/(165 + 45) = 13.5 g] recorded between the 80 to 120 ms interval. The peak belt load is near the expected failure level for a single belt system using standard D-ring attachments. The high speed films showed that the elasticity of the hold-back belts allowed the chair to move back during sled run-up, which delayed onset loading of the belt and resulted in a final high belt load. The occupant suffered a moderate head strike (HIC = 500, T_1 = 180, T_2 = 182) apparently from an impact on its legs. Forward head excursion was 64 inches.



Test 1079--Post Test Conditions

Figure A-43

TEST NUMBER: 1086 SLED SPEED: 22.2 mph

FACING DIRECTION: Forward CRASH PULSE: 12 g's

CHAIR TYPE: Manual

SECUREMENT

WHEELCHAIR: User and chair belt

DUMMY: Same belt as chair securement

TEST ACTION

In this test the chair was equipped with rigid type 770 footrests. The loss of high-speed photography resulted in repeated tests of this system (see Tests 1079 & 1099). The rigid type footrests were not used in Tests 1079 and 1099 so that a comparison could be made. Based on a comparison of the time-lapse sequence photographs from all three tests, the footrests do not affect the action of the floor belt securement system.

Upon impact, the dummy's upper torso rotated forward into a jackknife position with arms and legs extended. The belts held throughout the test providing effective control over the chair and dummy.

TEST RESULTS

WHEELCHAIR: The chair side frames were undistorted. The rear post-test view (Figure A-44) shows the wheel splaying and up bending of the cross brace members caused by the high downward component of the occupant loading.

DUMMY: Maximum floor belt tension was measured at approximately 2400 lbs (4800 lbs on the dummy). As in Tests 1079 and 1099, the occupant suffered a sharp head strike (HIC = 424, T_1 = 182, T_2 = 184) probably due to a leg-head interaction. Head excursion was not measured but is assumed to be similar to that in Test 1079.

Test 1086--Post Test Conditions

Figure A-44

TEST NUMBER: 1099 SLED SPEED: 22.5 mph

FACING DIRECTION: Forward CRASH PULSE: 12 g's

CHAIR TYPE: Manual

SECUREMENT

WHEELCHAIR: User and chair belt

DUMMY: Same belt as chair securement

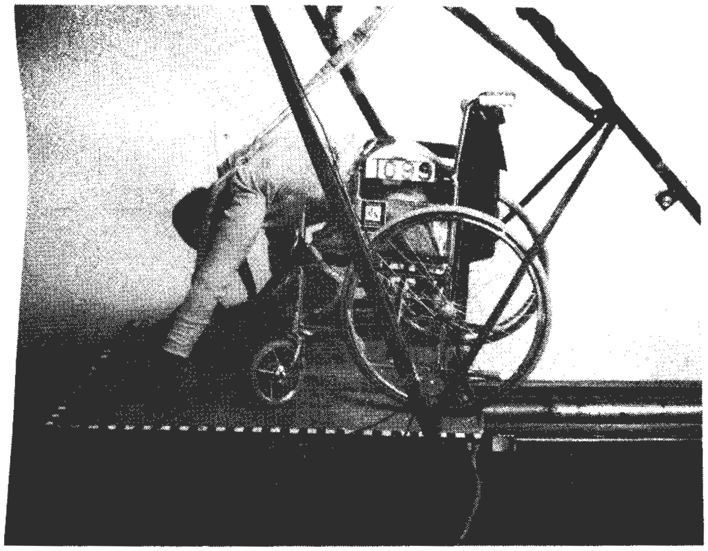
TEST ACTION

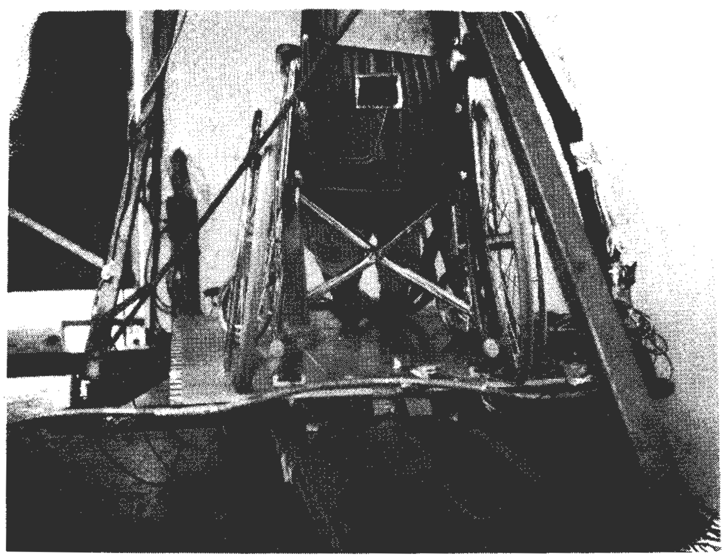
This was essentially a repeat of Test 1079 which experienced a failure in the securement belt. In this test, the footrests were removed. A breakaway push bar was used behind the chair backrest to eliminate rearward motion during sled run-up (acceleration). Upon impact, the dummy's upper torso rotated forward into a jackknife position with arms and legs extended. At about 160 ms into the event, the dummy's head appeared to have struck its legs. The belts held throughout the test providing effective control over the chair and dummy.

TEST RESULTS

WHEELCHAIR: Damage to the chair consisted of a torn seat at the forward edge and bending of the cross brace (Figure A-45) associated with the high downward load of the dummy.

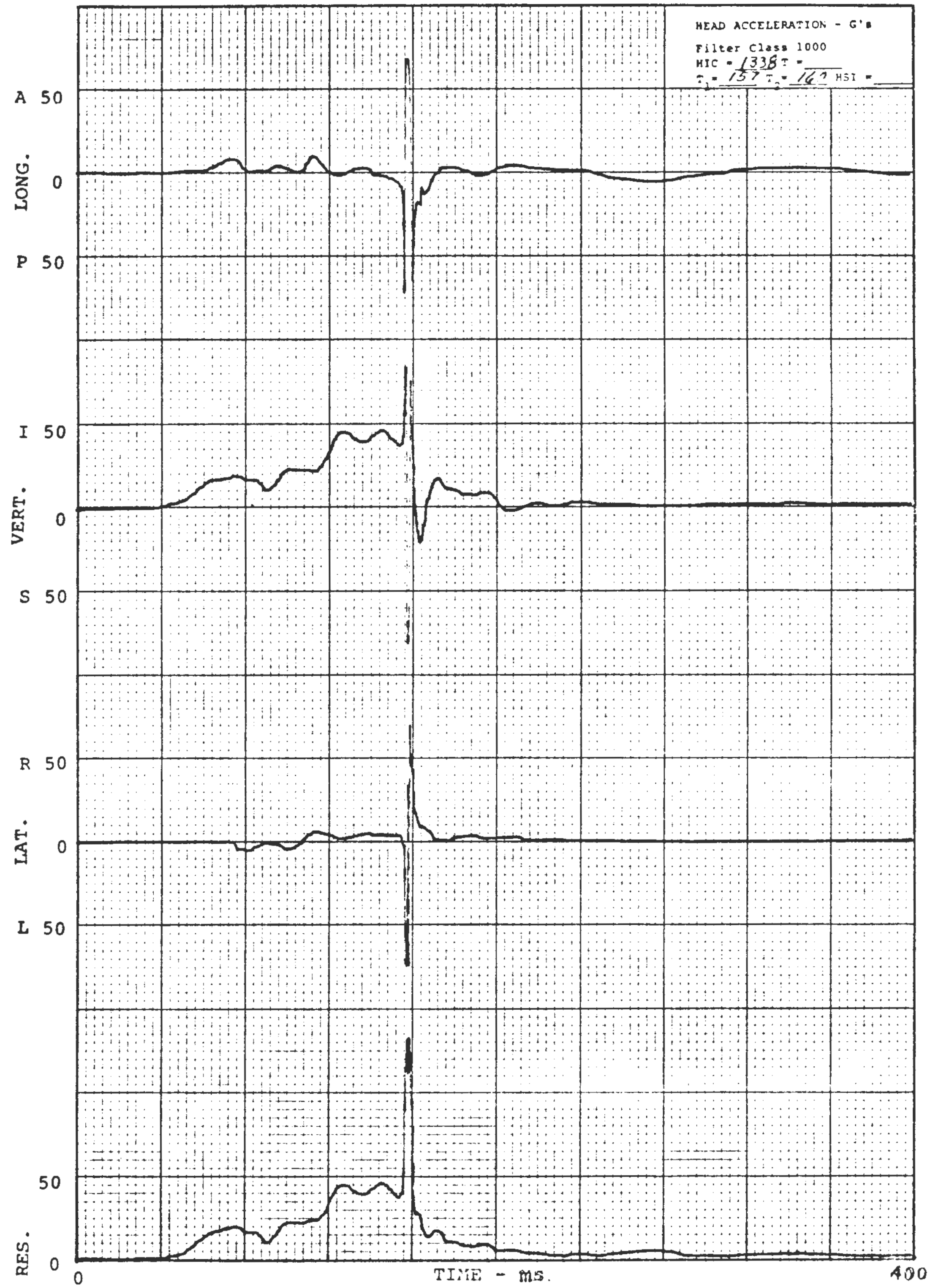
DUMMY: Maximum floor belt load was measured at approximately 2400 lbs (4800 lbs on dummy). The occupant suffered a severe head strike (HIC = 1338, T_1 = 157, T_2 = 160) apparently from an impact on its legs (Figures A-46 and A-47). Forward head excursion was 50 inches.





Test 1099--Post Test Conditions

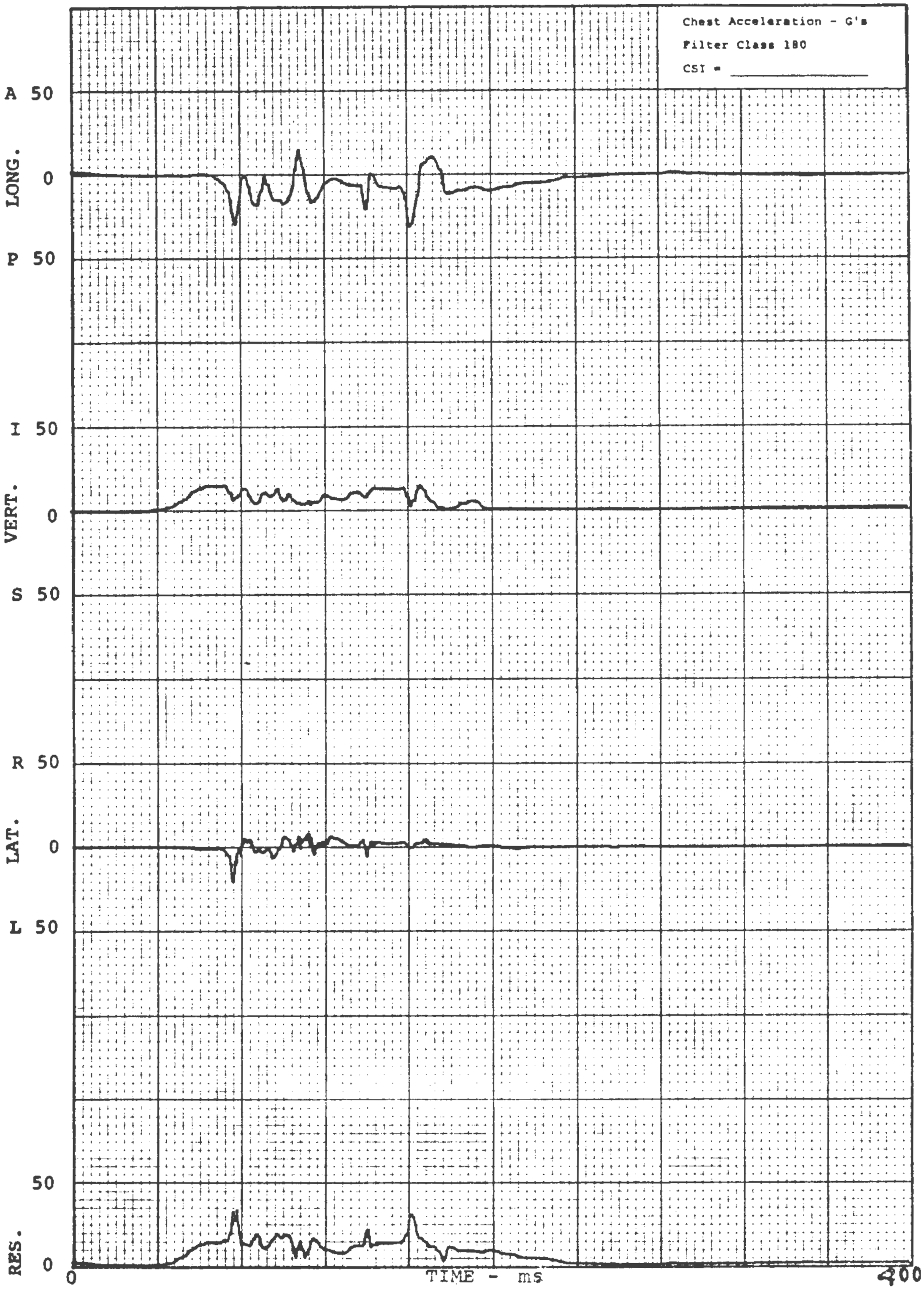
Figure A-45



Head Acceleration Graphs

Test 1099

Figure A-46



Chest Acceleration Graphs

Test 1099

Figure A-47

TEST NUMBER: 1078 SLED SPEED: 16.5 mph

FACING DIRECTION: Side CRASH PULSE: 10 g's

CHAIR TYPE: Manual

SECUREMENT

WHEELCHAIR: User and chair belt (no wall behind chair)

DUMMY: Same belt as chair securement

TEST ACTION

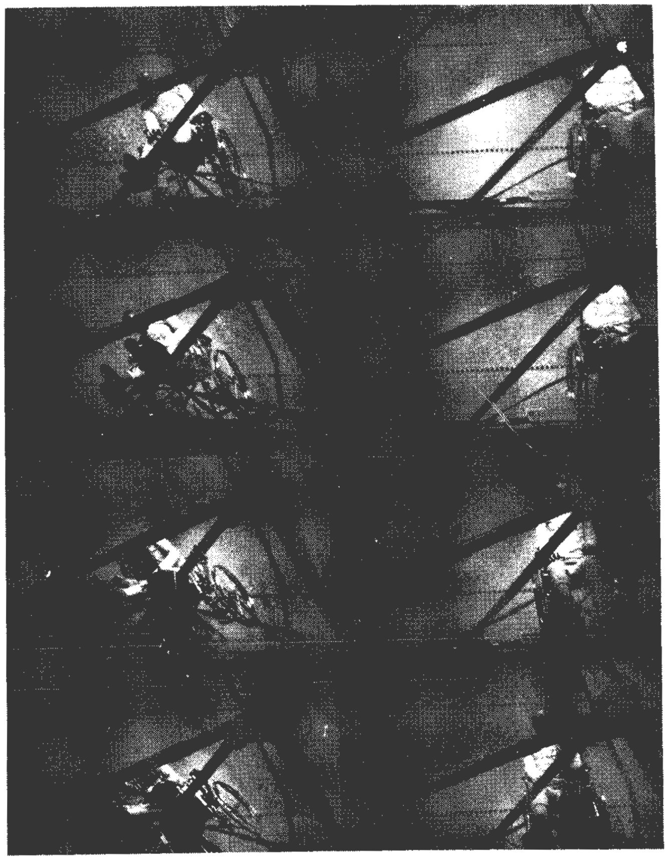
In actual practice, this securement is commonly used with the rear wheels of the chair placed against the wall of the vehicle. A wall behind the chair was not included in this test. Upon impact, the chair and occupant tipped in the direction of travel over the leading wheel and caster. The dummy then swung backwards over the belt anchor points lifting the casters off the platform (see Figure A-48). The dummy and chair came to rest against the nearby wall of the test building. From the marks and gouges made in the wall by the chair backposts, the travel of the chair and occupant would have been much greater in a free environment.

Refer to Test 1098 for a test of the same system with the addition of a wall directly behind the rear wheels of the chair.

TEST RESULTS

WHEELCHAIR: Wheelchair damage was limited to a bent lower right (leading) wheel and a slight inward bending of the right bottom rail (Figure A-49).

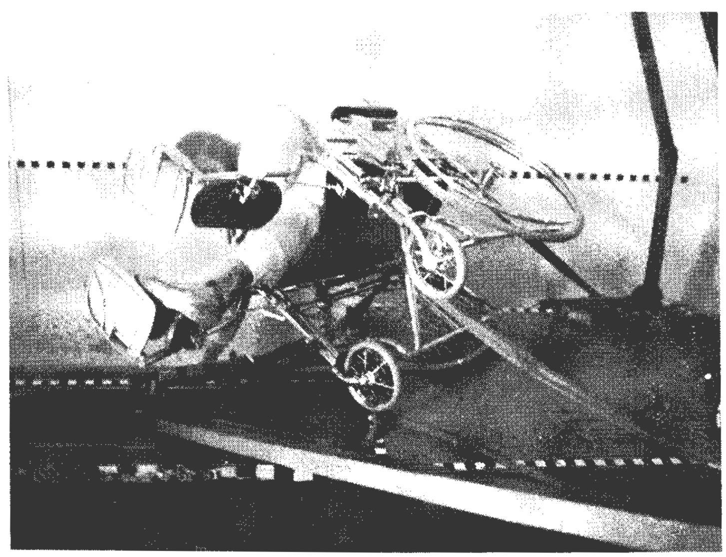
DUMMY: The dummy remained with the chair as it rotated forward and to the side. Forward excursion of the head relative to its initial position on the sled was 44 inches. Instrumentation was not provided to measure dummy accelerations. Belt loads were moderate with a maximum of 650 lbs tension in the trailing belt.

5  1

6 2 7 3 8 4

Test 1078--Sequence

Figure A-48



Test 1078--Post Test Conditions

Figure A-49

TEST NUMBER: 1098

FACING DIRECTION: Side

SLED SPEED: 10.5 mph

CRASH PULSE: 12 g's

CHAIR TYPE: Manual

SECUREMENT

WHEELCHAIR: User and chair belt (with wall behind chair)

DUMMY: Same belt as chair securement

TEST ACTION

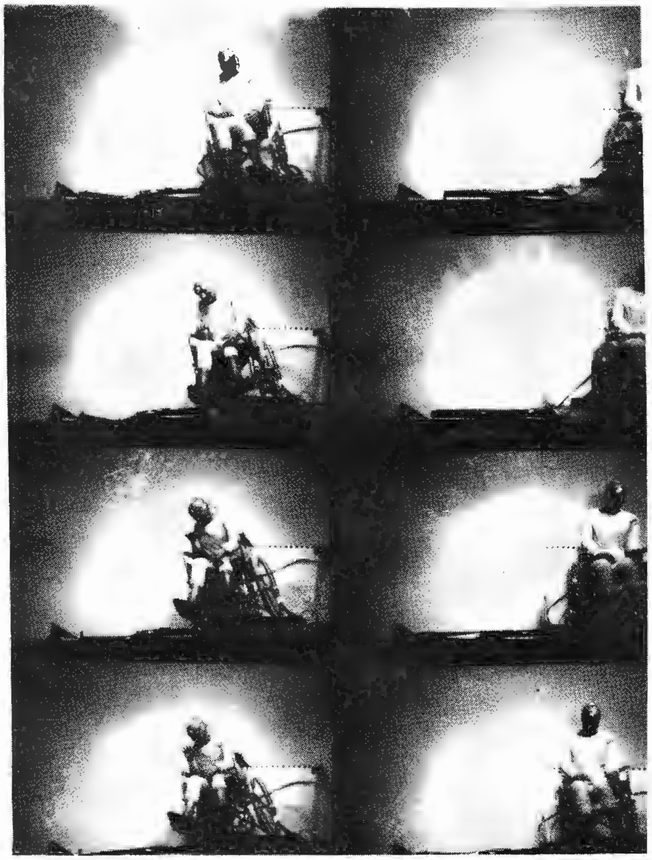
This test was essentially a repeat of Test 1078 with the addition of a wall behind the rear wheels of the chair. During the test, the chair and occupant tipped in the direction of travel and rotated about the leading belt (Figure A-50). Lift of the rear wheel and casters was moderate compared to that in Test 1078. The leading backpost lightly contacted the wall about 23 inches downrange of the original occupant centerline.

The dummy remained seated in the chair. At the end of the event, the chair was on its wheels with the casters rotated slightly forward (Figure A-51).

TEST RESULTS

WHEELCHAIR: The leading wheel of the chair was bent under about 2 inches at the floor (Figure A-52).

DUMMY: Forward excursion of the head relative to the initial position on the sled was 44 inches. Head and chest accelerations were nominal (HIC = 8, T_1 = 117 ms, T_2 = 302 ms). Maximum belt load was measured as 900 lbs tension in the trailing belt.

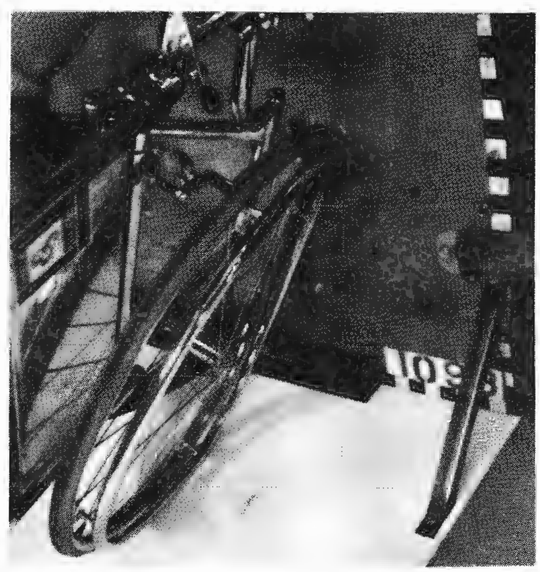


Test 1098--Sequence

Figure A-50

Test 1098--Post Test Conditions

Figure A-51



Test 1098--Wheel Damage

Figure A-52

Three-Point Belt

The California regulations for student transportation require a three-point system for wheelchairs. The most popular method for satisfying the three-point requirement is to use slotted tracks, locking brackets that fit into the tracks, and web belts (the same type of equipment normally used in air cargo securement). The system tested consisted of three separate automotive type belts--2 inches wide, 7% polyester webbing--attached to the frame of the chair, one near one of the front casters and the other two in the vicinity of the rear wheel axles, one on each side of the frame (Figure A-53). Each belt was anchored to the floor, at an angle of approximately 60 degrees, either forward or rearward of the attachment point on the chair. The belt buckles were adjusted snug so as to oppose each other, to restrict fore and aft movement of the chair.

Two tests--one forward and one side facing chair--were conducted with the three-point belt system.

Three Point Belt

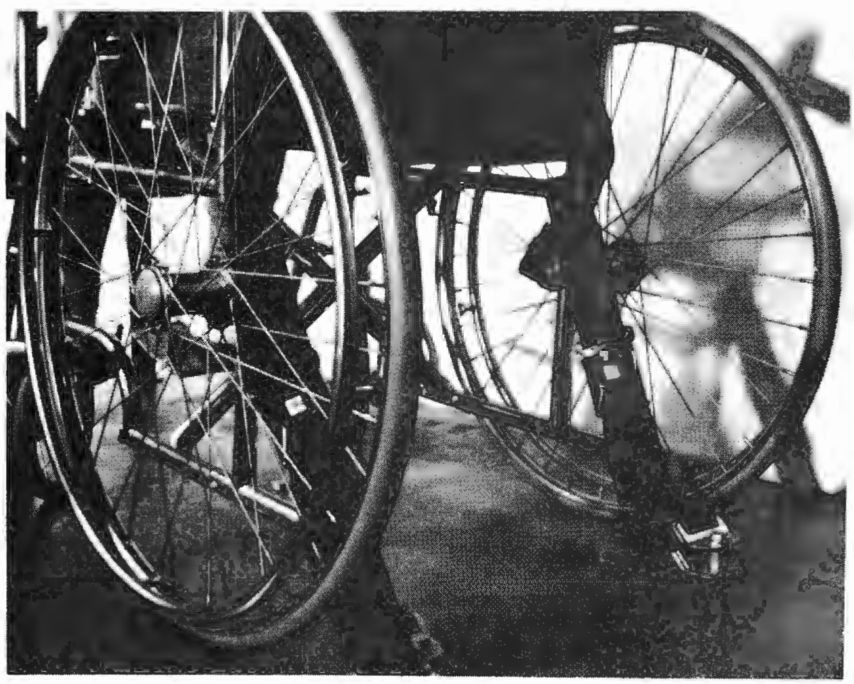


Figure A-53

TEST NO: 1183 SLED SPEED: 20.1 mph

FACING DIRECTION: Forward CRASH PULSE: 12 g's

CHAIR TYPE: Manual

SECUREMENT

WHEELCHAIR: Three-point belt

DUMMY: Lap belt to axle

This was the first test using obstructions to simulate the envelope at the wheelchair station inside most 35 to 40-foot buses.

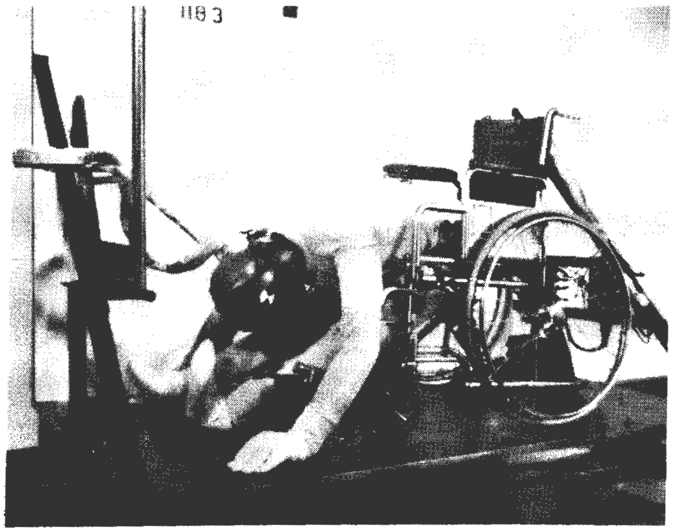
TEST ACTION

Upon impact the dummy slid forward on the seat taking up slack in the lap belt. As the lap belt loaded, the dummy jackknifed forward with hands and legs extended. The dummy's right hand and left arm struck the forward obstruction. The head cleared the obstruction. As the upper torso rotated forward and down, the head struck the dummy's legs.

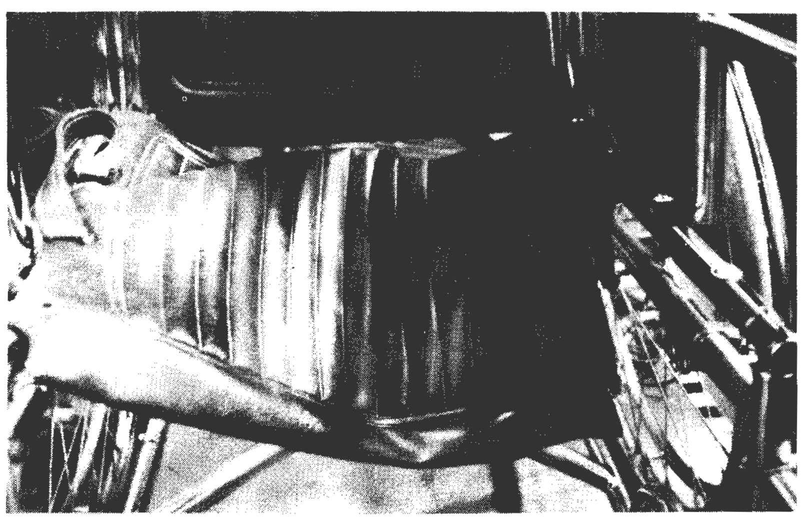
TEST RESULTS

WHEELCHAIR: The forward portion of the seat tore away from the anchorage to the top rail (Figure A-54). Figure A-54 also shows the wheel splaying and the cross frame members bending upward.

DUMMY: The data recorded a minor head strike (HIC = 306, T_1 = 10, T_2 = 128). Maximum head excursion was 50 inches. Maximum recorded tension in the seat belt was 450 lbs.



Test 1183--Post Test Conditions



Test 1183--Seat Damage

Figure A-54

TEST NO: 1184

FACING DIRECTION: Side

SLED SPEED: 20.1 mph

CRASH PULSE: 10 g's

CHAIR TYPE: Manual

SECUREMENT

WHEELCHAIR: Three-point belt

DUMMY: Lap belt to axle

TEST ACTION

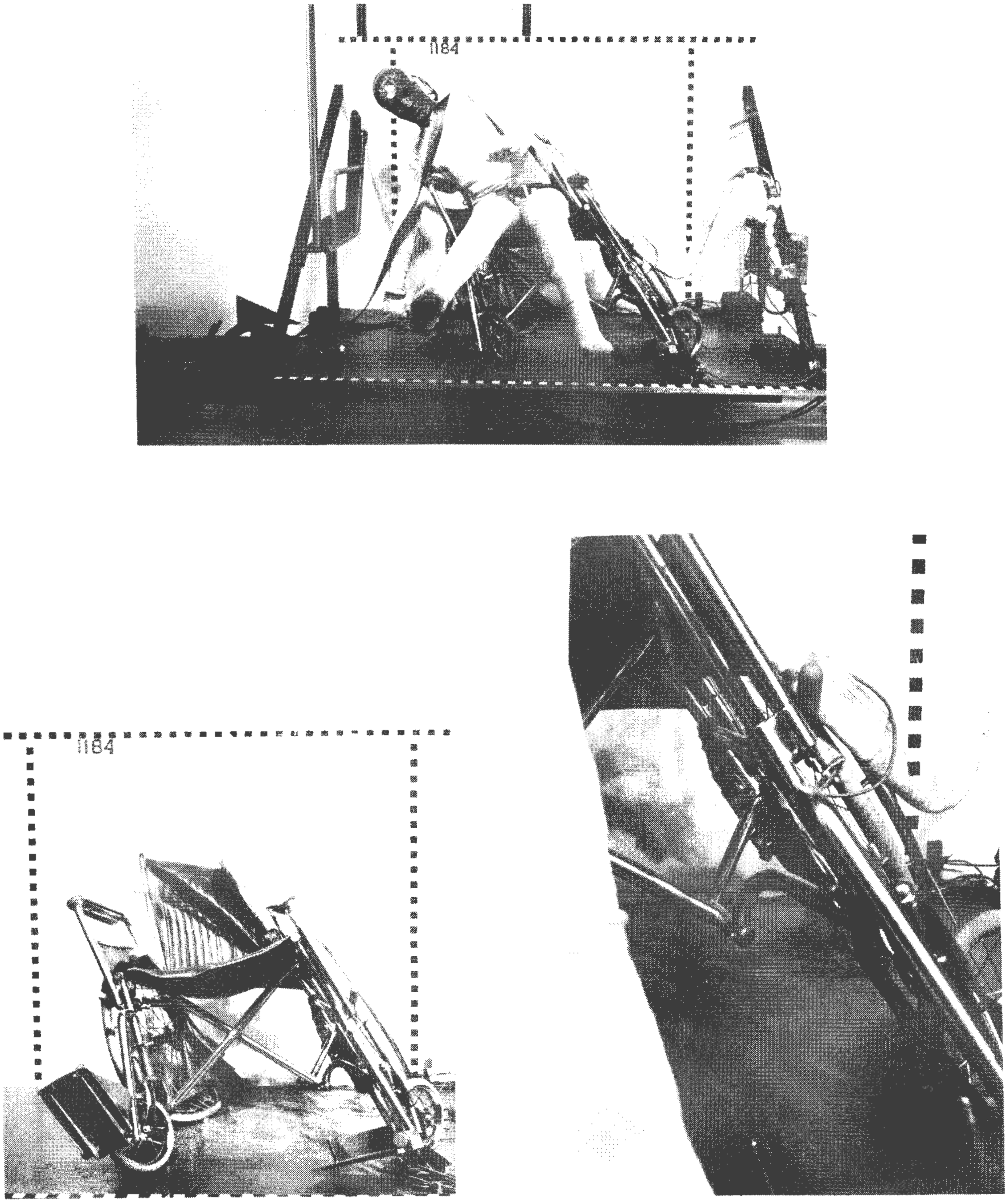
The chair and occupant twisted sideways in the direction of travel, racking the chair frame sideways at an angle of approximately 45 degrees. As the dummy continued to twist sideways over the chair armrest, its head struck a hard blow first on the wall support bracket and then on the obstruction armrest.

It became obvious from this test that the wall support bracket was improperly placed. Consequently, the bracket was subsequently modified for other tests. However, the head would have struck the armrest even though the brace had not been present.

TEST RESULTS

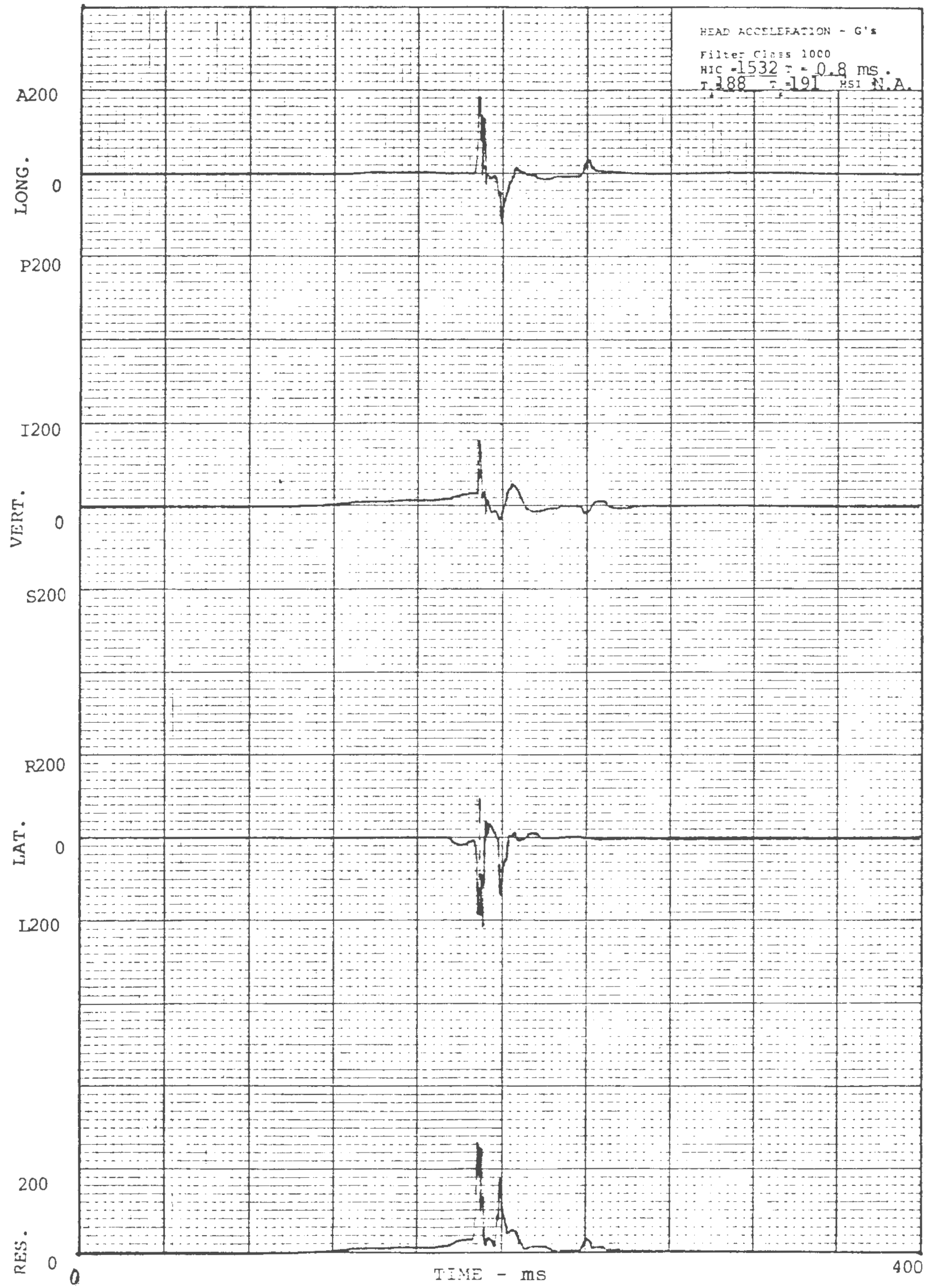
WHEELCHAIR: The chair was severely distorted sideways, bending the bottom rail of the aft side frame inwards (Figure A-55). The large leading wheel was bent under the side frame. Load cells on the trailing floor belts registered maximum loads of 850 lbs in the left caster belt and 500 lbs in the right rear axle belt.

DUMMY: The blow to the side of the head on the obstruction registered acceleration (Figure A-56) which indicated fatal injury (HIC = 1532, T_1 = 188, T_2 = 191).



Test 1184--Post Test Conditions

Figure A-55



Head Acceleration Graphs

Test 1184

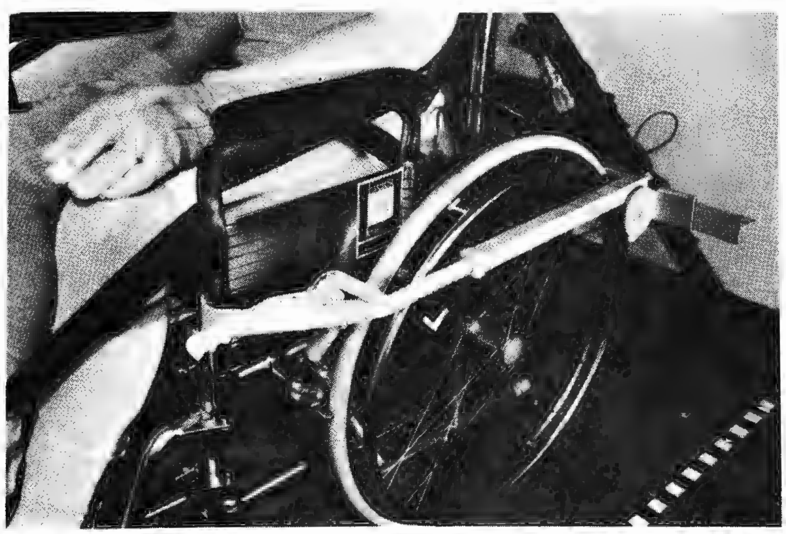
Figure A-56

Horizontal Bars

The horizontal bar system consists of two bars, one along each side of the wheelchair. Each bar is anchored to a keeper bracket (which is anchored to the vehicle) on one end and to the chair frame by a hook on the other. Bar length is adjustable by a ratchet assembly; final adjustment for snugness is made with an over-center lever lock; bar spacing is varied by sliding the anchored end along a keeper bracket. The anchor points to the chair are preferrably located such that the hooks can be attached to the front frame near the level of the chair's seat area (Figure A-57).

In the tests, the hook was attached to the forward portion of the arm assembly on a line just above the plane of the rear wheel axles. The ratchet was adjusted so that the over-center lock applied a slight preload to the chair.

Four tests were conducted with the horizontal bars securement system; two with forward facing and two with side facing chairs. The system was modified for two of the tests.



Horizontal Bars

Figure A-57

TEST NO: 1185 | SLED SPEED: 20.0 mph

FACING DIRECTION: Forward | CRASH PULSE: 10 g's

CHAIR TYPE: Manual

SECUREMENT

WHEELCHAIR: Horizontal bars

DUMMY: Lap belt to axles

TEST ACTION

As the sled began to decelerate, the dummy slid forward on the seat taking up slack in the seat belt. Loads in the seat belts were transferred through the chair frame to the horizontal bars. Application of load to the horizontal bars caused bending in both chair armrests. Bending in the armrests allowed the rear wheels to raise up (approximately 6 inches) off the sled until the wheels contacted the keeper bracket. As load was applied, the right horizontal bar anchor hook straightened out (Figure A-58) releasing the chair.

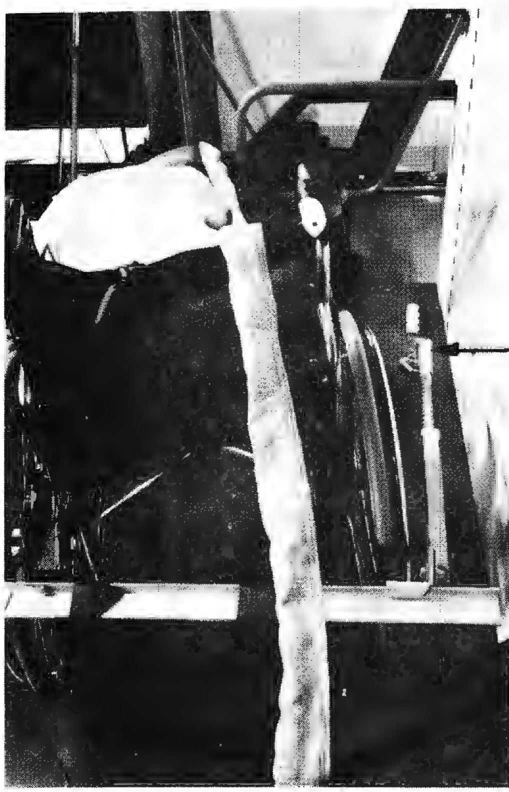
TEST RESULTS

WHEELCHAIR: Damage to the chair was minor (Figures A-59 and A-60). The left forward portion of the seat tore away from the anchorage to the top rail. The armrest suffered minor bending and crushing at the point of attachment of the horizontal bar.

DUMMY: Maximum seat belt tension and head excursions were measured. However, data is not applicable because the horizontal arms detached allowing a backup system of belts to restrain the chair. The backup system was used to protect test equipment. Refer to Test 1191 for applicable results.

Center: Before
Testing

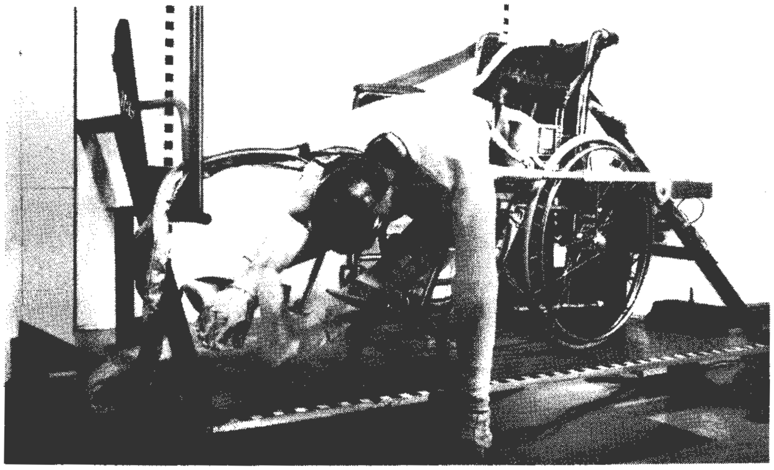
Sides: After
Testing



Note Disengaged
Arm

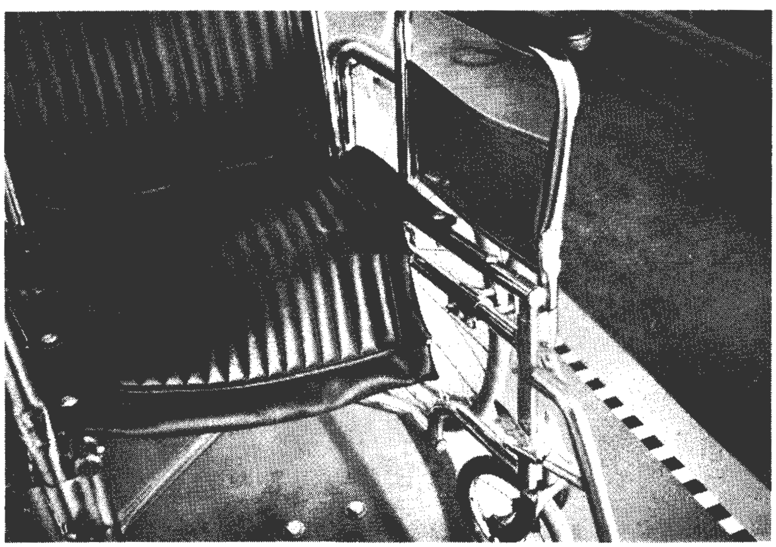
Test 1185--Anchor "Hook" Straightened

Figure A-58



Test 1185--Post Test Condition

Figure A-59



Test 1185--Chair Damage

Figure A-60

TEST NO: 1186

FACING DIRECTION: Side

SLED SPEED: 19.9 mph

CRASH PULSE: 12 g's

CHAIR TYPE: Manual

SECUREMENT

WHEELCHAIR: Horizontal bars

DUMMY: Lap belt to axles

TEST ACTION

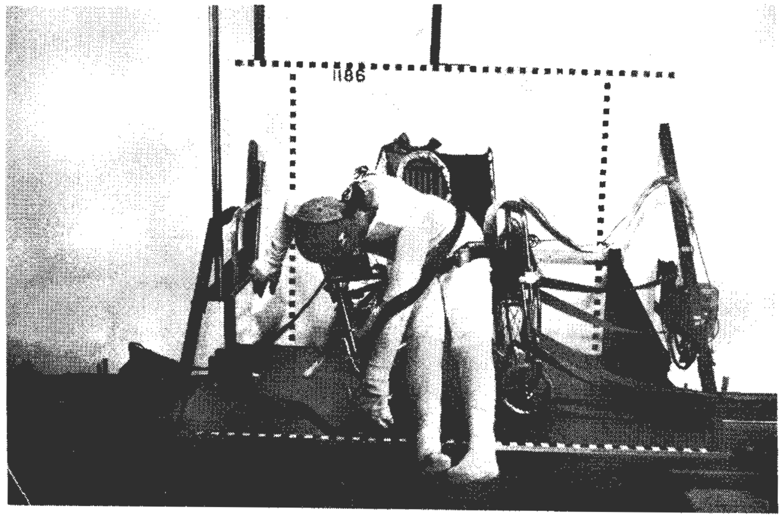
Footrests were removed from the wheelchair during this test but there was no indication that the removal affected the results. Upon impact, the chair swung sideways in the direction of travel and tipped slightly downrange. The rear anchorages of the horizontal bars slid downrange along the keeper bracket, allowing load to be taken by a backup system of belts attached to the left or aft side of the chair frame.

TEST RESULTS

WHEELCHAIR: The wheelchair side frames were separated (Figure A-61) tearing the seat along its right attachment. The right (downrange) armrest was bent outward. Also, the top of the large right wheel was bent outwards.

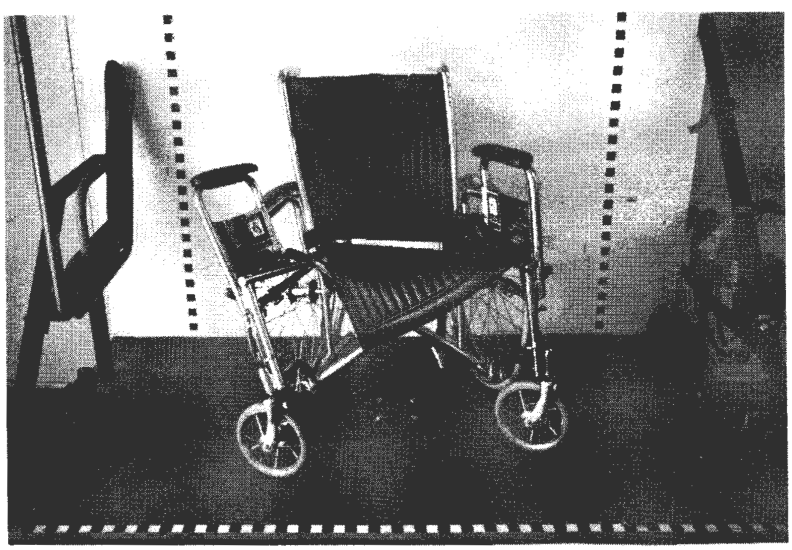
Damage to the wheelchair was probably compounded when the backup belt system (Figure A-62) restrained the aft side of the chair.

DUMMY: Head excursion, belt loads and injury criteria were measured but are not applicable due to the effects of the backup system. See Test 1193 for applicable results.



Test 1186--Post Test Conditions

Figure A-61



Test 1186--Chair Damage

Figure A-62

TEST NO: 1191 SLED SPEED: 20.0 mph

FACING DIRECTION: Forward CRASH PULSE: 10 g's

CHAIR TYPE: Electric Powered

SECUREMENT

WHEELCHAIR: Modified horizontal bars

DUMMY: Lap belt to axles

TEST ACTION

The securement system used in this test is a modification of the sytem used in Test 1185. Reinforcement was added to the attachment hook (Figure A-63) to prevent straightening. A rubber strip was also added to the hook to increase friction and reduce slippage. A heavier electric-powered chair was used in this test, whereas a manual type was used in Test 1185.

Action was very similar to that in Test 1185. The dummy slid forward in the chair, which applied load through the chair to the horizontal bars, and caused bending in the armrests. The anchor hooks held throughout the forward excursion; however, on rebound, the horizontal bars fell away due to slack resulting from armrest deformation (Figure A-64).

The dummy jackknifed forward and down with its head between its legs. The left hand struck the stanchion and the right hand struck the obstruction armrest.

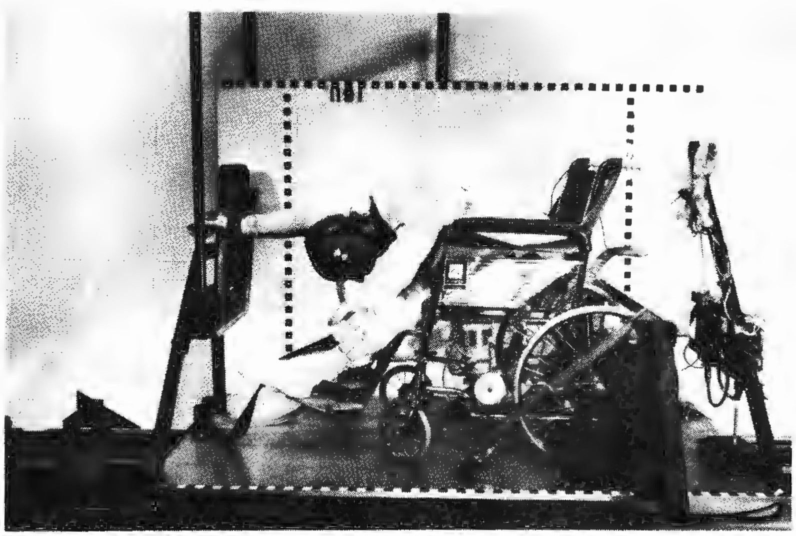
TEST RESULTS

WHEELCHAIR: Bending and crushing of the armrest was more extensive (Figure A-65) than in Test 1185.

DUMMY: A maximum head excursion of 43 inches was measured. Peak seat belt load was recorded at 500 lbs (1000 lbs on the dummy). Although significant head strikes were not noted, head injury criteria calculated from acceleration (Figure A-66) was fairly high in the minor range (HIC = 352, T_1 = 118, T_2 = 230).

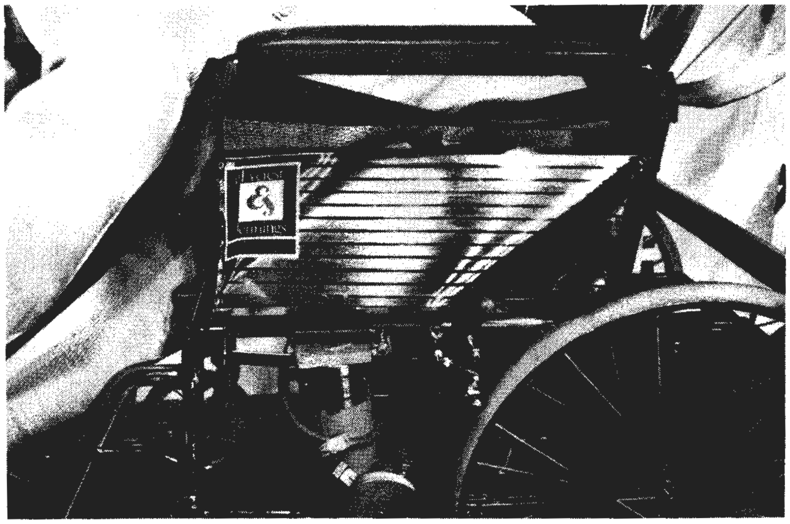
Modified Horizontal Bar Hook

Figure A-63



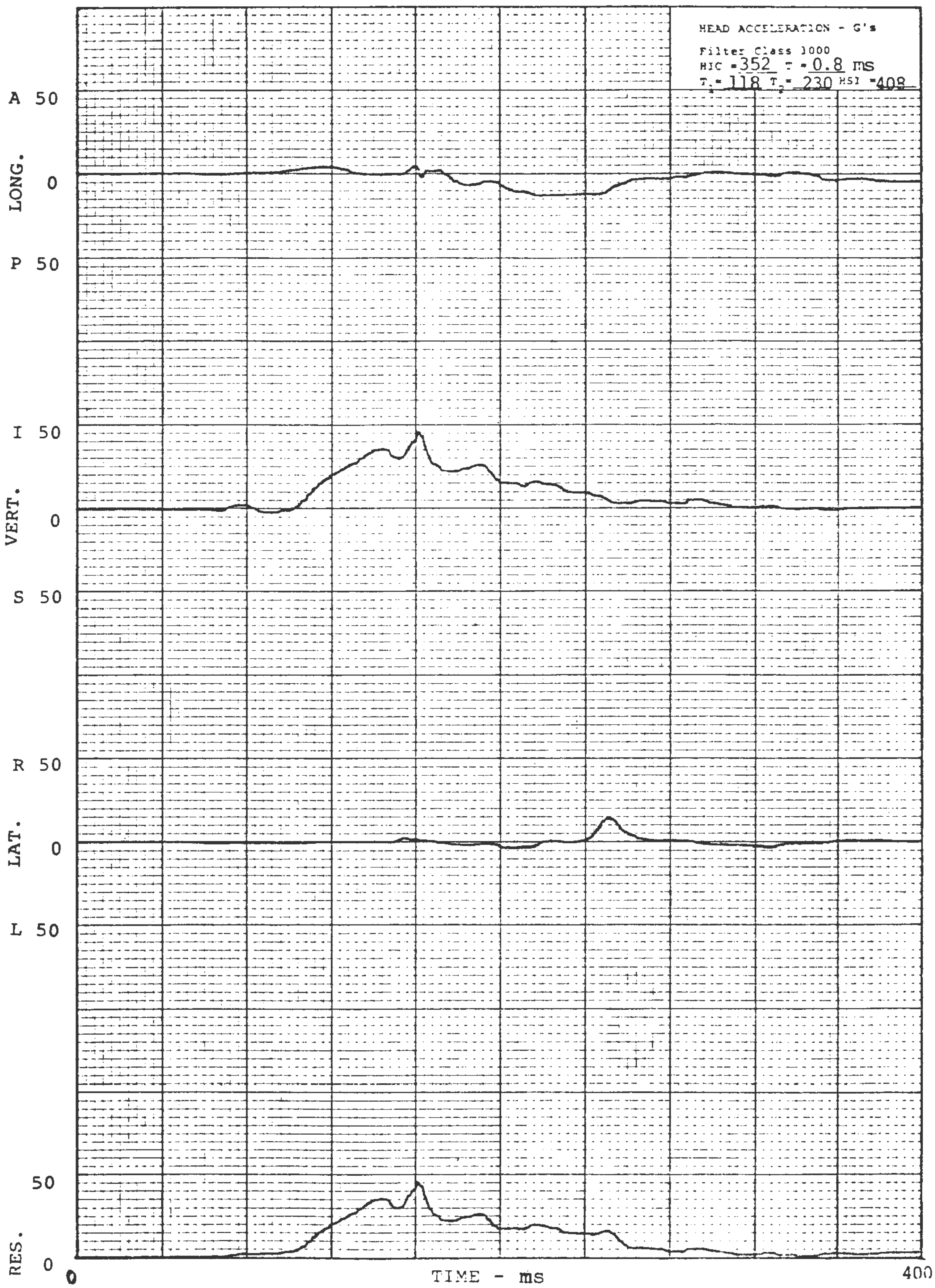
Test 1191--Post Test Conditions

Figure A-64



Test 1191--Armrest Damage

Figure A-65



Head Acceleration Graphs

Test 1191

Figure A-66

TEST NO: 1193

SLED SPEED: 20.0 mph

FACING DIRECTION: Side

CRASH PULSE: 10 g's

CHAIR TYPE: Electric Powered

SECUREMENT

WHEELCHAIR: Modified horizontal bars

DUMMY: Lap belt to axles

TEST ACTION

The securement system used in this test is a modification of the system used in Test 1186. In addition to the hook reinforcement and friction material described in Test 1191, bolts were installed in the keeper bracket to prevent excessive forward slippage of the horizontal bar anchorages. The bolts were located to permit 3 inches of lateral adjustment at each anchorage for positioning and chair width compensation.

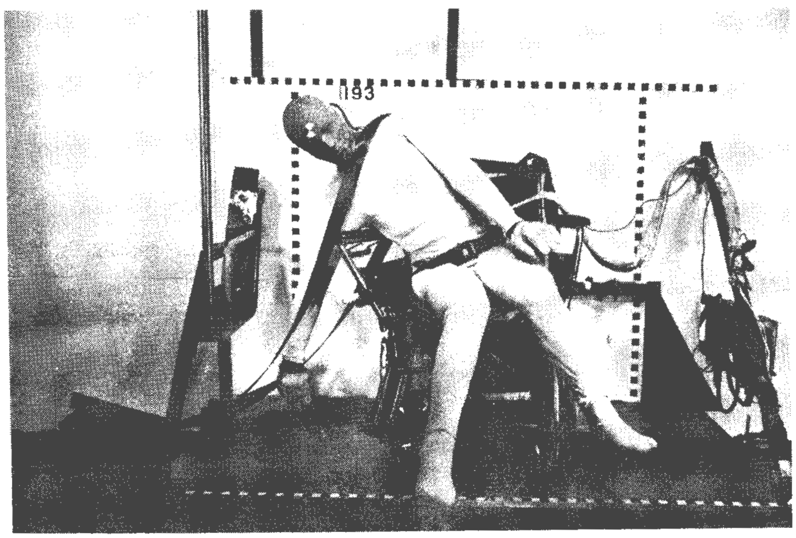
Upon impact, the chair slid sideways on the sled swinging in an arc about the horizontal bar anchorage points. The dummy continued in a downrange direction rotating sideways over the chair armrests until the upper torso was nearly horizontal (Figure A-67). The dummy's head struck a hard blow on the back cushion of the obstruction (Figure A-68). The right hand hit a glancing blow on the obstruction armrest and the left elbow hit the back wall.

The horizontal bars remained in contact with the chair throughout the incident.

TEST RESULTS

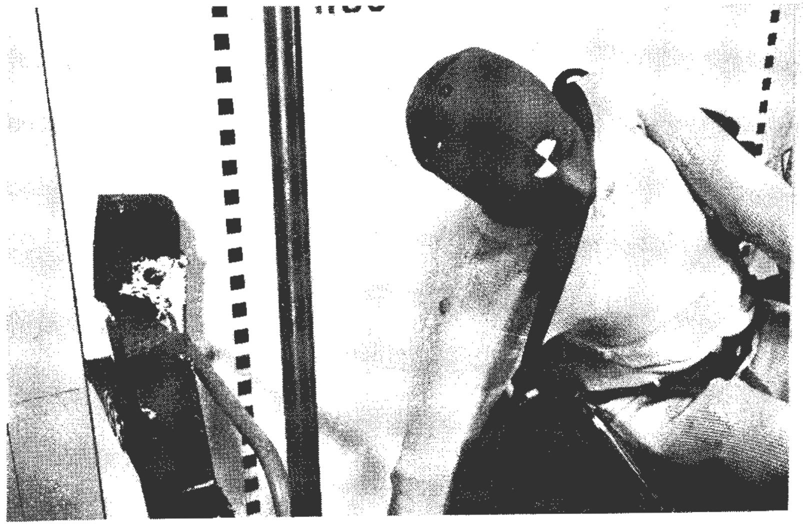
WHEELCHAIR: The right armrest was severely bent downrange (Figure A-69). The left armrest was crushed at the securement attachment point and bent outward (aft). The right rear wheel was bent inward below the axle. Extensive bending and twisting occurred in the lower framework.

DUMMY: The head strike on the forward obstruction registered accelerations resulting in a minor head injury criteria (HIC = 286, T_1 = 15, T_2 = 242). Maximum head excursion was 58 inches. Seat belt load peaked at 1200 lbs. Sideways bending of the torso was extreme, indicating the potential for injury.



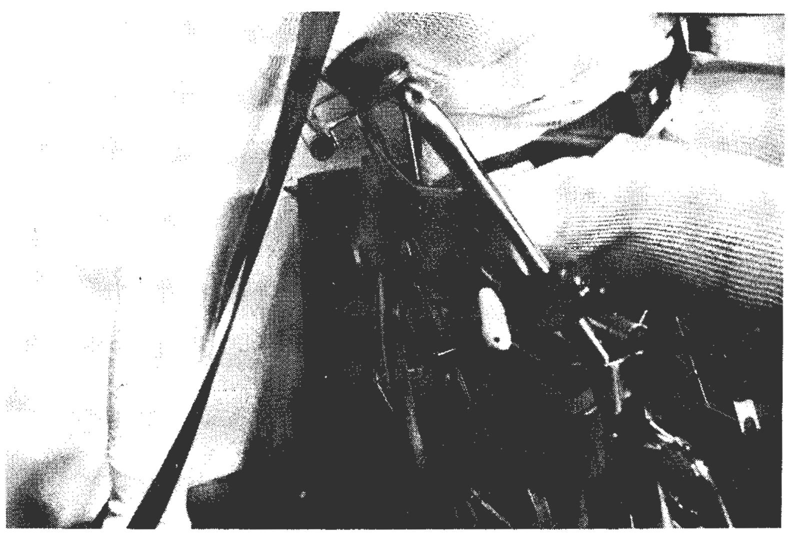
Test 1193--Post Test Conditions

Figure A-67



Test 1193--Head Strike

Figure A-68

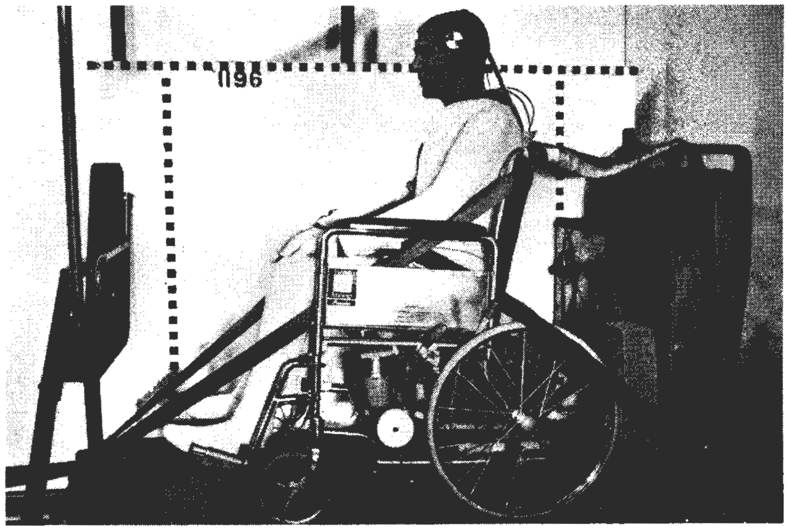


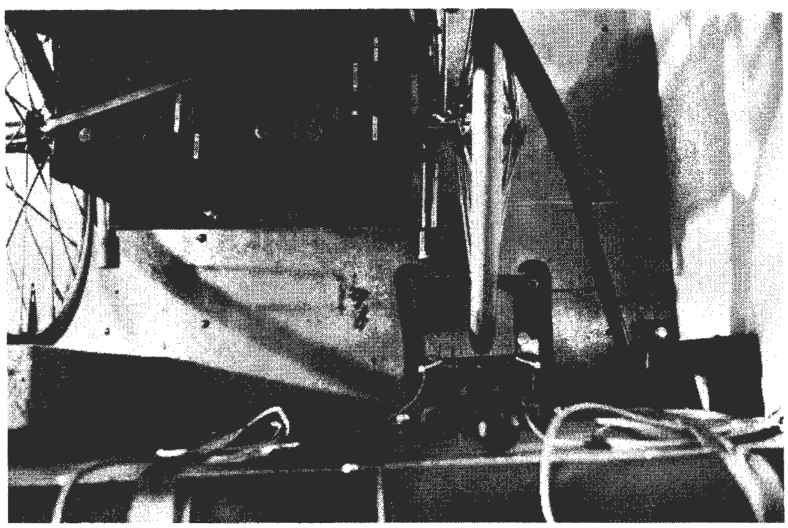
Test 1193--Armrest Damage

Figure A-69

Single Rim Latch

The single rim latch consists of gripper like jaws that fit around the rim of one of the large diameter wheels. The grippers are usually mounted on the underside of a folding seat, and about 13 inches from the floor when the seat is in the foldup position. When one of the large rear wheels is backed into the center portion of the single rim latch system a spring activates the grippers to close around the wheel. Lap or lap and torso belt securements for the wheelchair user are available as optional securement (Figure A-70).





Single Rim Latch

Figure A-70

TEST NO. 1187

SLED SPEED: 19.8 mph

FACING DIRECTION: Forward

CRASH PULSE: 11 g's

CHAIR TYPE: Manual

SECUREMENT

WHEELCHAIR: Single rim latch

DUMMY: Lap belt to axles

TEST ACTION

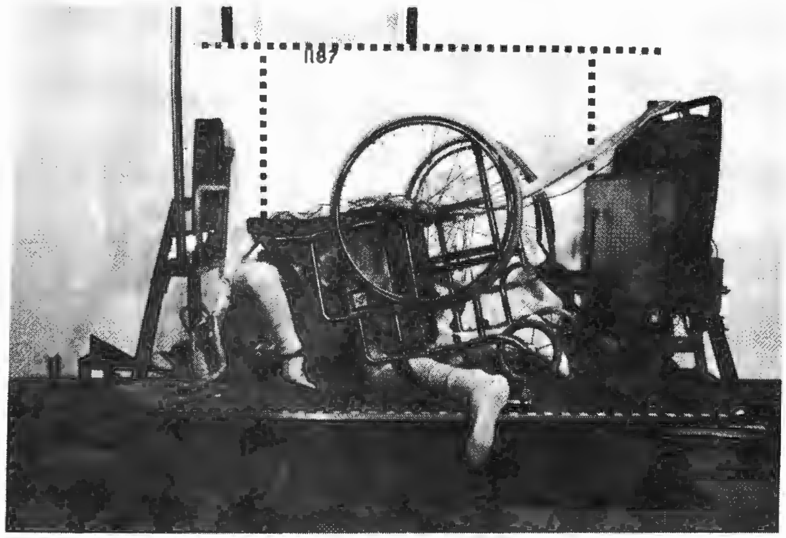
The wheelchair slid forward as the sled decelerated, causing the securement seat to unfold (downward movement). The unfolding motion of the seat forced the grippers downward against the rim of the wheel and caused the grippers to unlatch. The grippers' unlatching occurred without a noticeable change in the chair's velocity, indicating that the force to cause unlatching was small. After the grippers unlatched, restraint of the chair was maintained by a backup belt attached to the right rear wheel.

As the dummy and chair continued forward, the dummy's shoulder struck a hard blow on the stanchion, rebounded off and turned over face down on the sled. During this, the head struck a glancing blow on the obstruction armrest (Figure A-71).

TEST RESULTS

WHEELCHAIR: The backup belt restrained the wheelchair (Figure A-72) bending the right rear wheel rim and breaking several spokes.

DUMMY: Head excursion, belt loads and injury criteria are not applicable as they were a result of backup belts and not the primary system.



Test 1187--Post Test Conditions

Figure A-71

Test 1187--Right Rear Wheel

Figure A-72

TEST NO: 1196

FACING DIRECTION: Forward

SLED SPEED: 19.9 mph

CRASH PULSE: 10 g's

CHAIR TYPE: Electric Powered

SECUREMENT

WHEELCHAIR: Single rim latch

DUMMY: Externally anchored lap and shoulder harness

TEST ACTION

As in Test 1187, the wheel grippers unlatched without slowing the chair. Strain gauges mounted on the grippers registered a maximum load of 150 lbs at release. Similar to Test 1190, the chair continued forward bending the chair back as load was transferred through the dummy to the harness.

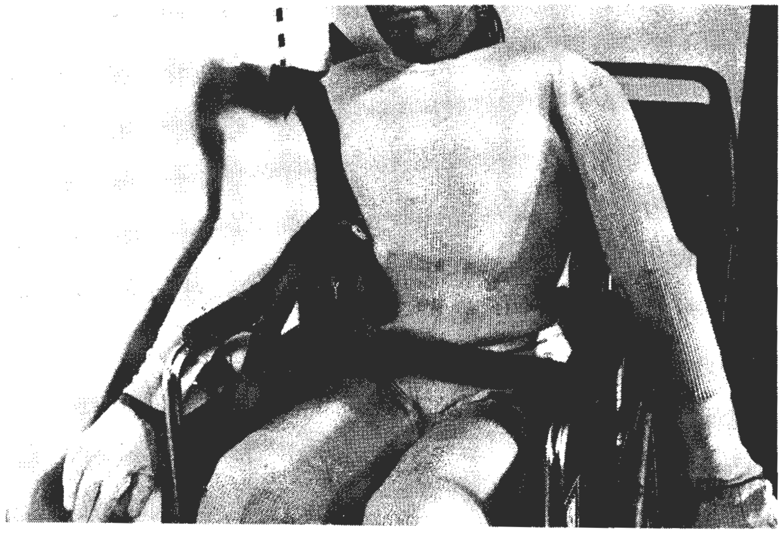
The lap belt was equipped with a spring reel (non-locking) retractor on the left half and a ratchet type (locking) retractor on the right half. In order to have an effective lap belt, the left half was pulled out to the full extent of the reel before latching with the right half. This improperly placed the mating point of the shoulder belt to the same side of the dummy as the shoulder over which the belt passed, thereby causing the belt to approximately parallel the dummy's side (Figure A-73).

The dummy's arms and upper torso extended forward to near horizontal. The shoulder belt, which was equipped with a spring reel (non-locking), provided very little restraint to the upper torso. As the torso rotated forward, the head struck the dummy's right leg (Figure A-74).

TEST RESULTS

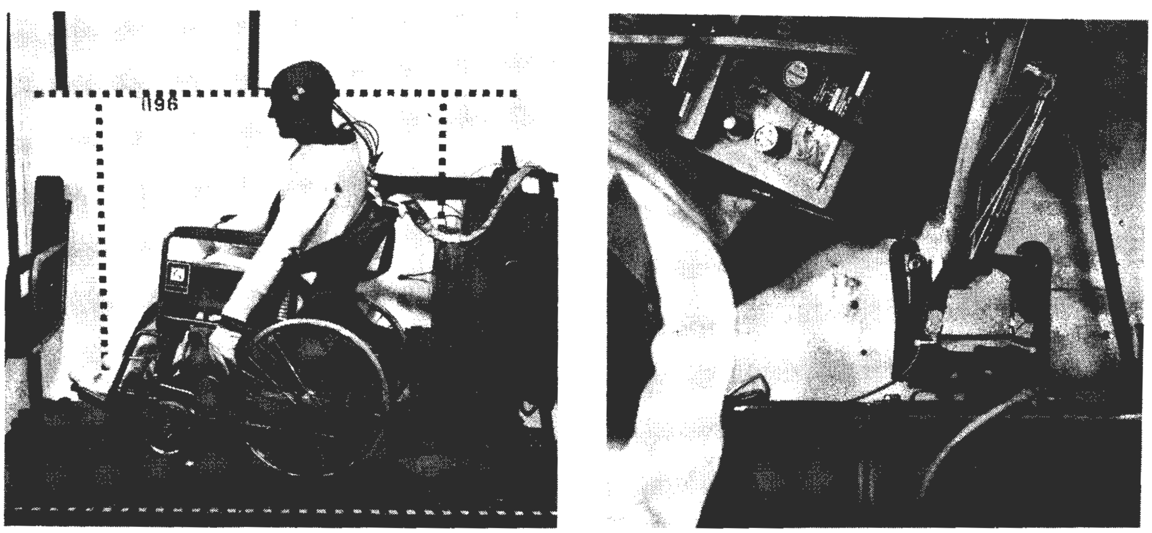
WHEELCHAIR: The chair backposts were bent aft approximately 20 degrees, separating the seat slides from the backposts. Bending also occurred in the right rear wheel.

DUMMY: Maximum head excursion in the direction of travel was 34 inches. Recorded head accelerations confirmed the head strike on the dummy's leg of a relatively moderate nature (HIC = 622, T_1 = 164, T_2 = 166). Lap belt load reached a maximum of 1400 lbs (2800 lbs on dummy).



Test 1196--Lap and Shoulder Harness

Figure A-73



Test 1196-- Post Test Conditions

Figure A-74

TEST NO: 1197 SLED SPEED: 19.9 mph

FACING DIRECTION: Forward CRASH PULSE: 10 g's

CHAIR TYPE: Manual

SECUREMENT

WHEELCHAIR: Modified single rim latch

DUMMY: Lap belt to axles

TEST ACTION

The same generic securement system used in Test 1187 was again tested. However, modifications were made to prevent unlatching and opening of the rear wheel gripper mechanism (Figure A-75). A backup system of belts was not used in this test.

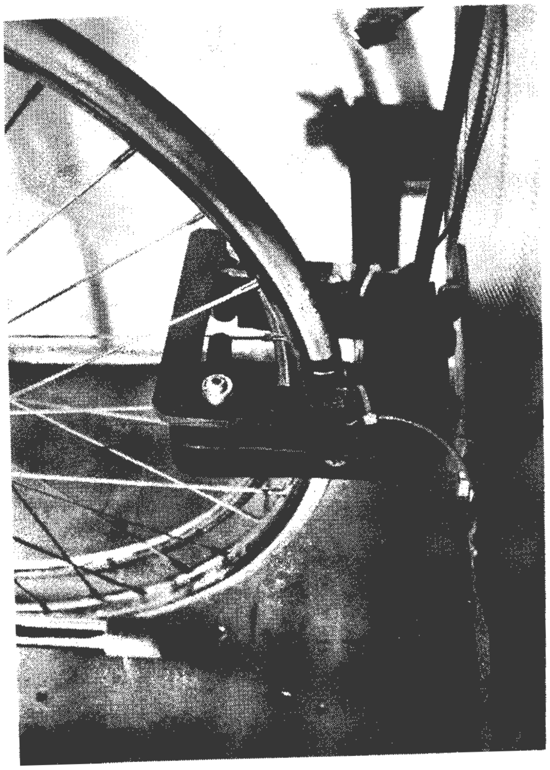
On impact, the chair slid forward turning slightly to the right as load was applied to the right rear wheel. Spokes in the right rear wheel failed, allowing forward motion to continue. In this test, the fold up securement seat did not unfold as in Test 1187.

The dummy and chair tipped forward raising the rear wheels off the sled, allowing the dummy's left shoulder to strike a hard blow on the stanchion and its knees to strike the end of the obstruction seat. In its final position, the chair was tilted approximately 45 degrees forward and 30 degrees to the right (Figure A-76).

TEST RESULTS

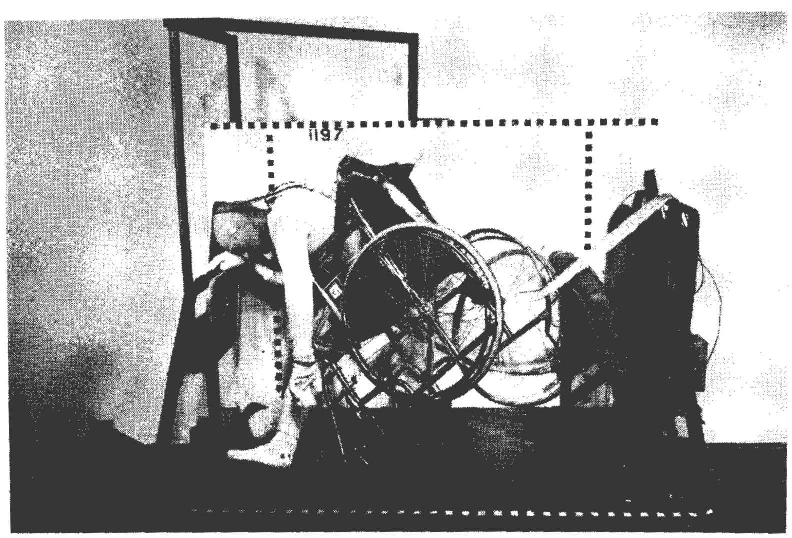
WHEELCHAIR: The right rear wheel was destroyed: The tire and rim were separated and badly distorted, and most of the spokes had failed (Figure A-77). Strain gauges mounted on the wheel grippers registered a maximum load of 700 lbs at wheel failure. A combination of lateral and longitudinal loads appears to have contributed to wheel failure. Early static tests indicated that a large wheel of a chair can sustain longitudinal loads of 800 lbs without failure. However, a 200 lb lateral load causes spoke failure.

DUMMY: Maximum head excursion in the direction of travel was 54 inches. However, excursion was limited by the shoulder impact on the stanchion. Although calculated severity indexes and injury criteria were low (HIC = 128, CSI = 98), injury to the shoulder could be expected from the blow on the stanchion. The maximum seat belt load recorded was only 180 lbs (360 lbs on the dummy) indicating minimal restraint by the single wheel attachment.



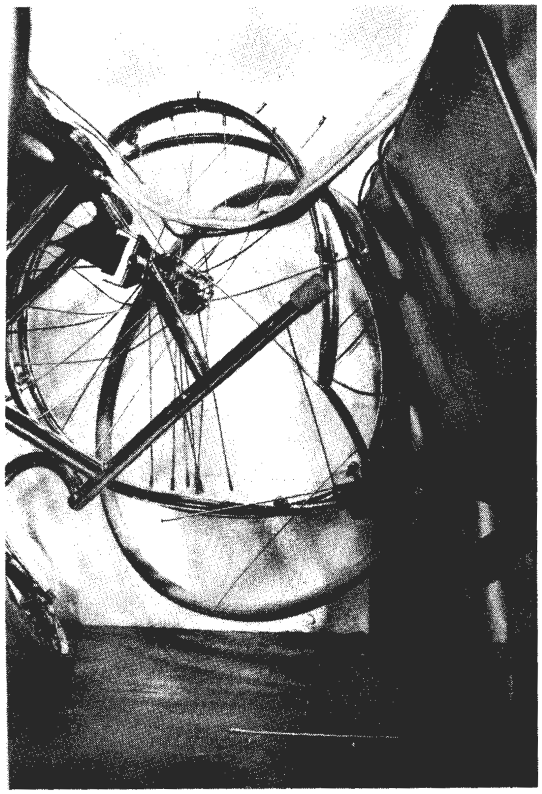
Test 1197--Gripper Modification

Figure A-75



Test 1197--Post Test Conditions

Figure A-76

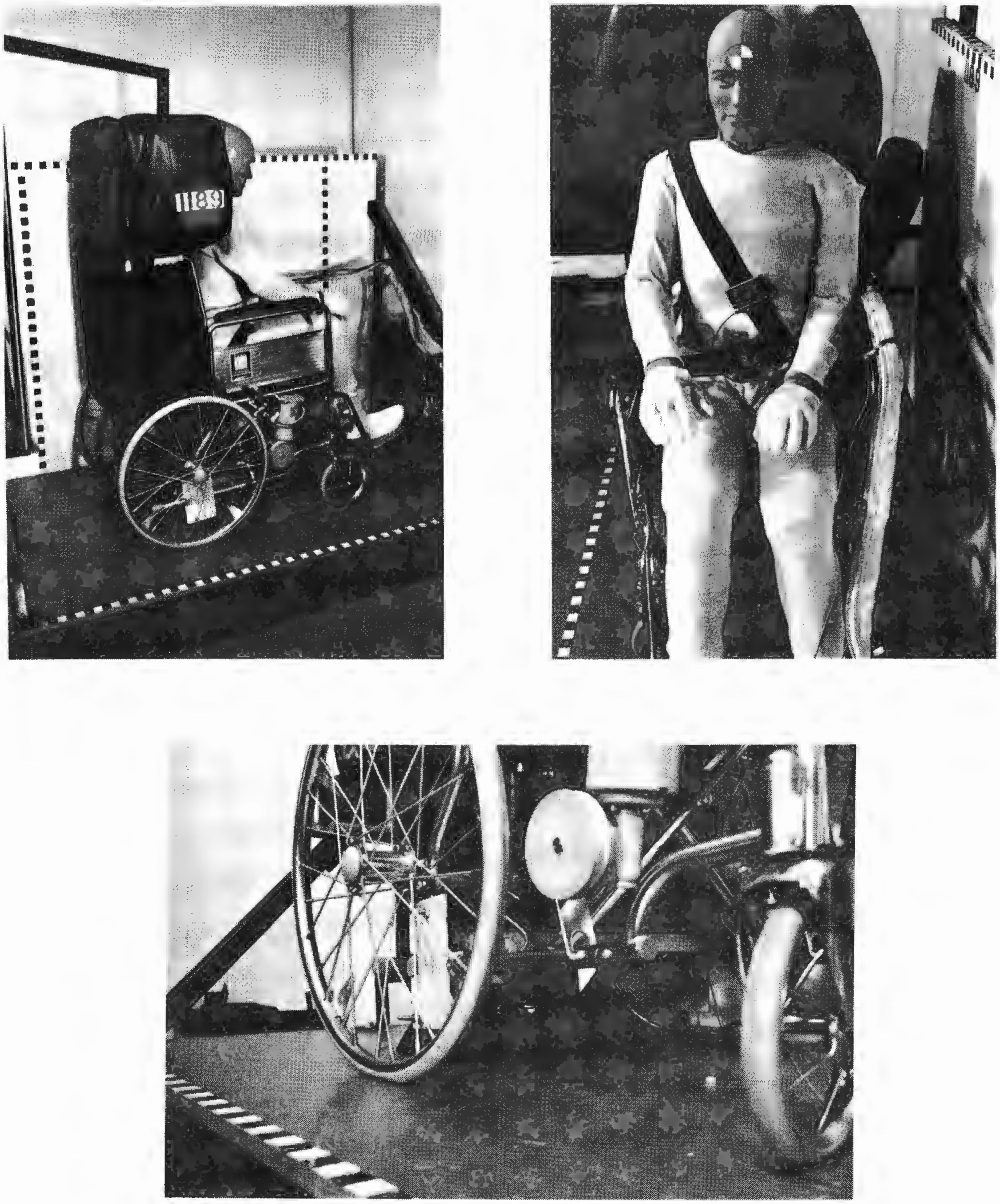


Test 1197--Wheel Failure

Figure A-77

Wayne State

The Wayne State system (developed at Wayne State University in Detroit) was designed primarily for backward facing transit and frontal impact. However, it has features for supplying securement for impacts regardless of the direction. It consists of a well-padded back and head support mounted on energy absorbing posts, a lap and torso harness system for the user, and a cable-latch system for the chair (Figure A-78).



Wayne State

Figure A-78

TEST NO: 1189

SLED SPEED: 20.0 mph

FACING DIRECTION: Rear

CRASH PULSE: 9 g's

CHAIR TYPE: Electric Powered

SECUREMENT

WHEELCHAIR: Wayne State

DUMMY: Lap and shoulder belt harness to securement posts

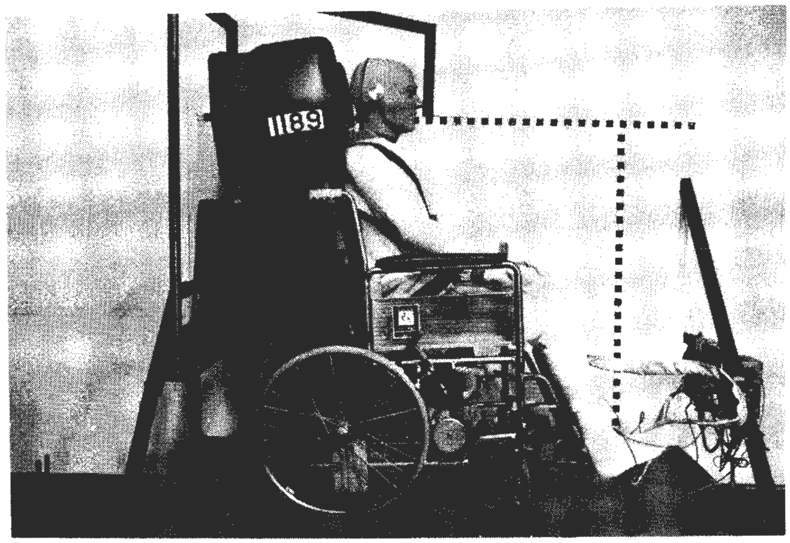
TEST ACTION

On impact, the chair and dummy moved in the direction of travel against the securement posts and padding. As load was applied, the securement support posts deflected allowing the combined securement, chair, and dummy to rotate approximately 15° downrange, lifting the casters off the sled. On rebound, the chair and dummy returned to a normal position on the sled and were restrained from aft movement by the lap and shoulder harness. The securement support posts rebounded to a deflected angle of approximately 10° (Figure A-79).

TEST RESULTS

WHEELCHAIR: No visible damage was sustained by the wheelchair.

DUMMY: Downrange head excursion into the securement padding was 14 inches. The impact of the head on the securement padding registered accelerations which indicate a minor head injury criteria (HIC = 144, T_1 = 114, T_2 = 160). Lap and shoulder belts recorded a maximum tension of 100 lbs on rebound.



Test 1189--Post Test Conditions

Figure A-79

TEST NO: 1190

SLED SPEED: 20.0 mph

FACING DIRECTION: Forward

CRASH PULSE: 10 g's

CHAIR TYPE: Electric Powered

SECUREMENT

WHEELCHAIR: Wayne State

DUMMY: Lap and shoulder belt harness to securement posts

TEST ACTION

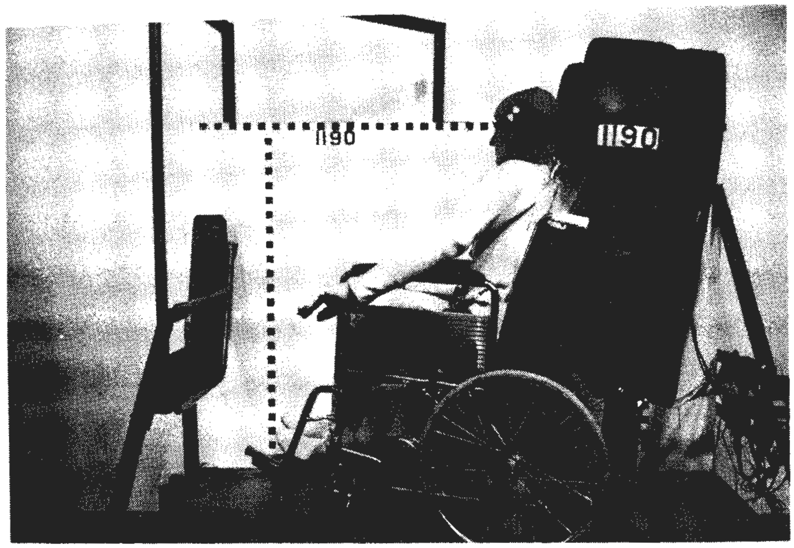
On impact, the chair and dummy slid forward on the sled applying load to the chair cable restraint and the dummy lap and shoulder harness. The cable restraint sustained some load, but soon failed and transferred the remaining energy of the chair through the dummy to the harness. The chair continued forward, causing the chair back to bend as load was transfered.

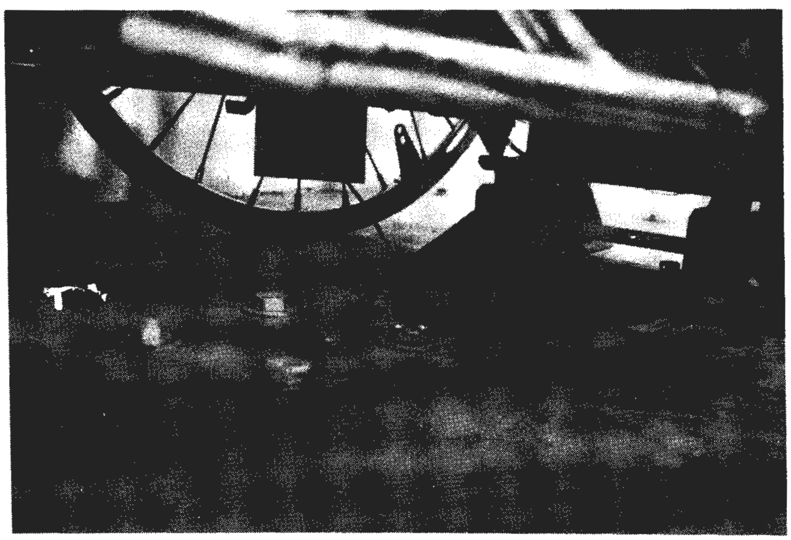
The dummy's arms extended out downrange and its head bent downrange at a sharp angle as the back and upper torso leaned slightly aft. The support posts leaned slightly downrange during deceleration, but did not deform permanently. On rebound, the dummy and chair returned aft against the securement. Loading of the shoulder belt caused the dummy and chair to turn approximately 25° to the right.

TEST RESULTS

WHEELCHAIR: The chair's backposts were bent aft approximately 10 degrees. At approximately 110 ms into the event, the 5/32 inch cable securing the chair failed (Figure A-80).

DUMMY: Maximum head excursion in the direction of travel was 24 inches. Seat belt load reached a maximum of 460 lbs. Tension in the shoulder belt peaked at 250 lbs.





Test 1190--Post Test Conditions

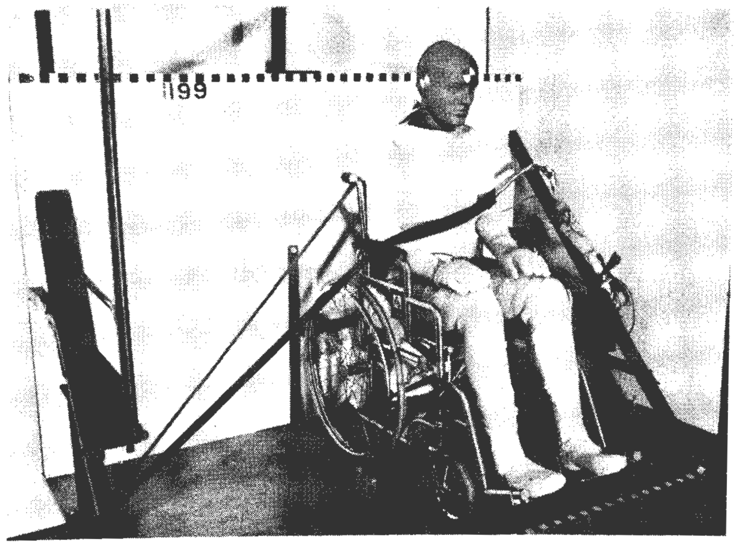
(Note failed cable restraint)

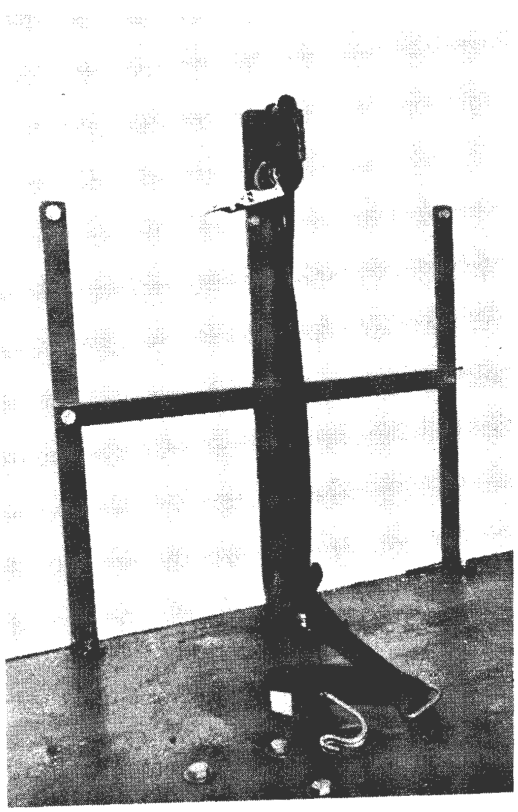
Figure A-80

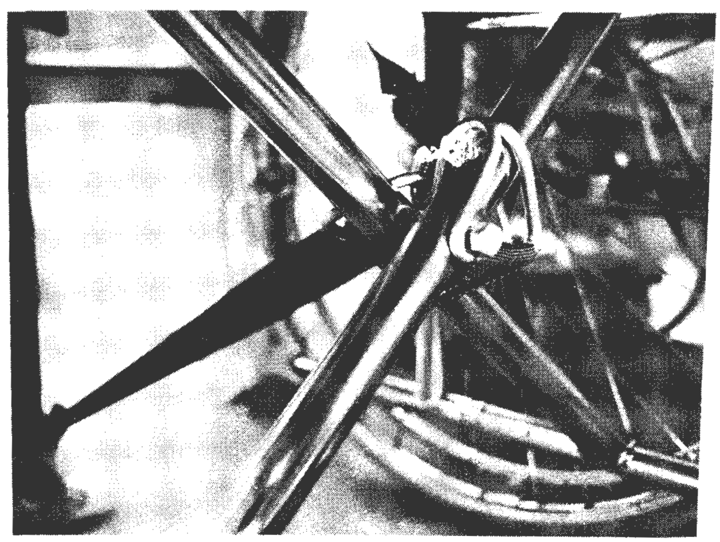
Cross Brace Belt

The cross brace belt system consists of a web belt, hook, ratchet, and roller. The ratchet mounts on a wall with a roller mounted at the junction of wall and floor. The hook is attached to one end of the belt. The belt plays out of the ratchet, down through the roller and up to the center of the wheelchair's cross brace. The hook engages the cross brace where the members forming the "X" are bolted (the chair is backed into the wall). The ratchet places tension in the belt, pulling the chair down and back toward the wall. A horizontal, angled shaped metal piece located on the wall about 15 inches above the floor is designed to minimize rideup of the rear wheels during inline impacts (Figure A-81).

One test, with a side facing chair, was conducted with a cross brace belt system.







Cross Brace Belt

Figure A-81

TEST NO: 1199

FACING DIRECTION: Side

SLED SPEED: 19.9 mph

CRASH PULSE: 10 g's

CHAIR TYPE: Manual

SECUREMENT

WHEELCHAIR: Cross brace belt

DUMMY: Lap belt to axles

TEST ACTION

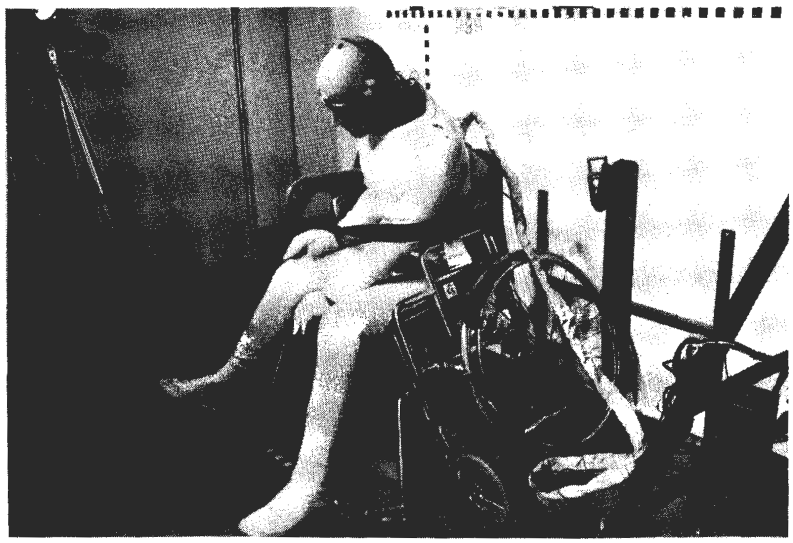
As the sled decelerated, the chair and dummy slid in a downrange arc about the wall anchor point of the securement belt. The chair then tilted sideways (downrange) approximately 45 degrees lifting the aft wheel and caster off the sled.

The dummy struck the obstruction armrest at elbow height, twisting the upper torso sideways over the armrest.

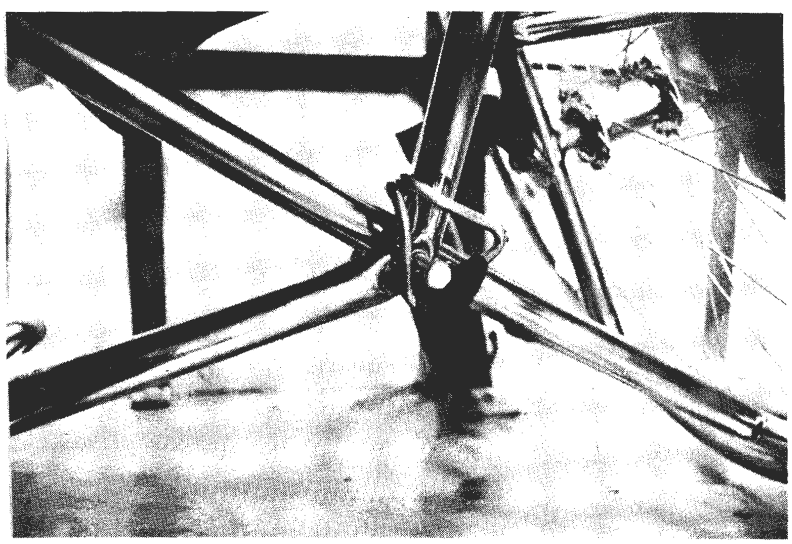
TEST RESULTS

WHEELCHAIR: The chair frame was severely distorted sideways (approximately 28 degrees downrange). Failure occurred in the cross brace tubing at the draw bolt (Figure A-82). The downrange rear wheel was bent. A tear occurred in the seat support at the right rear corner.

DUMMY: Maximum downrange head excursion was 54 inches. However, excursion was limited by impact on the obstruction armrest. Although not indicated by the calculated injury criteria (HIC = 130, T_1 = 198 ms, T_2 = 298 ms), side impact and torso twisting could have resulted in injury. Seat belt loads reached a maximum of 1100 lbs.



Test 1199--Post Test Conditions



Test 1199--Cross Frame Failure

Figure A-82

Frame-Cable

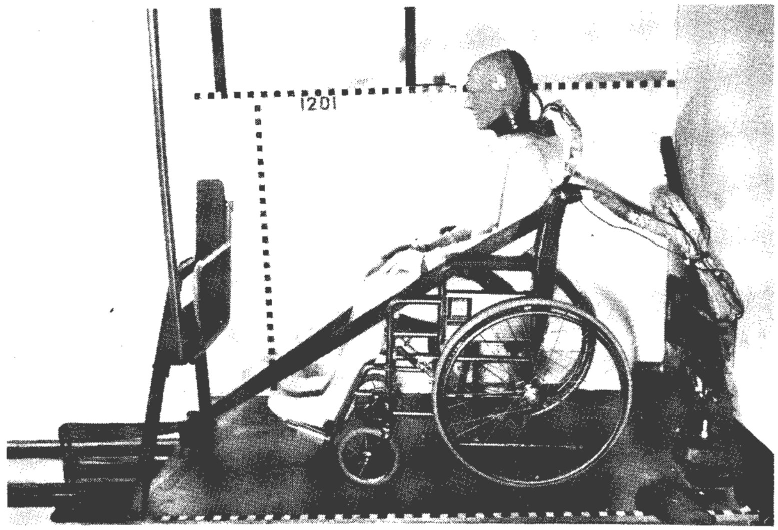
The frame-cable system is a modification of that portion of the Wayne State system that includes a cable. It consists of a cable attached to the chair and a receiving latch mounted on the floor.

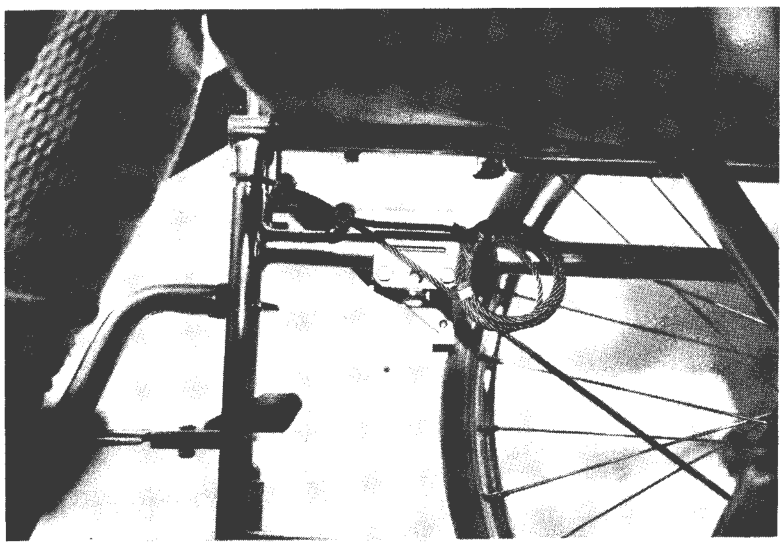
One end of the cable is attached to the chair's frame where the top horizontal rail meets the vertical side frame forward post. The cable passes from the front attachment diagonally down one side to the junction of the bottom horizontal rail and back vertical post. It then crosses over to the same junction point on the other side of the chair and follows the same diagonal path along that side, and is attached to the same relative point as on the other side (Figure A-83). In this study the cable was wrapped around the lower junction points, but normally there would be an attached eyelet for the cable to pass through so that it could easily slide during folding of the chair for storage.

The two receiving "latches" were 1/4-inch steel plates with drilled holes for the cable. The edges of the holes were rounded to minimize cutting of the cable.

A 5/32-inch diameter cable was used.

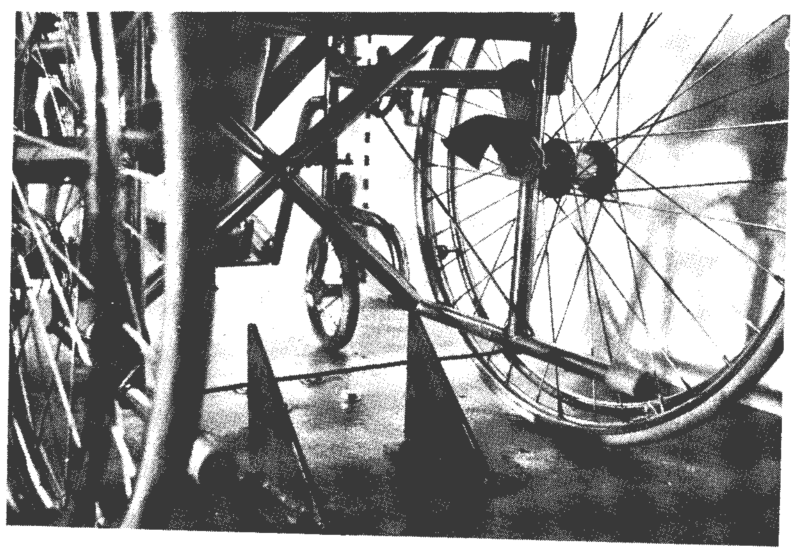
One test, with a forward facing chair, was conducted with the frame-cable system.





Frame Cable

Figure A-83



TEST NO: 1201 SLED SPEED: 20.0 mph

FACING DIRECTION: Forward CRASH PULSE: 9 g's

CHAIR TYPE: Manual

SECUREMENT

WHEELCHAIR: Frame cable

DUMMY: Lap belt to axles

TEST ACTION

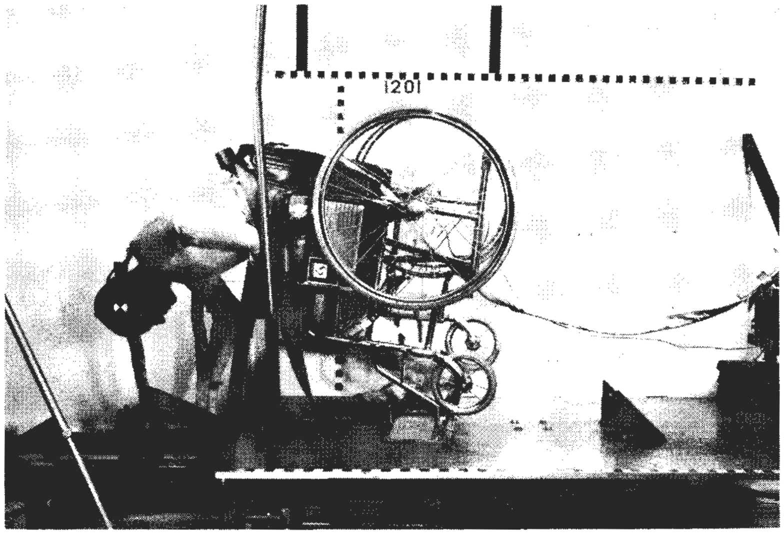
Upon impact, the chair and dummy slid forward on the sled causing tension in the cable. The chair then rotated slightly forward raising the rear wheels off the sled. The dummy slid forward on the seat placing full load on the lap belt. At this point (136 ms), the securement cable failed (Figure A-84) allowing the chair and dummy to continue forward without restraint.

The dummy's left shoulder struck and bent the stanchion. Its legs hit the obstruction seat. The dummy and chair rotated over the obstruction armrest with the torso parallel to the sled floor and the chair (tilted forward 90°) still attached to the dummy (Figure A-85).

TEST RESULTS

WHEELCHAIR: Minor bending occurred in the backposts and forward cross brace.

DUMMY: Maximum head excursion was not measured since movement was not restricted by the securement. Seat belt load reached a maximum of 370 lbs. (720 lbs on the dummy) at failure of the securement cable. Although calculated severity indexes and injury criteria were low (CSI = 80, HIC = 70), injury to the shoulder could be expected from the blow o the stanchion.



Test 1201--Post Test Conditions

Figure A-84

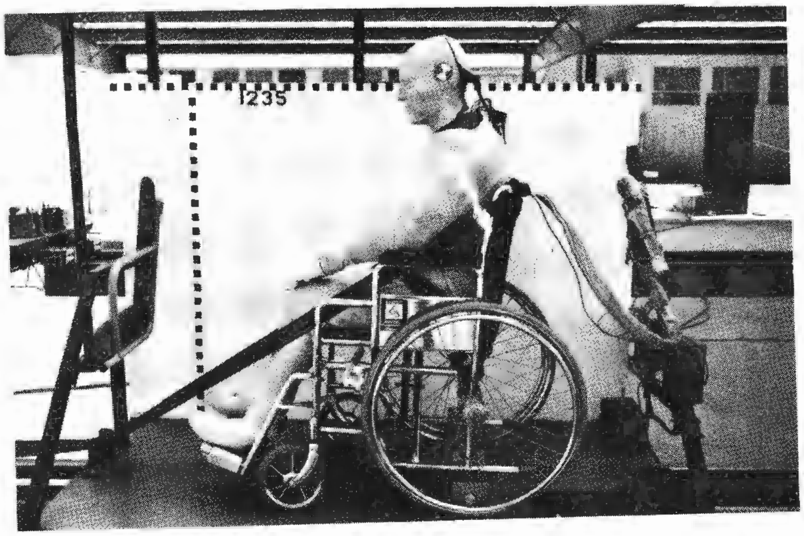
Test 1201--Failed Cable

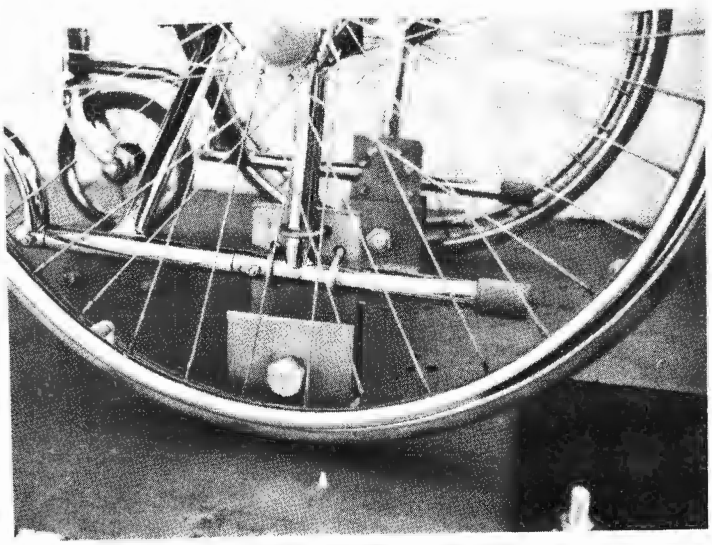
Figure A-85

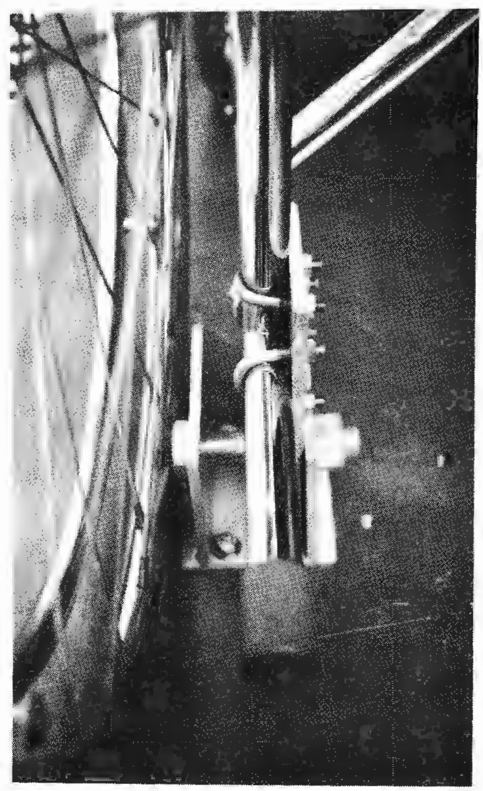
Frame Anchor

The frame anchor consists of plates fastened to each side of the chair frame at the junction of the bottom horizontal rail and the vertical backposts. The plates fit inside the legs of U-shaped brackets located on the floor. Bolts through holes in the legs of the brackets and plates provide securement (Figure A-86).

One test, with a forward facing chair, was conducted with the frame anchor system.







Frame Anchor

Figure A-86

TEST NO: 1235

FACING DIRECTION: Forward

SLED SPEED: 20 mph

CRASH PULSE: 10 g's

CHAIR TYPE: Manual

SECUREMENT

WHEELCHAIR: Frame anchor

DUMMY: Lap belt to axles

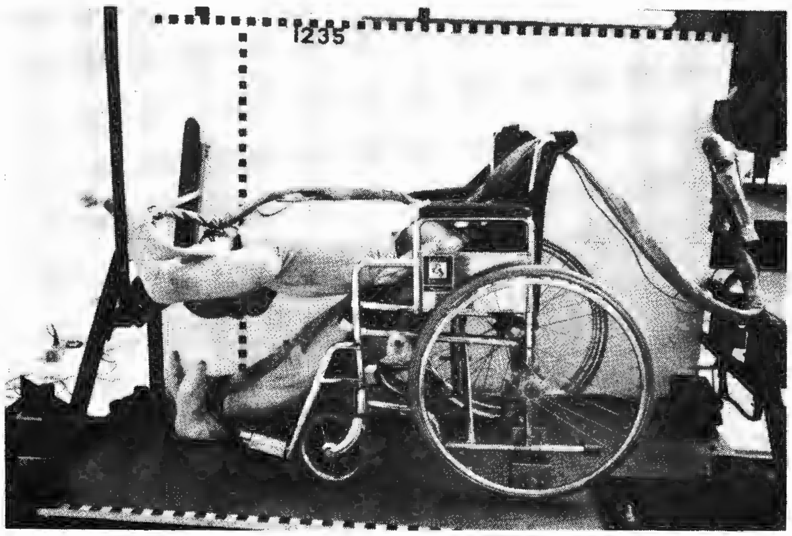
TEST ACTION

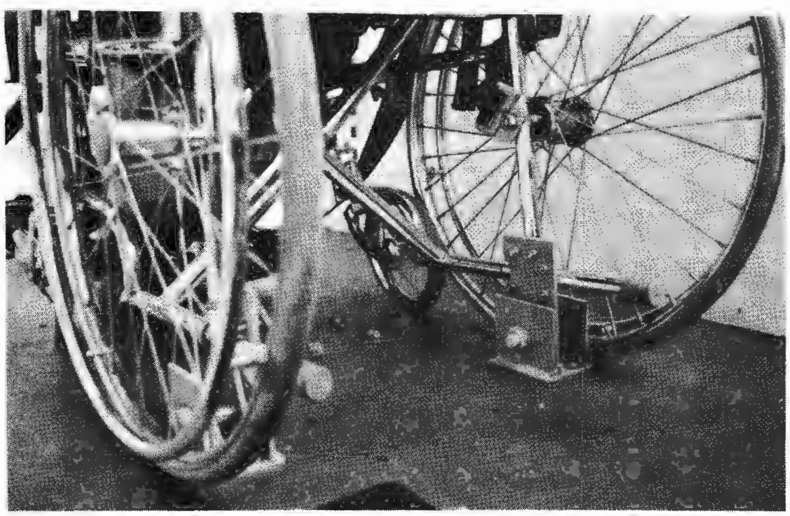
Upon impact, the chair remained stationary as the dummy slid forward on the seat taking up slack in the seat belt. The dummy jackknifed forward striking the obstruction seat on the bottom with its legs. The dummy's hands struck the obstruction armrest but its head cleared. As the upper torso rotated downward, the head struck a light blow on the left arm and a hard blow on the right leg (Figure A-87).

TEST RESULTS

WHEELCHAIR: The forward portion of the seat attachment to the side frame failed. The chair securement held with only moderate bending in the chair frame. Bending occurred in the right front caster mount and in the rear cross brace member.

DUMMY: Maximum seat belt load was recorded as 300 lbs (600 lbs on the dummy). Recorded head accelerations confirmed the head strike on the dummy's leg of a minor nature (HIC = 306, T_1 = 114, T_2 = 211). Maximum head excursion was 39 inches.





Test 1235--Post Test Conditions

Figure A-87