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UMTRI-85-19

SLED IMPACT TESTS OF WHEELCHAIR TIE-DOWN SYSTEMS FOR HANDICAPPED DRIVERS

FINAL REPORT TO
MASSACHUSETTS REHABILITATION COMMISSION

MAY 1985

UMTRI The University of Michigan
Transportation Research Institute

SLED IMPACT TESTS

OF WHEELCHAIR TIE-DOWN SYSTEMS

FOR HANDICAPPED DRIVERS

May 31, 1985

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16. Abstract

Six dynamic impact tests were conducted on the UMTRI rebound sled facility to evaluate the effectiveness of three wheelchair tie-down systems intended for use by wheelchair seated drivers of vans. The three systems tested were developed by Creative Controls, Inc., Target Industries ("Speedlock" tie-down), and Intex Northeast, Inc. (formerly "The Claw" by Falcon Equipment Specialties). The tests were performed at nominal impact conditions of a 30-mph velocity differential at an average deceleration of 20 g's, using an instrumented 50th-percentile male dummy seated in an E&J power wheelchair. Occupant restraint included a lap belt attached to the wheelchair or tie-down hardware on the wheelchair and a shoulder belt or shoulder/lap belt combination attached to the vehicle (i.e., the sled). One test was performed on the Intex tie-down system, two on the Target system, and three on the Creative Controls system. The final test of each demonstrated effective wheelchair securement for the test conditions.

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OVERVIEW AND SUMMARY

This report describes the test conditions and results of six sled impact tests conducted at the University of Michigan Transportation Research Institute (UMTRI). The purpose of these tests was to dynamically evaluate three wheelchair tie-down systems currently being purchased, or being considered for purchase, by the Massachusettes Rehabilitation Commission (MRC) for its clients. These systems, or earlier versions of these systems, had been previously tested in the summer of 1983 for the Univerity of Michigan Rehabilitation Engineering Center (UMREC) funded through the National Institute of Handicapped Research (NIHR). As a result of those tests, it became apparent that improvements were needed and that systems that had previously performed well had been modified or reduced in size to the point that they were no longer effective under expected impact loading conditions.

The three tie-down systems tested were developed by Creative Controls, Inc. (CCI), Target Industries, Inc. ("Speedlock" tie-down), and Intex Northeast, Inc. (tie-down formerly developed by Falcon Specialties, Inc. and referred to as "The Claw"). Table 1 shows the test numbers and the tie-down evaluated in each. The Intex system performed well on the first test and so was not re-evaluated. The Target system required two tests, and the Creative Controls system required three tests as indicated.

The impact conditions used for all tests were a 30-mph velocity differential at 20 g's average deceleration. This is believed to be a conservative but acceptable level of impact for testing restraints used in van-type vehicles, which is currently the primary mode of personal licensed vehicle transportation for severely handicapped drivers seated in wheelchairs. All tests used a 50th-percentile male anthropomorphic test dummy (DOT part 572) weighing 167 pounds as the wheelchair occupant. The occupant restraint system in each case consisted of a lap belt anchored to the wheelchair or tie-down hardware on the wheelchair (if provided for) and a vehicle-anchored shoulder belt or lap-shoulder belt combination (i.e., 3-point belt).

In the pages that follow, the tie-down systems, test conditions, and test results for these six tests are described and presented in some detail. The tests are presented in the order tested (i.e., WM8501 through WM8506) and the results are briefly interpreted in the SUMMARY AND DISCUSSION sections at the end of each test. For each tie-down system, the final impact test demonstrated effective performance in securing the wheelchair and, based upon these results, all three systems can be recommended for purchase by MRC and use by its clients.

Table 1

Summary of Impact Tests

Test No.	Tie-down System	Results
WM8501	CCI prototype	Failure due to freeplay in system resulting in release at front hook and back flip of wheelchair on sled acceleration
WM8502	Intex Northeast, Inc. (modified Falcon "Claw")	Good wheelchair securement
WM8503	Target Industries' "Speedlock" tie-down with strengthened cross bars	Failure due to unexplainable release of rear tie-down pin. Tension spring was not fully tightened by motor.
WM8504	CCI prototype modified to capture front tie-down in front tie-down hook	Improved wheelchair restraint but tie-down released on re-bound.
WM8505	Target Industries' "Speedlock", tie-down motor fully powered to tighten tie-down spring	Good wheelchair securement
WM8506	CCI prototype with modified rear retaining mechanism	Good wheelchair securement

TEST METHODS

These tests were conducted on the UMTRI impact sled illustrated in Figure 1. The sled operates on the rebound principle, achieving a desired velocity by reversing its direction of motion during the impact event. The sled crash pulse is trapezoidal in shape and is reported as an average deceleration level in g's. The sled velocity is monitored immediately before and after impact.

Head and chest accelerations of a 50th-percentile male anthropomorhic test dummy (ATD) were measured from two sets of three orthogonal transducers mounted in the head and chest. GSE seat belt load cells were used to measure webbing tensions in the lap and shoulder occupant restraint belts during impact. Data generated during the test were multiplexed and recorded on the direct record channels of a Honeywell Model 96 magnetic tape recorder. The signals were subsequently de-multiplexed and time-expanded for digitizing, filtering, and analysis on a NOVA/4 computer. All test signals were filtered to the requirements of SAE J-211.

The photoinstrumentation consisted of two high-speed (1000 frame/sec) 16mm motion picture cameras (Photosonics 1B) for side and overhead views and a quick-look sequenced Polaroid camera. The transducer data and the motion picture test films were simultaneously marked by a timing pulse generated at ten millisecond intervals. A strobe flash recorded the onset of impact.

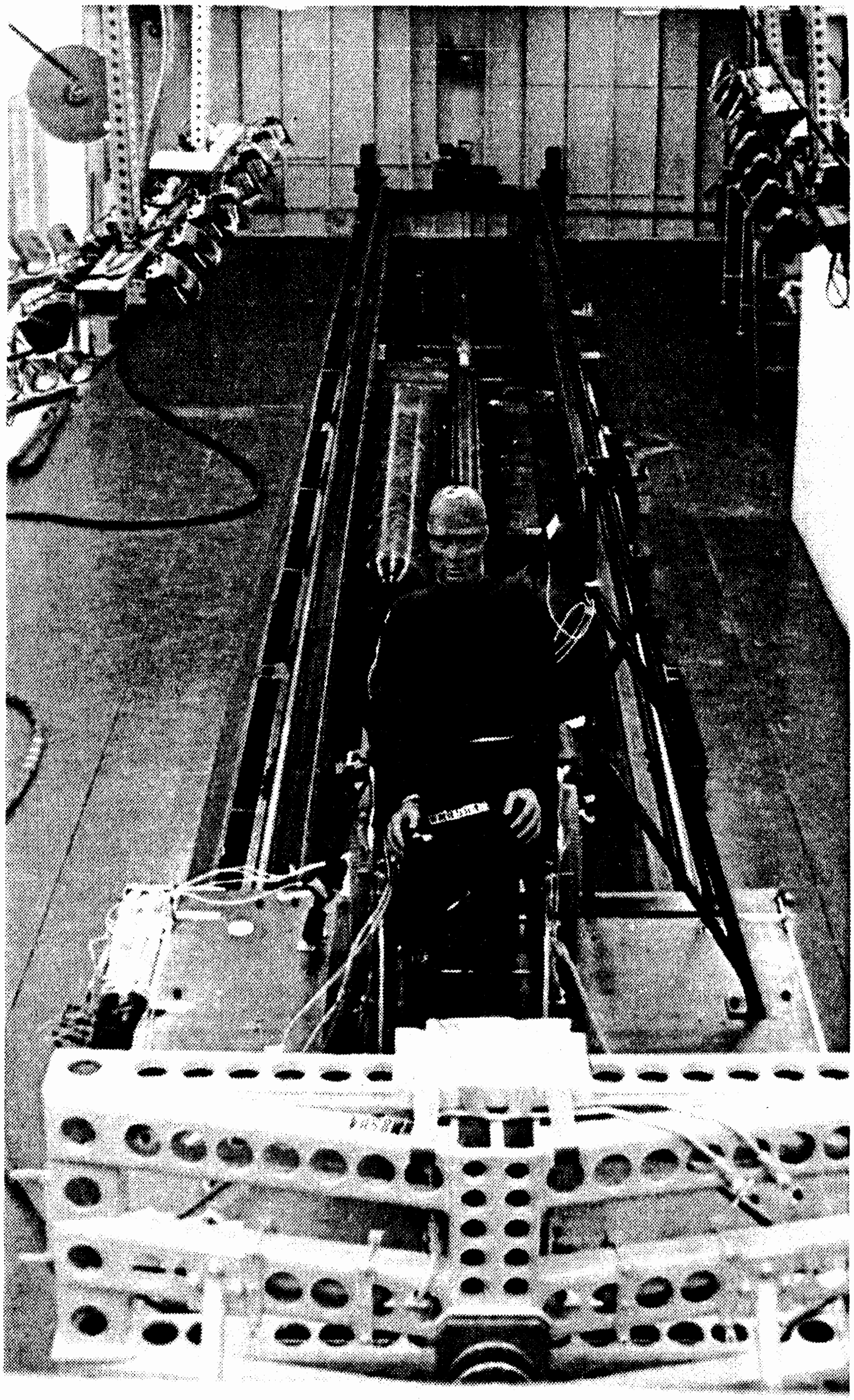


Figure 1. UMTRI Sled Impact Facility

UMTRI

SLED IMPACT TEST

WM8501

CREATIVE CONTROLS

WHEELCHAIR TIE-DOWN

FOR DRIVERS

Test Date:

January 23, 1985

INTRODUCTION

The purpose of this test was to evaluate the effectiveness of a prototype wheelchair tie-down system developed by Creative Controls, Inc. (CCI) for handicapped drivers of vans. In addition to a lap seat belt attached to the tie-down hardware on the wheelchair, a three-point vehicle-anchored restraint system was used to provide occupant restraint for the 50th-percentile male anthropomorphic test dummy.

TEST SETUP

* Wheelchair Tie-Down .... Creative Controls prototype
* Weight of Tie-down hardware on wheelchair ...... 18 lbs.
* Wheelchair .... E&J 3P power wheelchair
* Occupant Restraint .... lap belt to wheelchair plus 3-point belt to vehicle
* Test Dummy .... 50th percentile male (167 lbs.)
* Orientation of Test .... Forward facing, frontal impact
* Desired Impact Velocity ..... 30 mph
* Desired Deceleration .... 20 g's

Figure 1 shows the CCI tie-down hardware that bolts to the lowered vehicle floor and straddles the longitudinal vehicle frame member as shown in the mock-up. Figures 2 and 3 show the tie-down hardware that attaches to the wheelchair. Two triangular plates made from 12 gauge steel are bolted to the insides of the wheelchair side-frames by means of three steel U-brackets on each side. Rectangular brackets made of 10 gauge steel are bolted to these plates at the rear and contain holes for anchoring the wheelchair lap belt and for holding the rear tie-down bar. A piece of steel angle extends to the front on the bottom of each triangular plate under the lower horizontal frame tubing on the wheelchair and contains the hole for retaining the front tie-down bar. The two tie-down bars made from 5/8" diameter solid steel insert easily into the holes provided and are held in position by spring-loaded retaining pins. These bars are easily removed without the use of tools for folding of the wheelchair. The lowest clearance to the floor is 1-3/4" at the bottom of the rear brackets which hold the rear tie-down bar.

The floor-anchored structure consists of two parts. The front structure supports a vertical steel plate with a horizontal slot open to the rear for capturing the front tie-down bar. The rear part is the primary restraining structure and captures the rear tie-down bar. When the wheelchair rolls into position from behind, the spring-loaded plate moves down, allowing the rear bar to slip under the steel retaining lip. Once in position, the spring-loaded plate moves back up, capturing the rear bar from above and behind, as shown in Figures 4 and 5. The rear retaining structure is approximately 12" across at the widest point and, for the wheelchair of this test, the distance from the back of the front part to the front of the back part was 22 inches.

Figures 6, 7, and 8 show side, front, and oblique views of the pre-test setup. A 50th-percentile male dummy (Hybrid II) weighing 167 lbs. was positioned in the wheelchair and restrained by a lap belt anchored back to the tie-down hardware as previously described. The dummy was also restrained by a vehicle-anchored three-point belt. A belt retractor was bolted to the floor on the right side of the wheelchair about 4" behind the main axle and a few inches outboard of the wheelchair. As shown in Figures 7 and 8, the lap/shoulder belt combination was sewn together, placed between the chair arm and the seat back and, buckled into the floor belt near the large wheel on the right side. The shoulder belt was bolted to the simulated "B" pillar structure about 15 inches to the left of the wheelchair centerline and about 9 inches behind the wheelchair seat back. For webbing lengths of this three-point restraint system, the lap/shoulder belt junction was up near the abdomen instead of being down near the right hip as desired.

Three GSE seat belt load cells were installed to measure forces in the upper shoulder belt, the right floor belt, and the left side of the wheelchair lap belt. The wheelchair, with batteries, motors, and tie-down hardware attached, weighed 160 lbs. The tie-down hardware accounted for about 18 pounds. Sled pressures were set to achieve a velocity differential of 30 mph and a sled deceleration of 20 g's during impact.

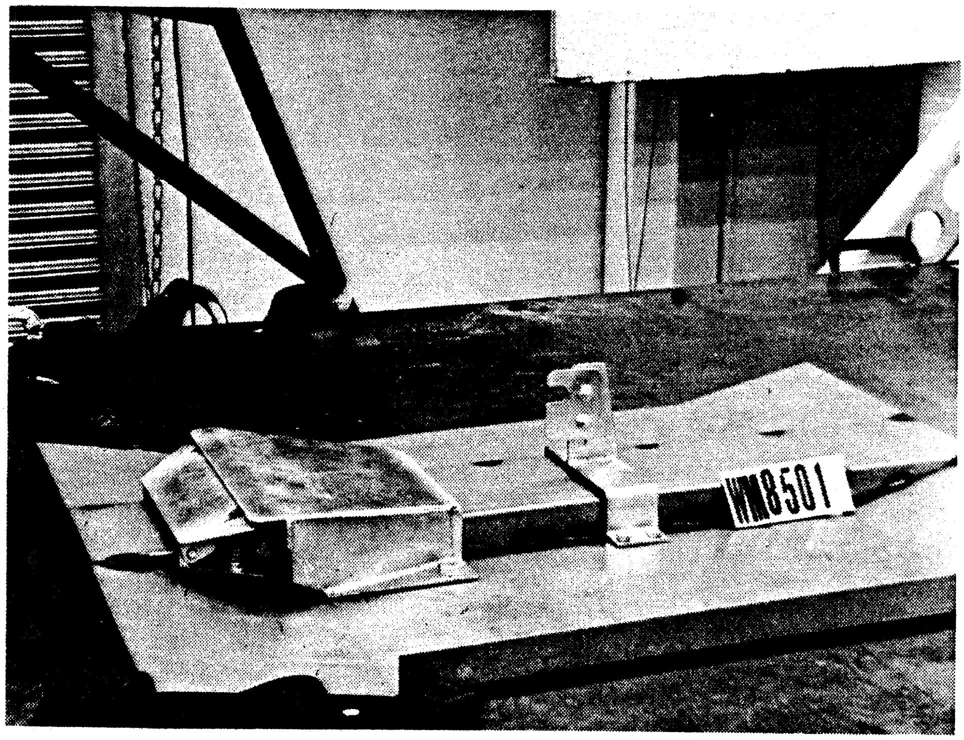


Figure 1. Vehicle-anchored tie-down hardware.

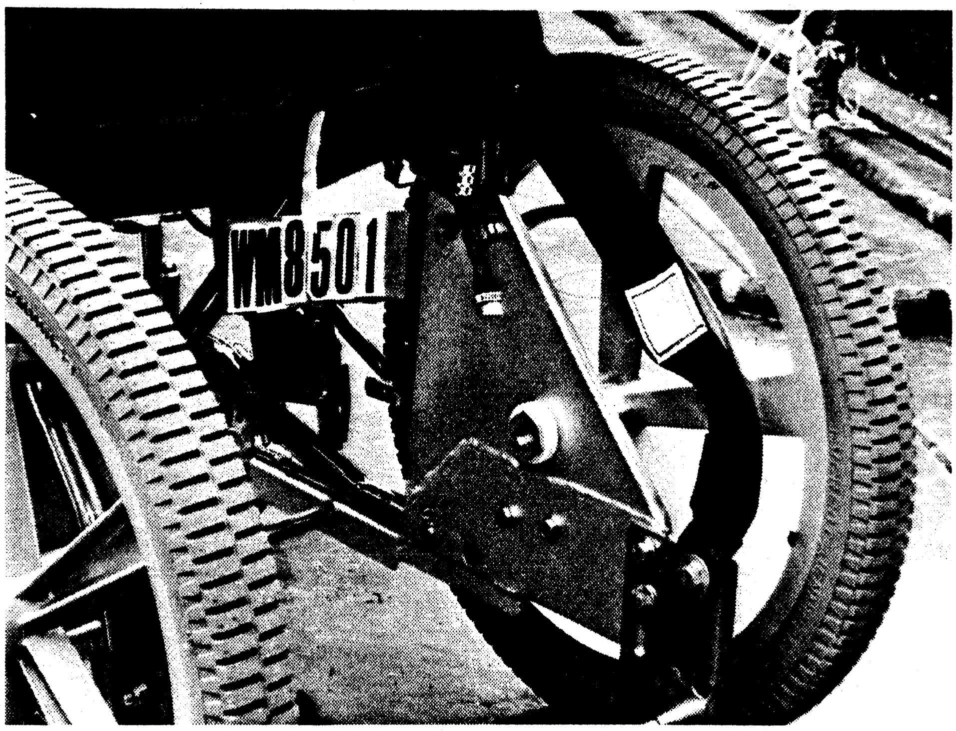


Figure 2. Triangular plates with brackets attached to wheelchair. Note lap belt anchor point.

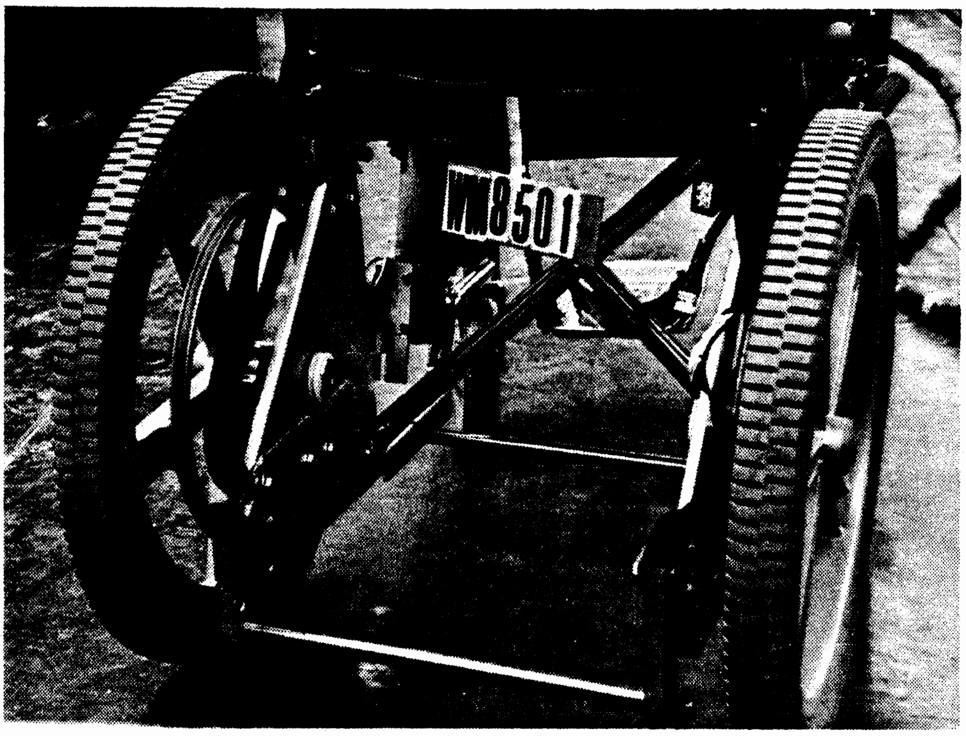


Figure 3. Tie-down hardware on wheelchair, showing front and rear steel bars.

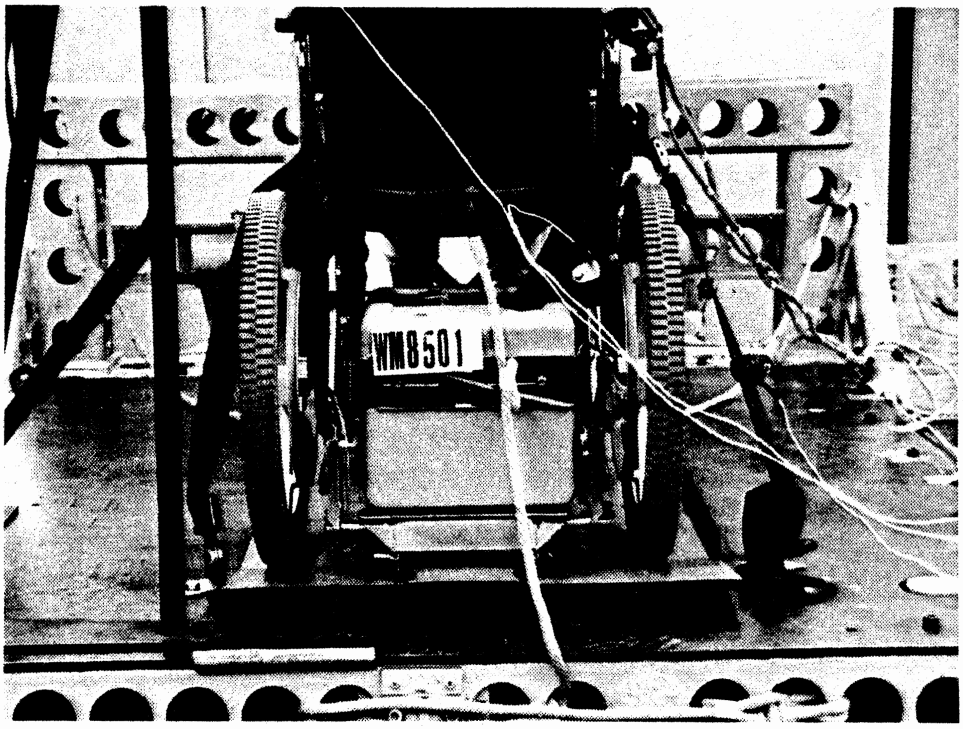


Figure 4. Rear view of wheelchair locked into tie-down, showing captured rear bar.

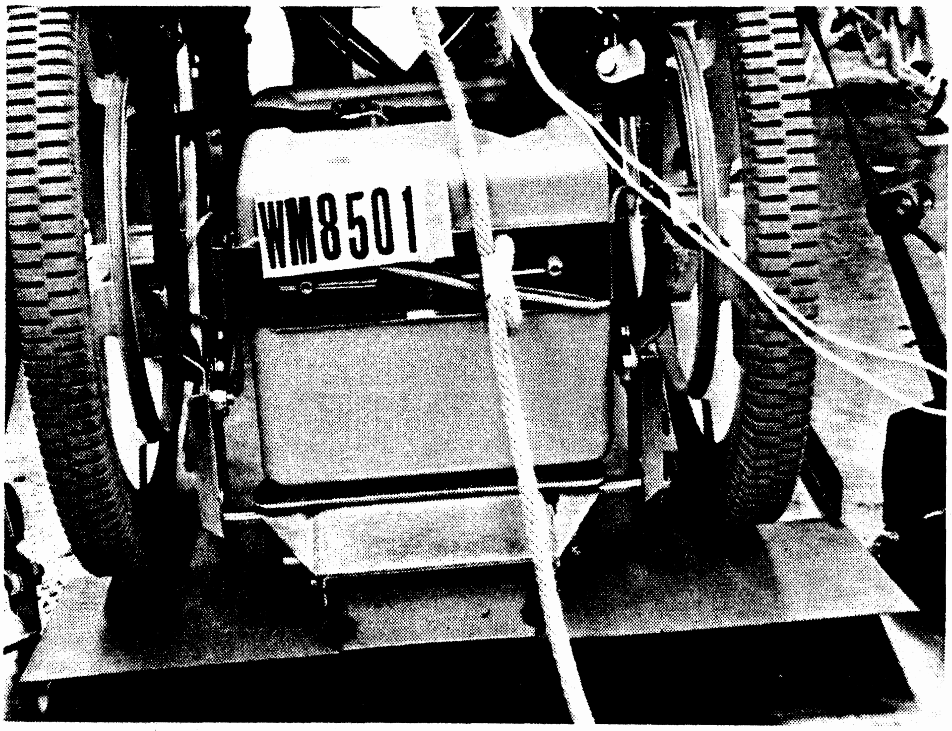


Figure 5. Close-up of rear bar captured under spring-loaded plate.

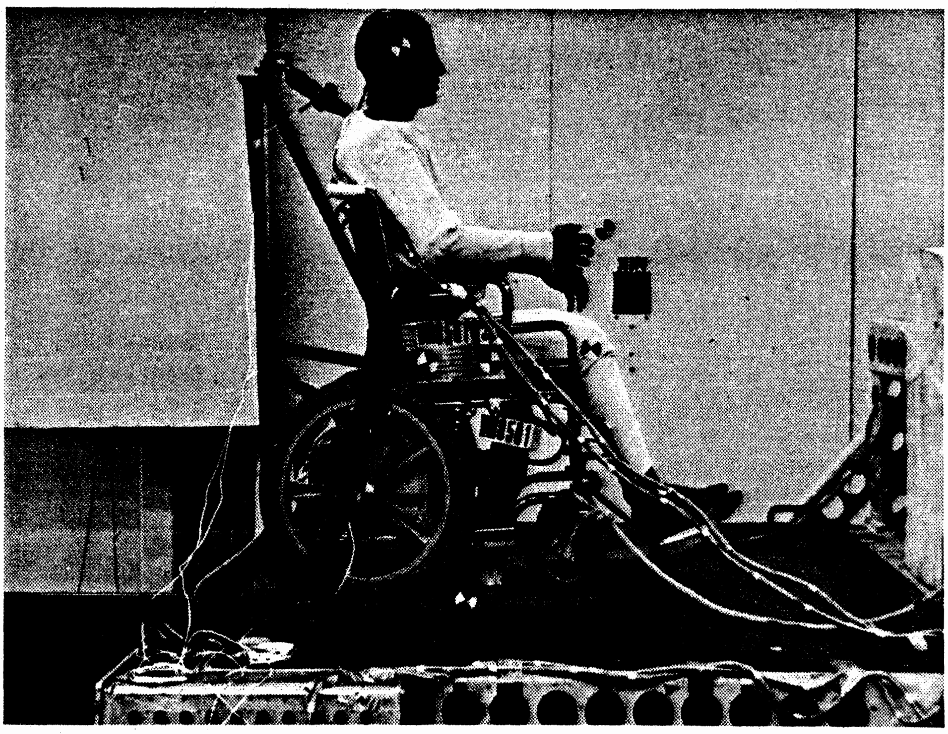


Figure 6. Side view of test setup.

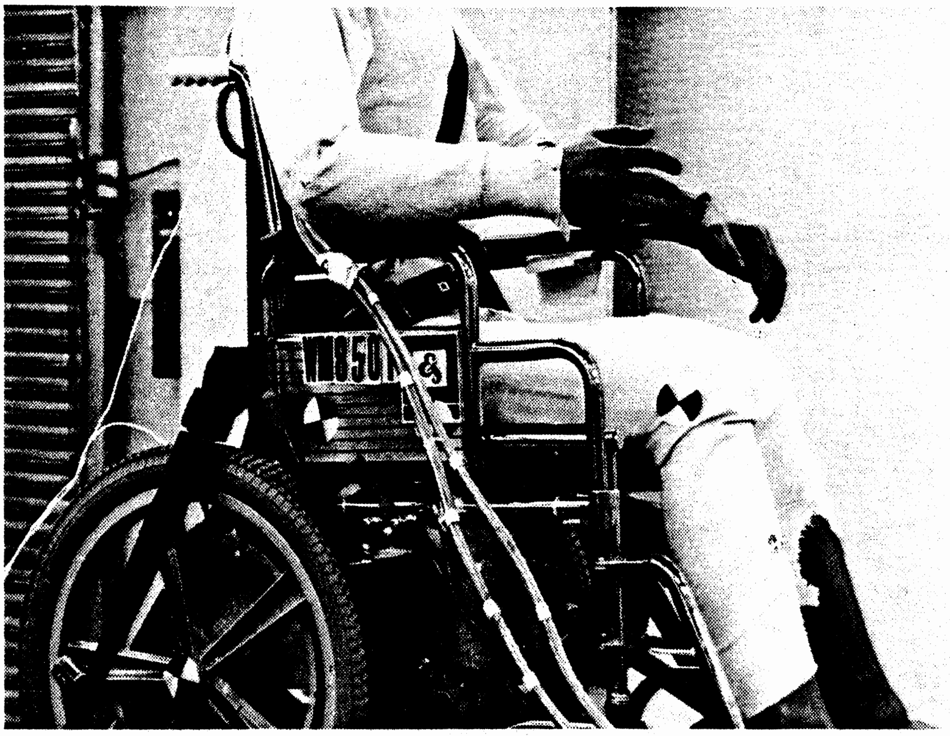


Figure 7. Oblique view of test setup, showing positioning of three point belt.

Figure 8. Front view of test setup, showing high position of shoulder/lap belt junction.

RESULTS

* Actual Sled Deceleration .... 21.1 g's
* Actual velocity .... 29.4 mph
* Peak force right chair lap belt ..... 409 lbs.
* Peak force left shoulder belt .... 779 lbs.
* Peak force right floor lap belt ..... 500 lbs.
* Peak resultant head acceleration .... 245 g's.
* Head Injury Criteria 913
* Peak resultant chest acceleration ... 74 g's

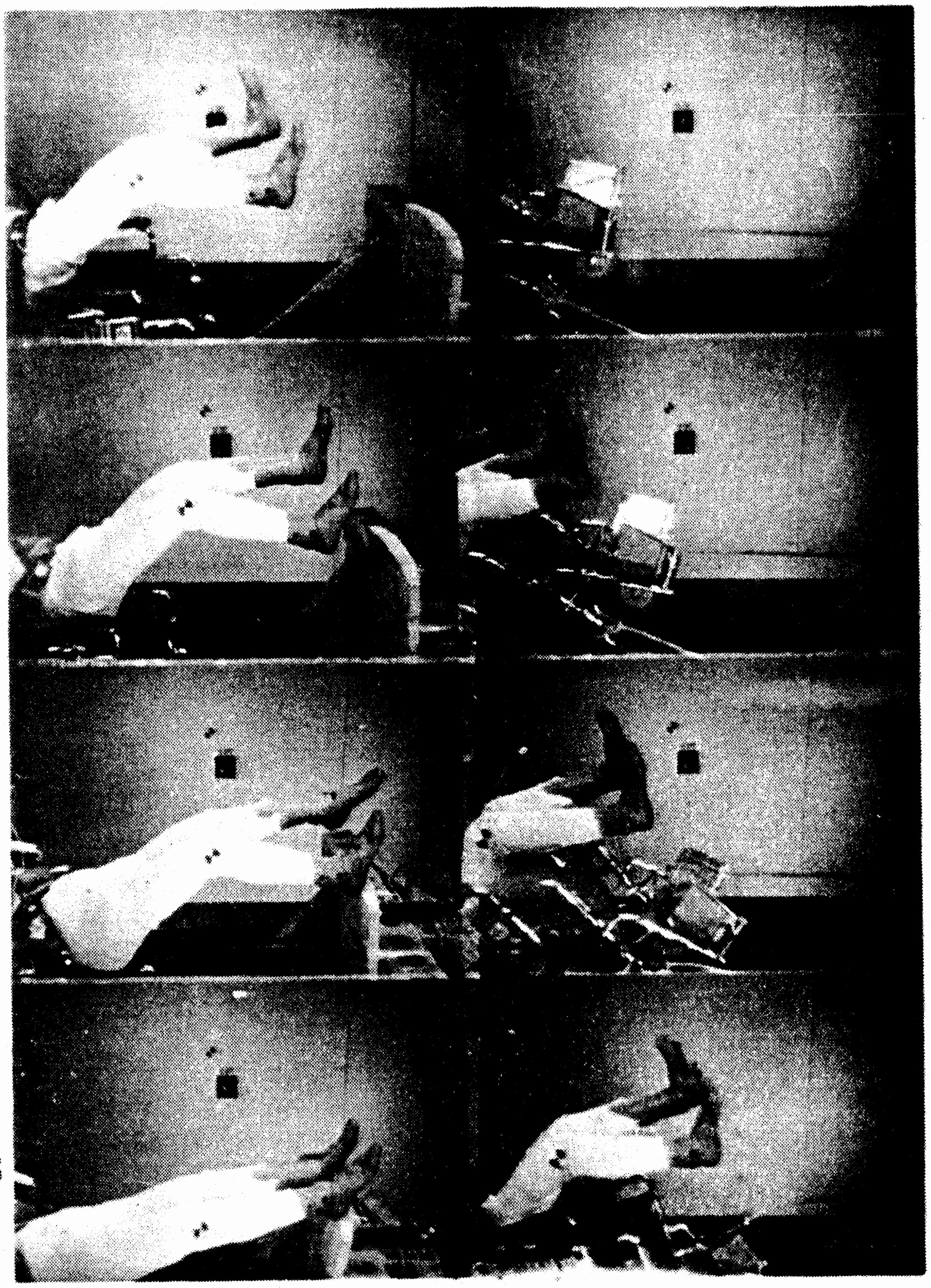
Figure 9 shows the polaroid sequence photographs of the impact event, while Figure 10 shows a stop-action photograph taken during the impact. During sled acceleration, which reaches a peak of about .5 g's, the wheelchair moved back on the sled, allowing the front tie-down bar to pull out of the front retaining slot. This allowed the wheelchair and dummy to flip backward as the sled continued to accelerate. Backward rotation was eventually restrained by the front tether ropes, but sufficient tipping had occurred (approximately 70 degrees of tilt for the wheelchair) so that the chair remained in a tilted position at the time of impact. The dummy therefore went into the impact feet first and in nearly a supine position, resulting in an invalid test in terms of "normal" occupant loading.

Figure 11 shows the post-test orientation of the wheelchair and dummy. Note the chair back broken to the rear. The high-speed films indicate that this probably occurred when the chair flipped backward prior to the main impact. Figure 12 shows the front retaining bracket post-test with the steel bar out of the slot, while Figure 13 shows the rear tie-down bar still captured in the retaining structure.

Even though the test results must be considered invalid because of the tipped orientation of the chair and dummy at the beginning of impact, it was noted on inspection of the tie-down hardware that a grade 5 bolt attaching the left rear bracket to the triangular plate had sheared and a slot in the left rectangular bracket had torn open, as shown in Figure 14. The rear bar itself showed little bending, however, and the retaining structure also showed little damage post-test.

Figure 15 shows the shoulder/lap belt junction after the test with torn stitching. This is primarily a consequence of the high placement of this junction, which caused the two pieces of belt webbing to be pulled apart rather than loaded in shear. Nevertheless, the strength of the stitching should be increased in future designs.

Figure 16 shows the sled velocity and deceleration profiles a velocity differential of 29.44 mph and an average deceleration of 21.1 g's. Figures 17 through 19 show the head and chest accelerations and belt loads, which have relatively little significance under the loading conditions of this test. The high head resultant acceleration and Head Injury Criteria are a consequence of the dummy's head striking the floor behind the wheelchair.



WM 8501

Figure 9. Polaroid graph sequence photograph.

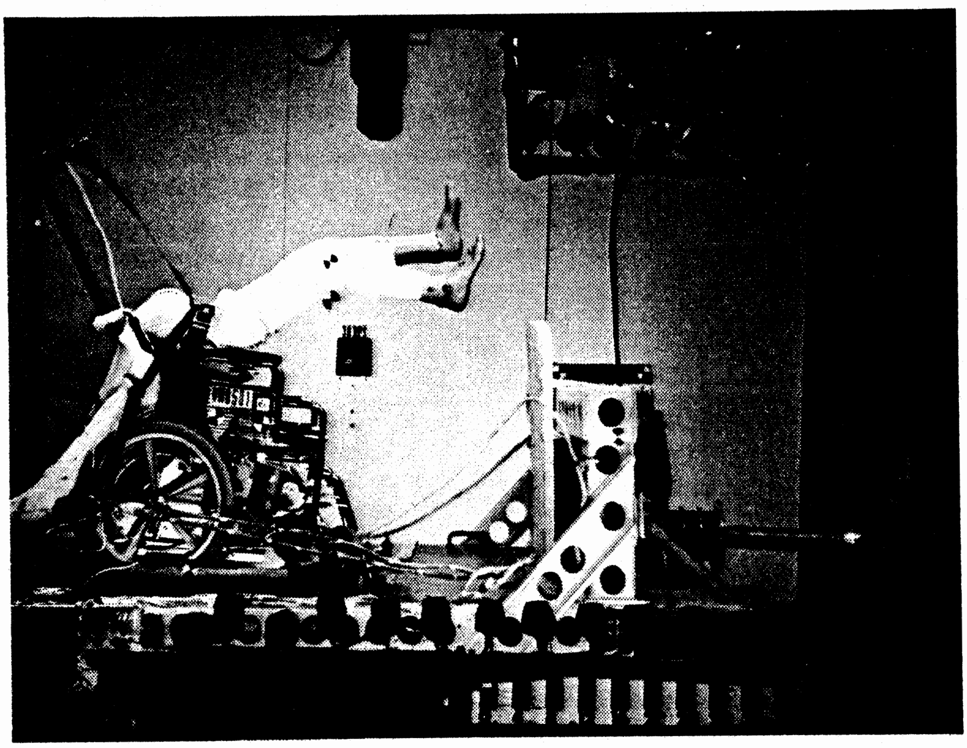


Figure 10. Stop-action photograph.

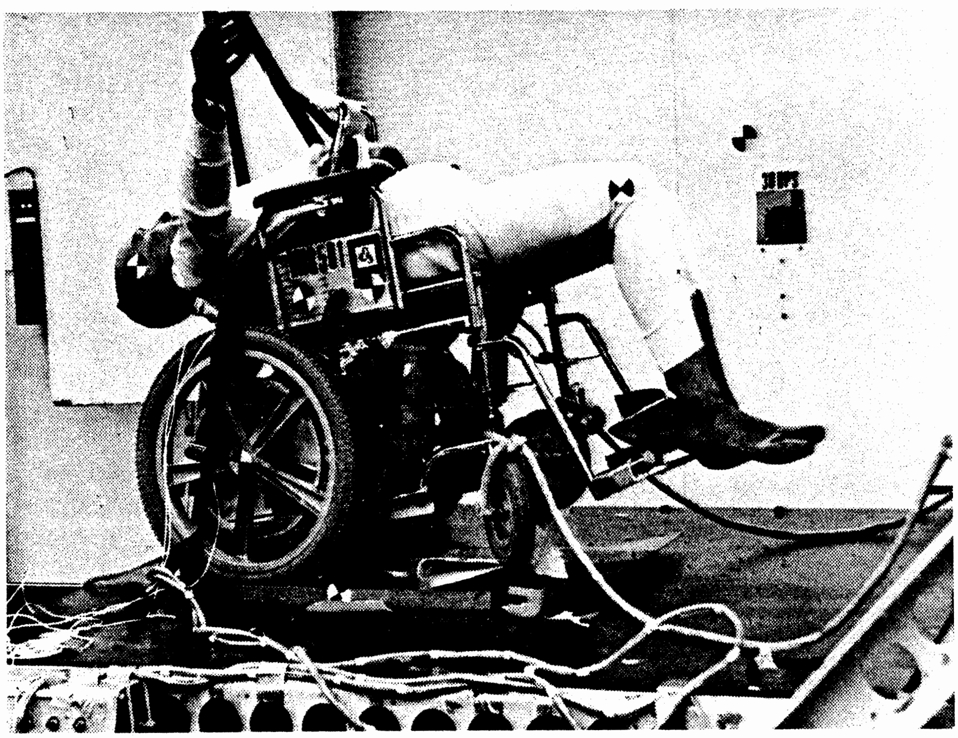


Figure 11. Post-test photograph.

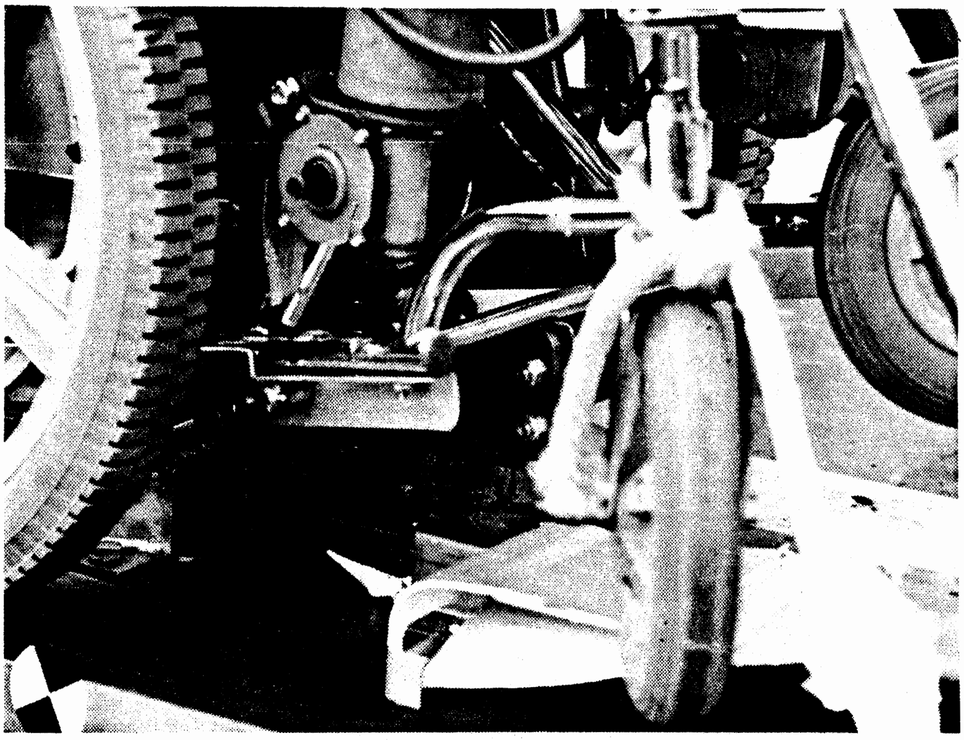


Figure 12. Post-test view of front retaining bracket showing bar out of slot.

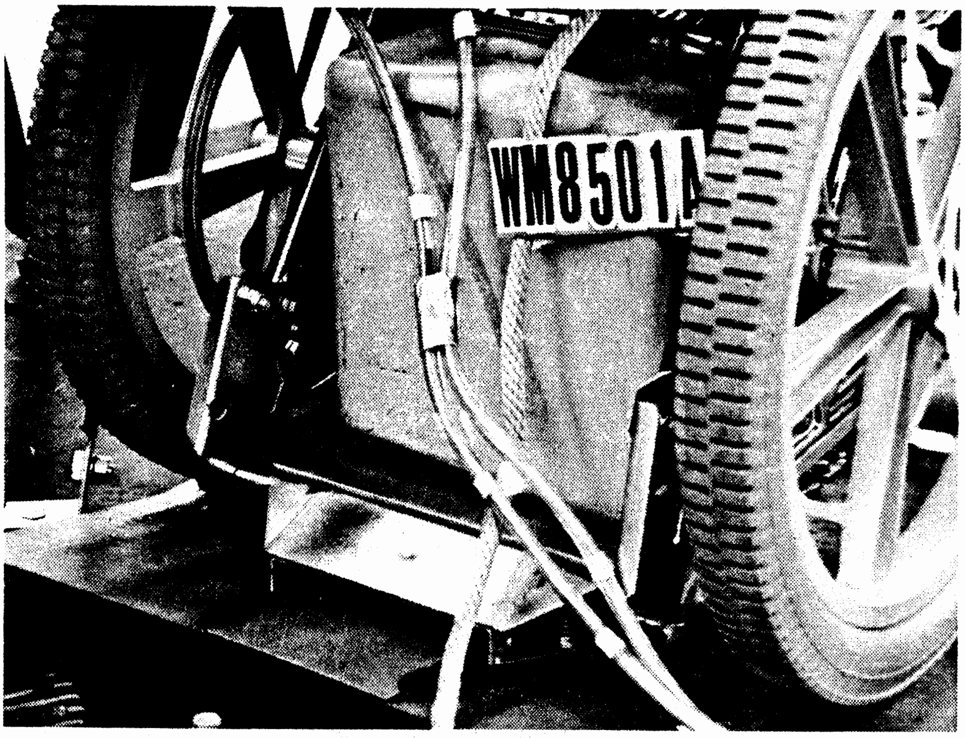


Figure 13. View of rear bar still captured in tie-down structure after impact. Note sheared bolt in foreground.

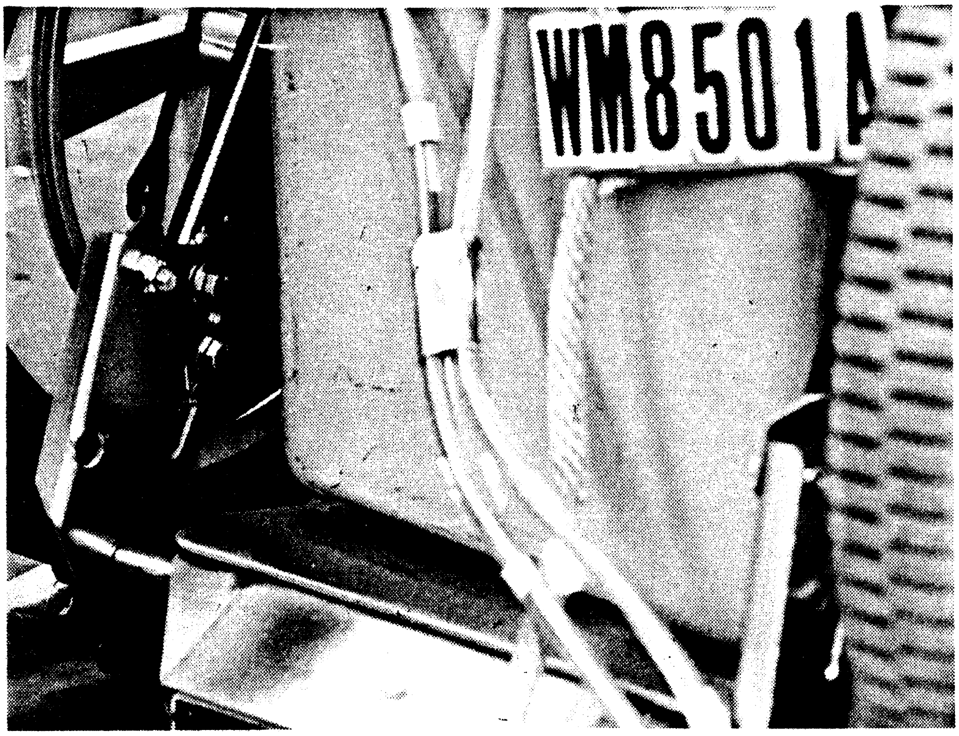


Figure 14. Close-up of left rear retaining bracket showing torn slot.

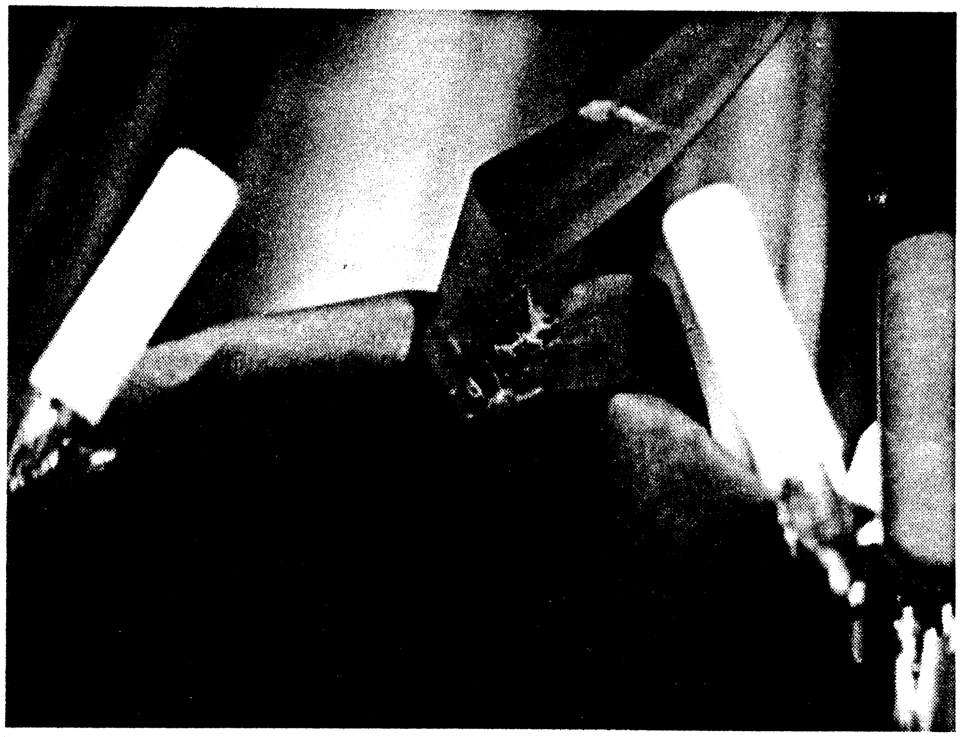


Figure 15. Shoulder/lap belt junction showing torn stitching after impact.

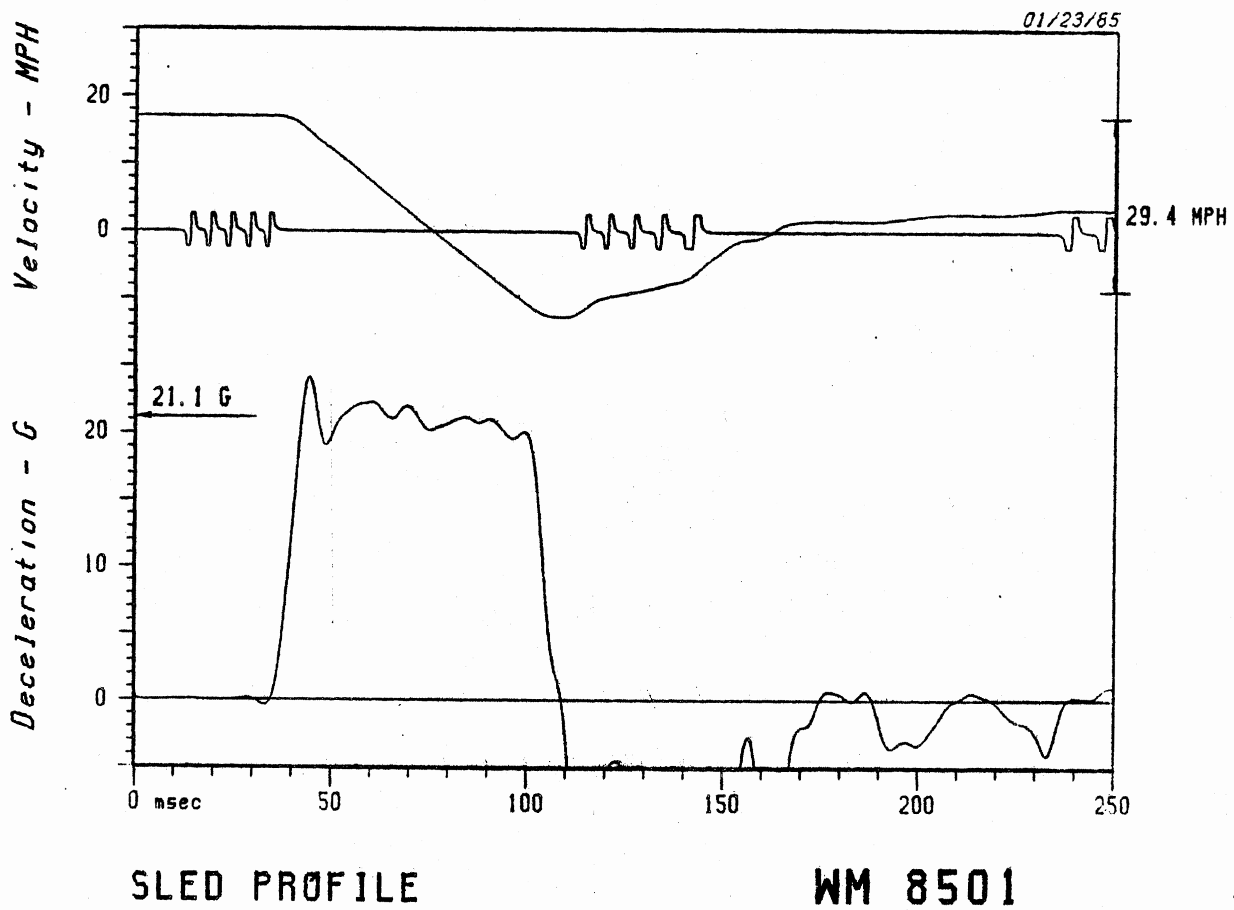


Figure 16. Sled velocity and deceleration profiles.

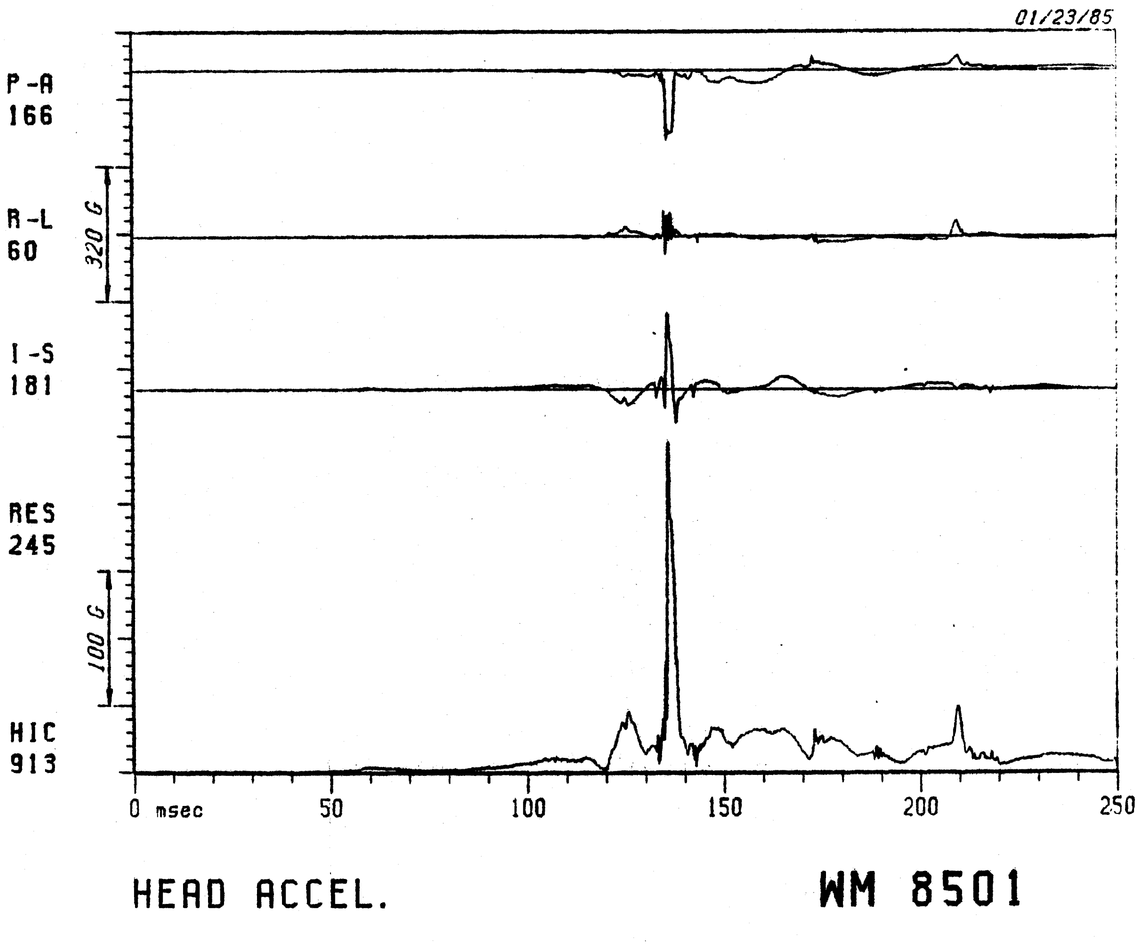


Figure 17. Head accelerations versus time.

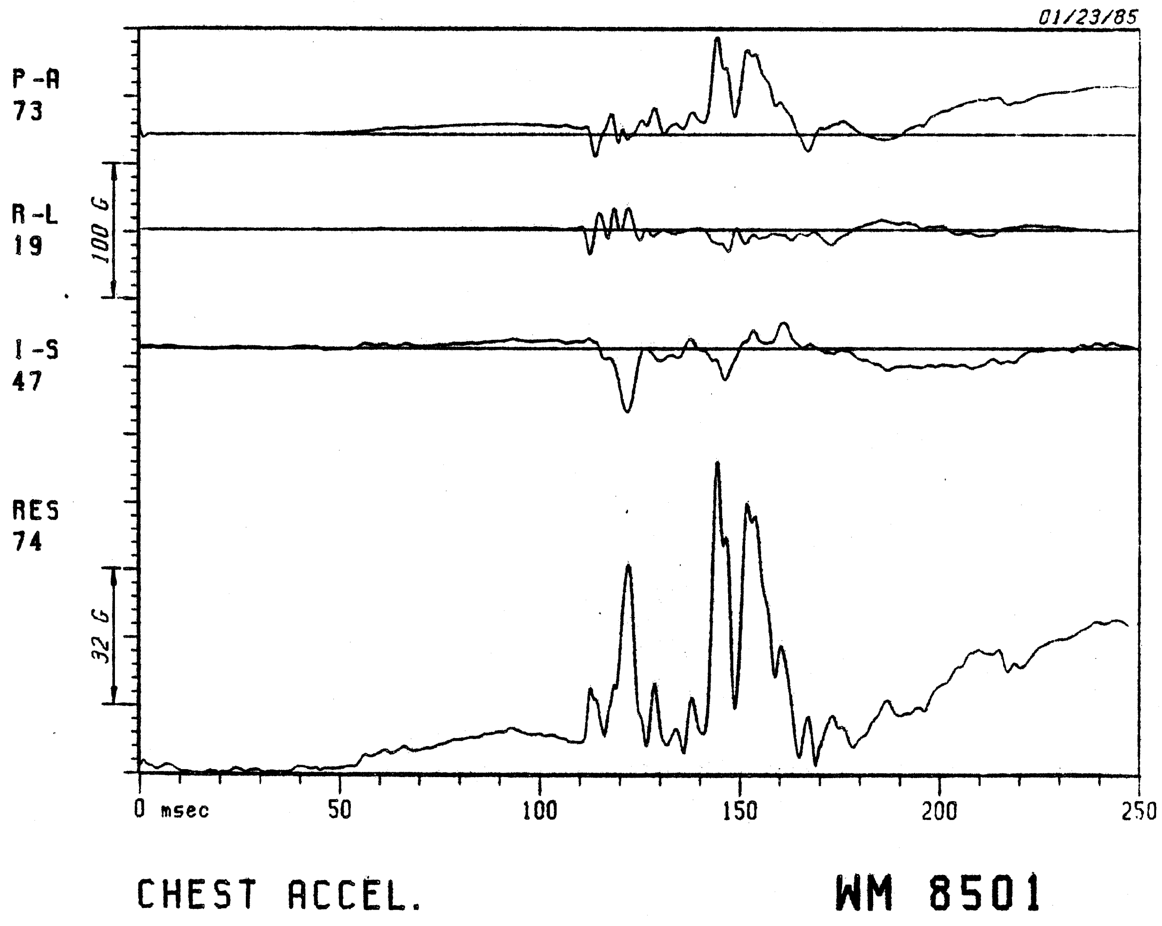


Figure 18. Chest accelerations versus time.

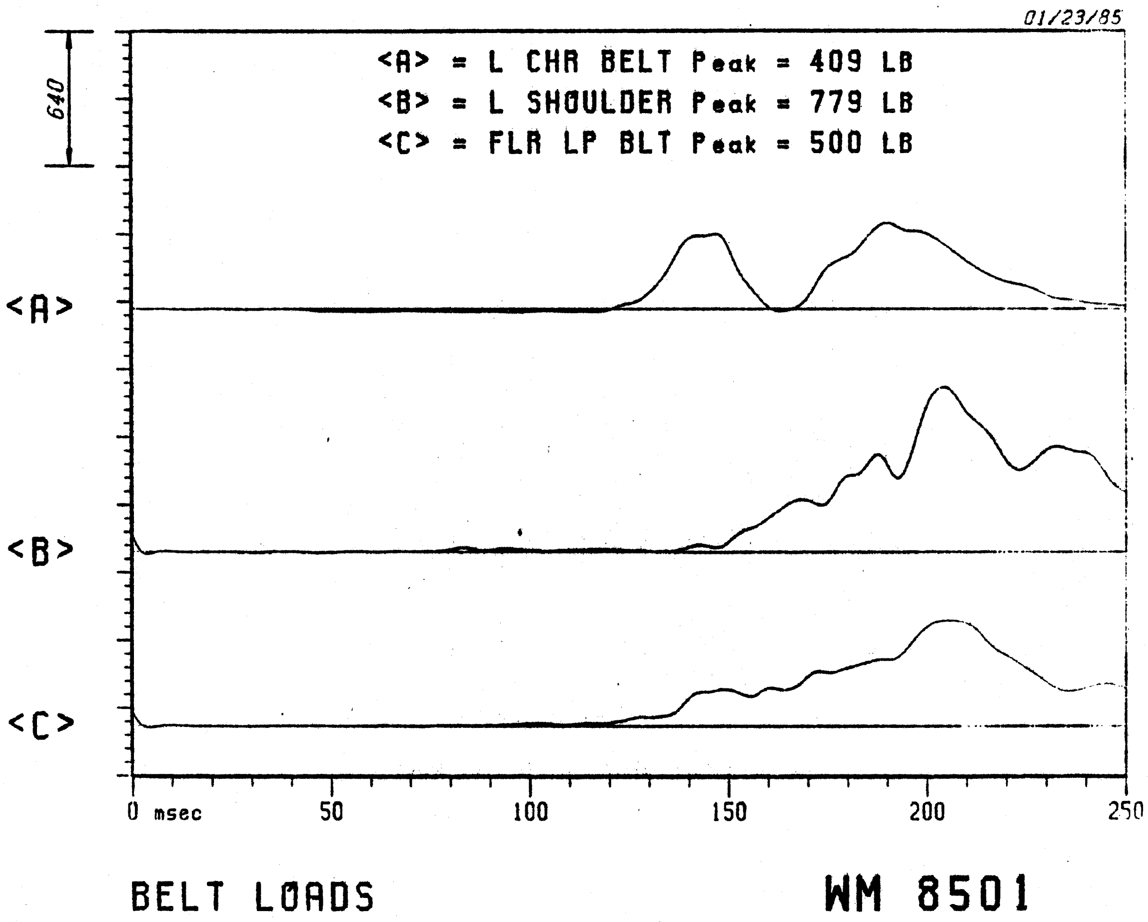


Figure 19. Belt loads versus time.

SUMMARY AND DISCUSSION

Because the wheelchair and dummy flipped backwards during the sled acceleration and entered the impact in this position, the results of this test must be considered invalid in terms of evaluating the performance of the CCI tie-down during standard occupant loading conditions. The fact that the wheelchair was allowed to flip backwards, however, is in itself a measure of tie-down performance. During sled start-up, a peak acceleration of about .5 g's may be reached. This is very low compared to rearward impact accelerations that could be experienced during rear collisions or from frontal collisions involving multiple impacts. Thus, if the tie-down was rendered ineffective during the sled acceleration, it could very likely be rendered ineffective in the real world.

The primary defect in the CCI tie-down was the excessive amount of slack or looseness in the rear retaining mechanism. In order for the rear bar to be easily captured and released, this looseness was built into the system. While the amount of freeplay was not measured prior to the test, it is estimated that it was on the order of an inch or more and, in any case, was sufficient to allow the front steel bar to come completely out of the front retaining bracket. Thus, one solution to preventing the chair from flipping on rear impacts and still have the slack in the rear mechanism would be to increase the length of the front slot to be significantly greater than the amount of wheelchair travel allowed.

This solution, however, ignores another important and detrimental consequence of having freeplay in the tie-down system. As pointed out in a study by California DOT (Stewart and Reinl, 1981), this "decoupling" between wheelchair and tie-down can lead to greatly amplified decelerations and forces resulting from the impact of the wheelchair with the tie-down structure. In the present test, the sheared grade 5 bolt and the torn bracket in the 10-gauge steel are evidence of these kinds of forces. It is also noted that the peak force measured in the wheelchair lap belt is quite low compared to what it would have been had the dummy been properly seated. It is therefore very questionable that the tie-down would have held up if the dummy and chair had not flipped backwards, and it is strongly recommended that the modified design significantly reduce or eliminate the freeplay in the tie-down system.

UMTRI

SLED IMPACT TEST

WM8502

INTEX NORTHEAST, INC.

WHEELCHAIR TIE-DOWN

FOR DRIVERS

Test Date:

January 23, 1985

INTRODUCTION

The purpose of this test was to evaluate the effectiveness of the current production wheelchair tie-down system developed by Intex Northeast, Inc. (formerly "The Claw" by Falcon Equipment Specialties, Inc.) for handicapped drivers of vans. In addition to a lap seat belt attached to the wheelchair via the tie-down hardware, a vehicle-anchored shoulder belt was used to provide occupant restraint for the 50th-percentile male anthropomorhic test dummy.

TEST SETUP

*	Wheelchair Tie-Down	Intex Northeast, Inc. power tie-down.
*	Weight of Tie-down hardware on wheelchair	12 lbs, 10 oz.
*	Wheelchair	E&J 3P power wheelchair
*	Occupant Restraint	lap belt to wheelchair shoulder belt to vehicle
*	Test Dummy	50th-percentile male (167 lbs.)
*	Orientation of Test	Forward facing, frontal impact
*	Desired Impact Velocity	30 mph
*	Desired Deceleration	20 g's

Figure 1 shows the Intex tie-down structure that bolts to the lowered vehicle floor (i.e., the stationary floor of the power pan) while Figures 2 through 4 show the assembly of rectangular aluminum plates (2024-T3), steel cross bars, and square steel box tube structures that attach to the wheelchair by means of two "U" brackets on each side as shown. The weight of the tie-down hardware attached to the wheelchair is 12 lbs. 10 oz. and the base of the vehicle-anchored structure measures 5" by 20 inches. Figures 5 and 6 show front and rear views of the wheelchair locked in position on the sled with the front steel bar captured in the front hook of the tie-down structure and the rear steel bar retained by the wider rear hook. In this position, rearward motion of the wheelchair is prevented by the linkage on the front hook, which is driven up behind the front bar when the actuator is powered.

The tie-down bars are made of 3/4-inch diameter solid steel and are fastened to the 1/8-inch thick aluminum side plates by means of steel pins placed outboard of steel washers. These bars fit freely through slots in the centrally located steel plates that attach to the square box tubes which run parallel to the bars. After some amount of bending takes place in the bars, resistance to bending will increase as the square box tubes begin to take up the loads transferred through the longitudinal plates. Because these square cross pieces are bolted to the side plates, folding of the wheelchair cannot be accomplished without significant effort and the use of tools. The lowest clearance of the wheelchair is 1-3/4" under the bottom edge of the aluminum side plates.

Figures 7 through 10 show different views of the wheelchair and dummy in position prior to the test. The 50th-percentile male dummy weighing 167 pounds (Hybrid II) was restrained to the wheelchair by a lap belt which anchored to the rectangular side plates just behind the wheelchair axles. A single shoulder belt that anchored to the floor on the right side of the chair and to the simulated "B" pillar above and behind the dummy's left shoulder provided upper torso restraint. This shoulder belt was placed between the wheelchair back post and the chair arm on the right side to achieve optimum fit to the shoulder and chest. Adjustment of the shoulder belt length was facilitated by a steel buckle which ended up positioned on the dummy's chest in the pre-test setup. Three GSE seat belt load cells measured the forces in the upper shoulder belt webbing, the right lap belt webbing, and the right floor belt webbing.

The wheelchair with batteries and motors weighed 152 lbs. of which 12 lbs., 10 oz. was due to the tie-down hardware. The battery box support brackets were lowered about 1" so that the box cleared the tie-down hardware. Sled pressures were set to achieve a sled velocity differential of 30 mph and a sled deceleration level of 20 g's.

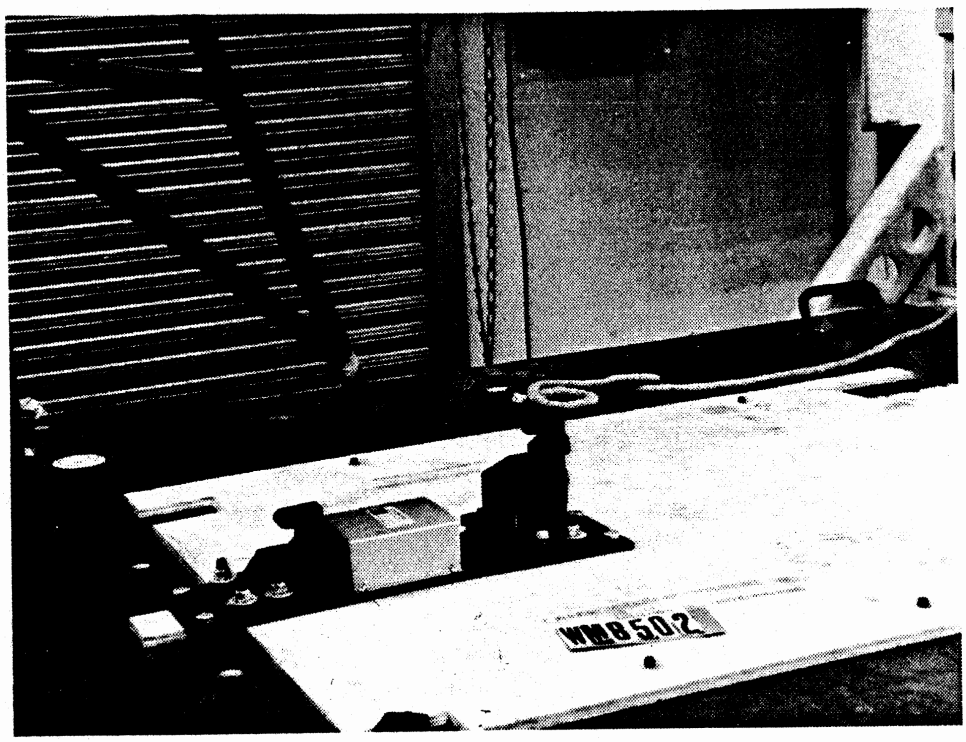


Figure 1. Floor-anchored tie-down structure.

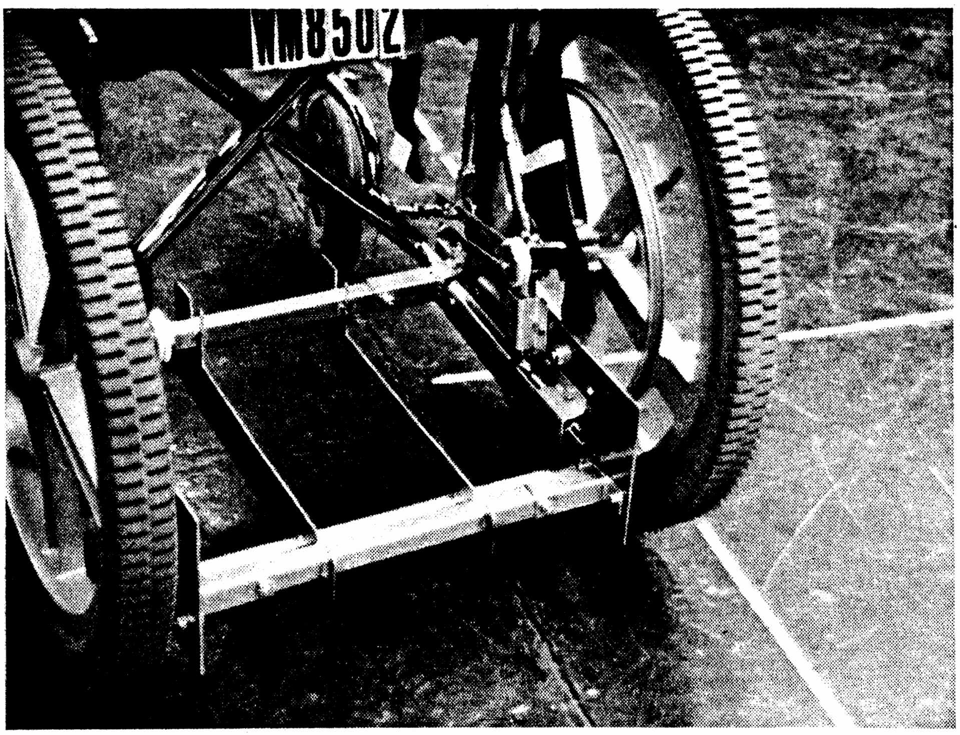


Figure 2. Tie-down hardware attached to wheelchair.

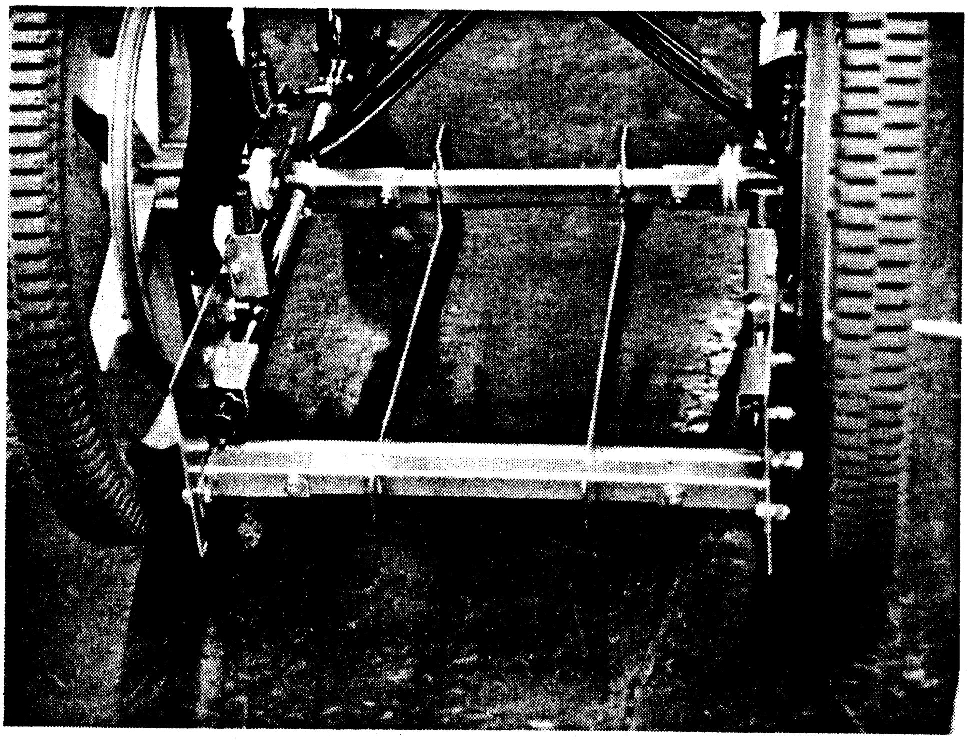


Figure 3. Tie-down hardware attached to wheelchair.

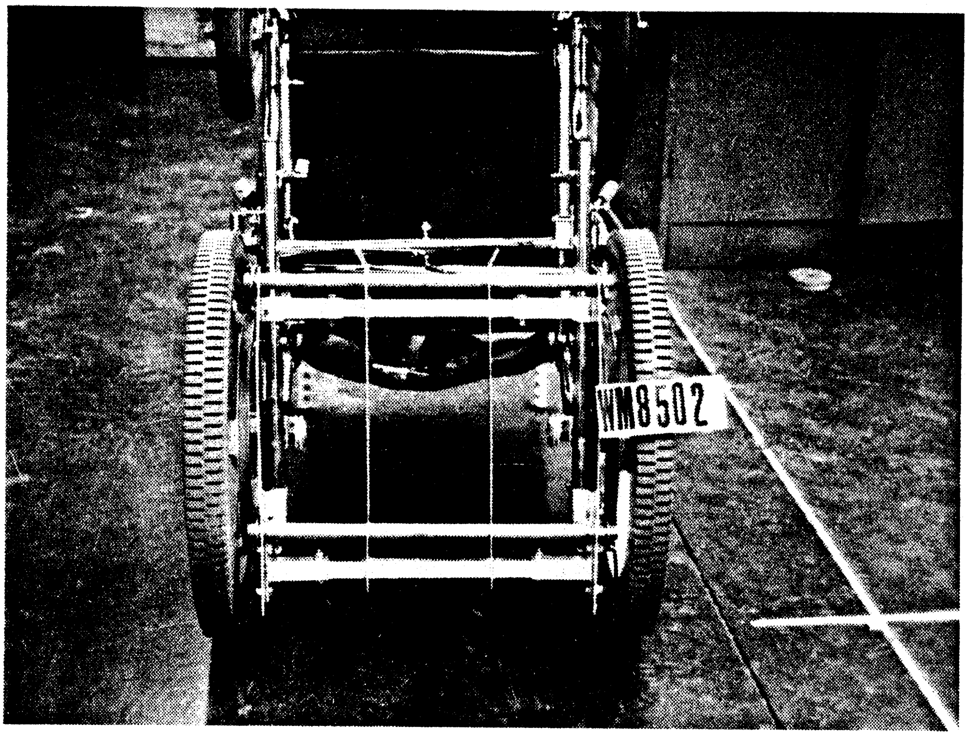


Figure 4. Bottom view of wheelchair, showing parallel steel bars and square box tubes.

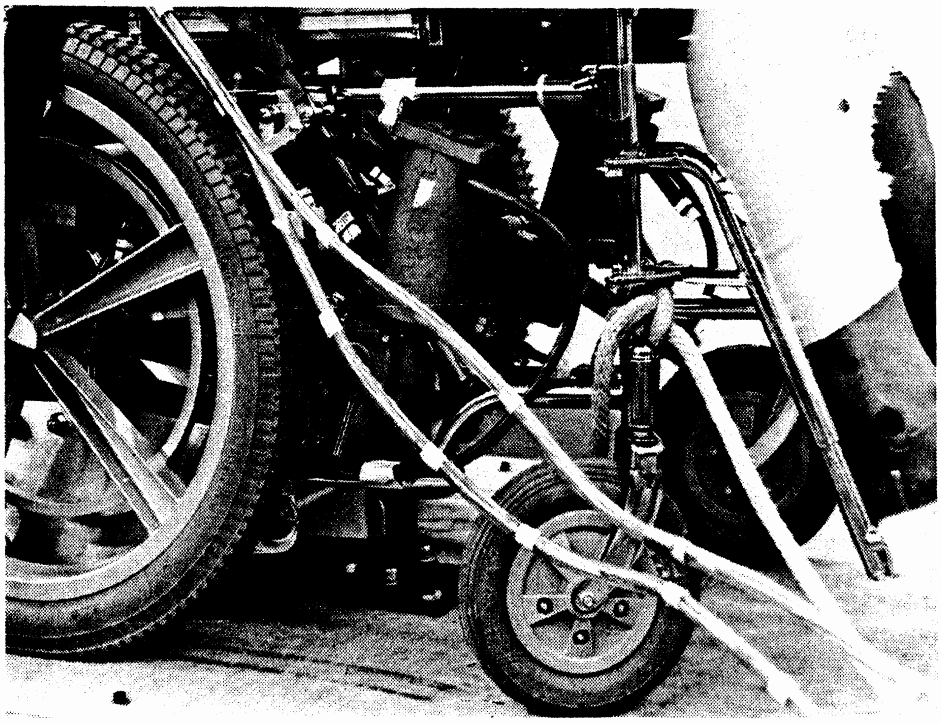


Figure 5. View under front of wheelchair, showing front bar captured in front hook.

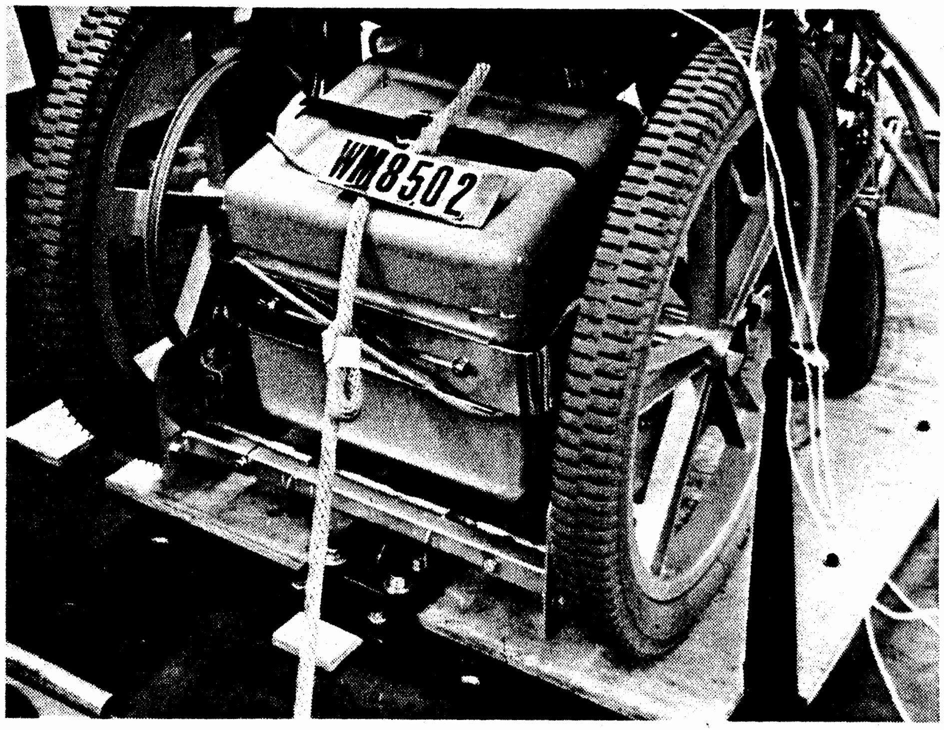


Figure 6. Rear view showing rear tie-down bar captured in rear retaining hook.

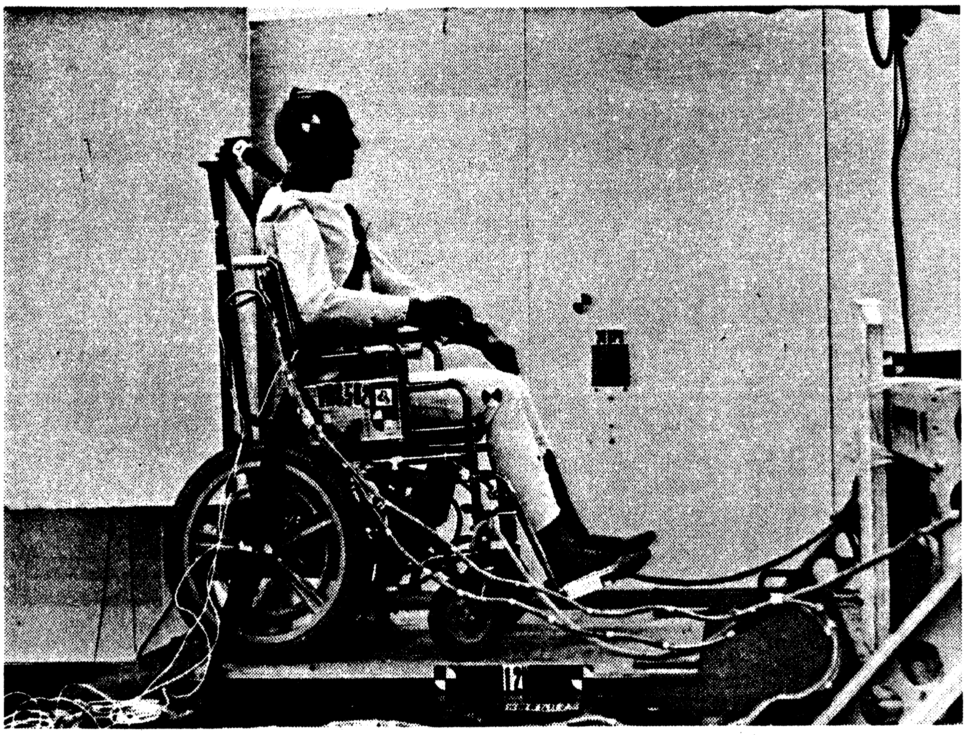


Figure 7. Side view of test setup.

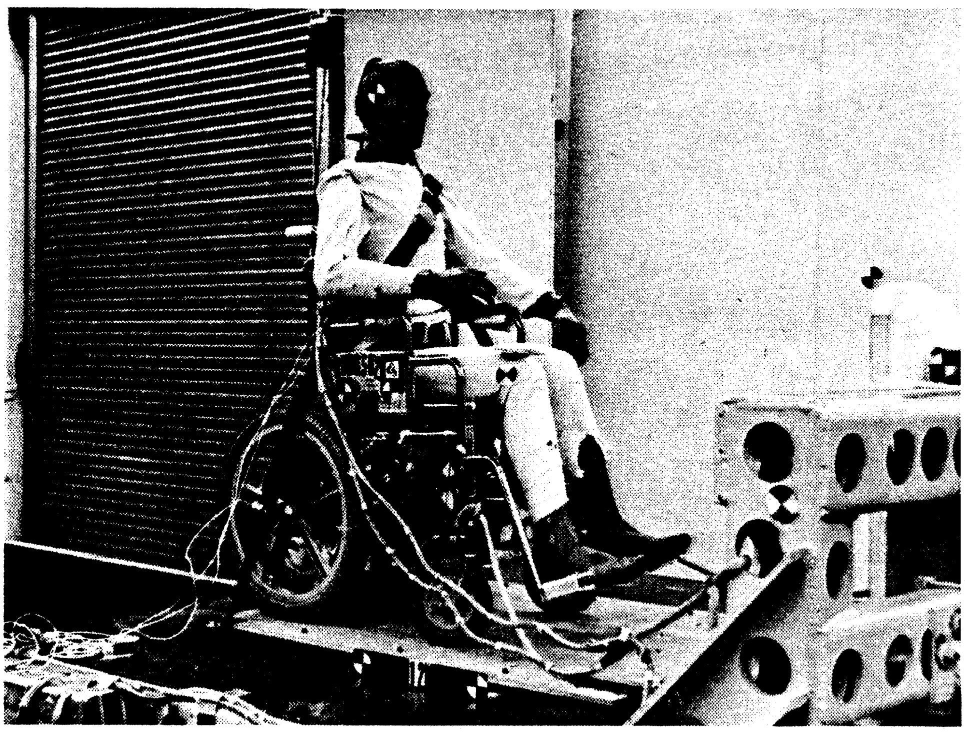


Figure 8. Oblique view of test setup.

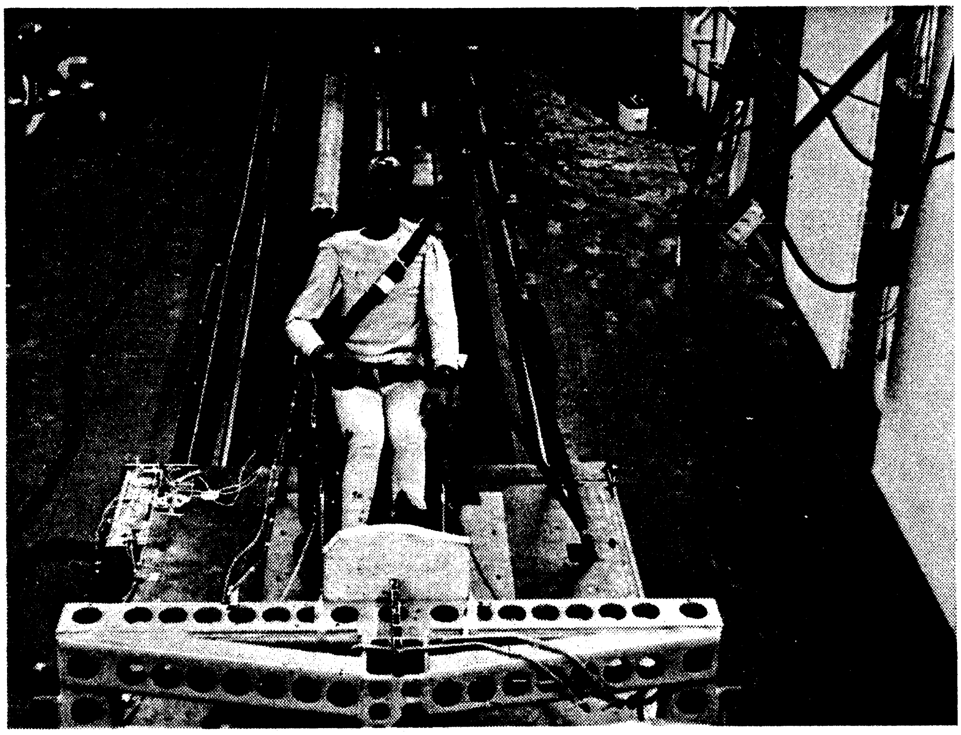


Figure 9. Front view of test setup.

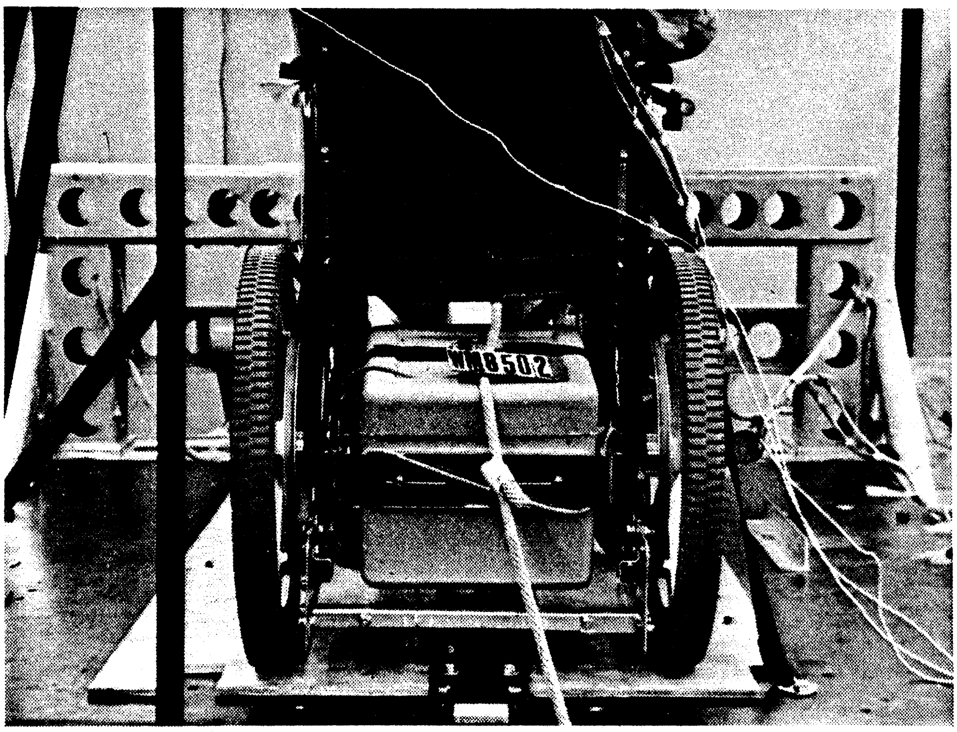


Figure 10. Rear view of test setup.

RESULTS

* Actual Sled Deceleration .... 17.4 g's
* Actual velocity .... 28.1 mph
* Peak force right chair lap belt ..... 1260 lbs.
* Peak force left shoulder belt .... 2505 lbs.
* Peak force right floor belt .... 1041 lbs.
* Peak resultant head acceleration .... 48 g's.
* Head Injury Criteria 426
* Peak resultant chest acceleration ... 43 g's

Figure 11 shows the polaroid sequence photograph of the impact, and Figure 12 shows a stop-action photograph taken during the impact. Figures 13 through 15 show different views of the wheelchair and dummy after the test, while Figures 16 and 17 show the tie-down hardware after removing the battery box. The wheelchair was effectively restrained by the tie-down, and the dummy was well restrained in the chair by the combination of lap and shoulder belt. Some bending in the steel bars occurred, but the longitudinal brackets and square tubing appeared to be effective in limiting the excursion of the wheelchair. Analysis of the high-speed films indicated maximum wheelchair excursions of about 3-1/2 inches forward and 5 inches up at the hub of the large wheels. That the inside longitudinal plates transferred significant force to the square tubing is indicated by the fractures at the slots shown in Figure 18. The primary damage to the wheelchair was the bent front frame as shown in Figure 19.

Figure 20 shows the sled velocity and deceleration profiles. A velocity differential of 28.1 mph and an average deceleration of 17.4 g's were achieved. The reason these values are lower than desired is not immediately apparent but probably relates to the manner in which the potential energy of the impacting mass of the wheelchair and dummy was absorbed by the tie-down structure and restraint belts.

Figures 21 through 23 show the head accelerations, chest acceleration and belt load time histories. Resultant accelerations and the Head Injury criteria (HIC) are well below existing tolerance levels for the able-bodied population. The high value of peak shoulder belt force indicates that some of the restraint of the wheelchair may have been due to the shoulder belt's acting on the chair through the chest of the dummy.

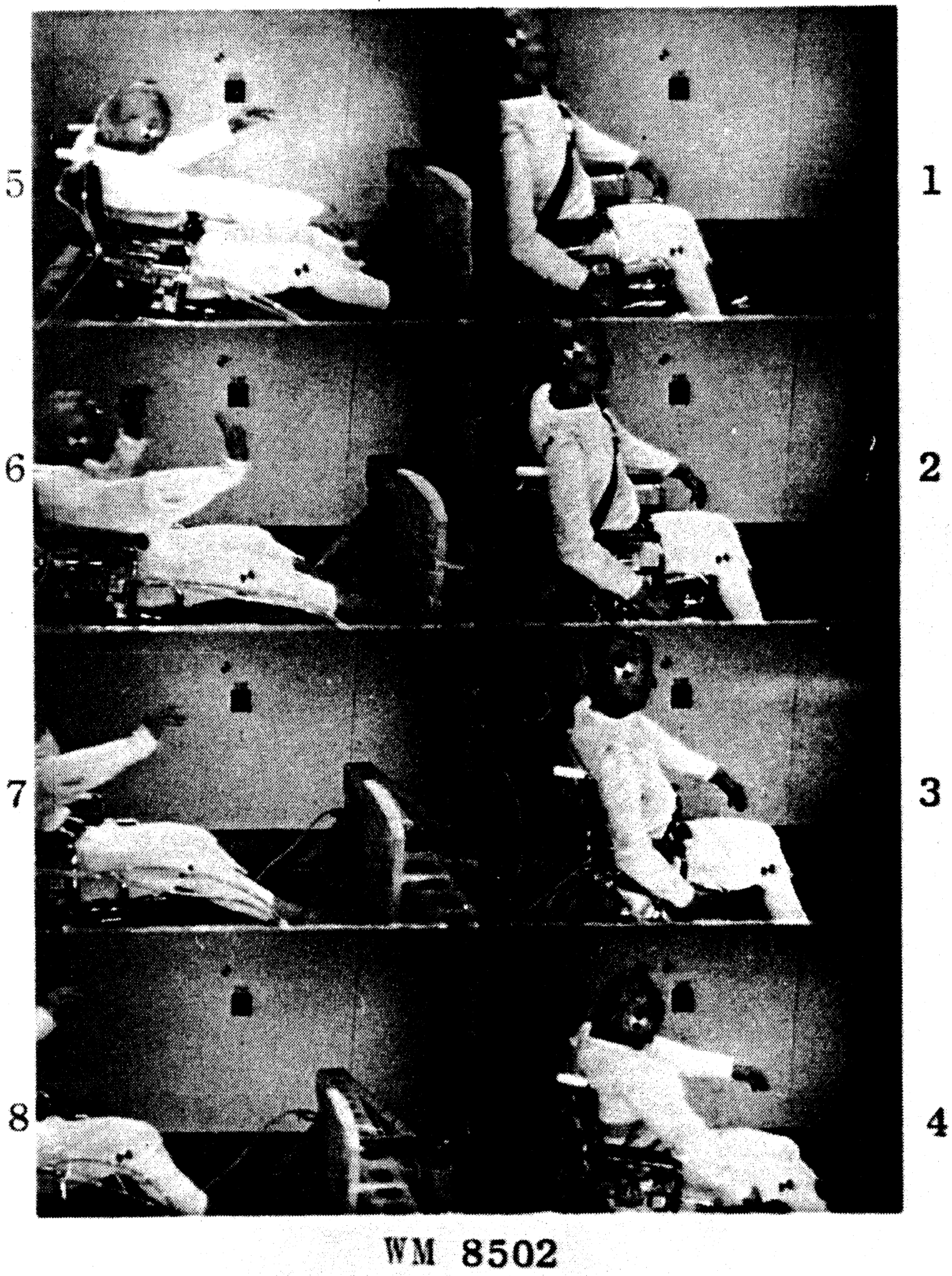


Figure 11. Polaroid graph sequence photograph.

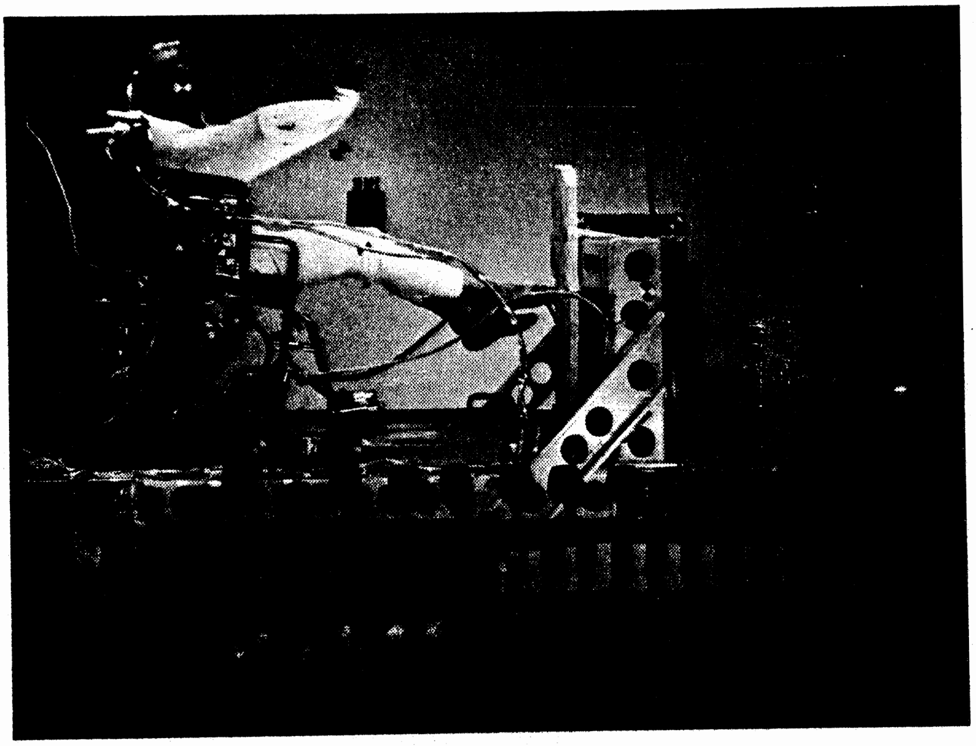


Figure 12. Stop-action photograph.

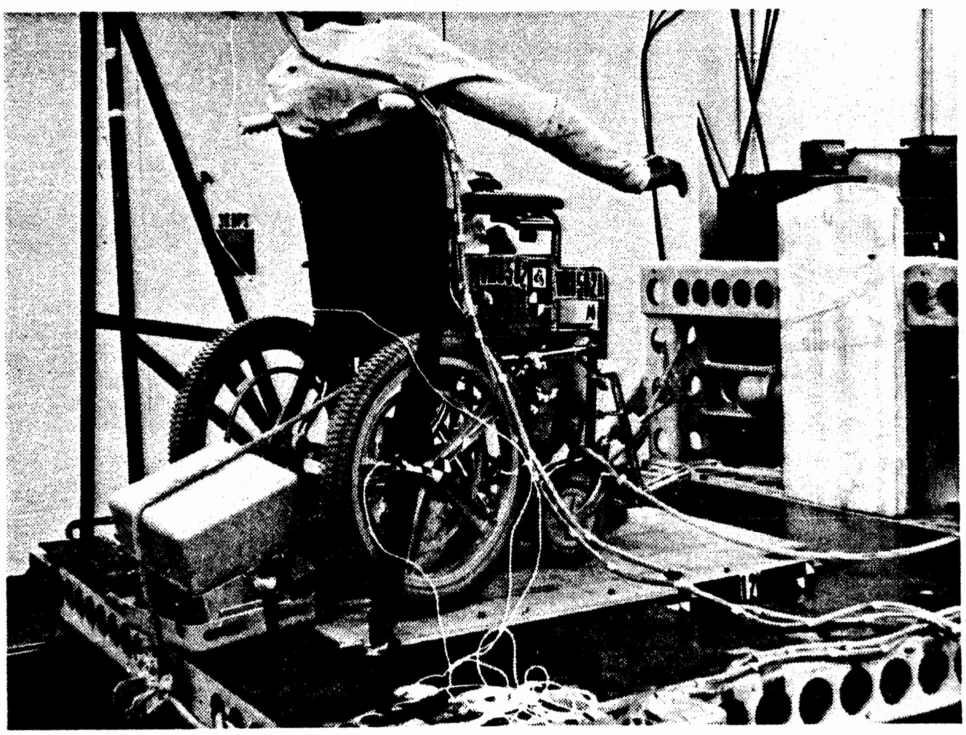


Figure 13. Rear oblique view, post-test.

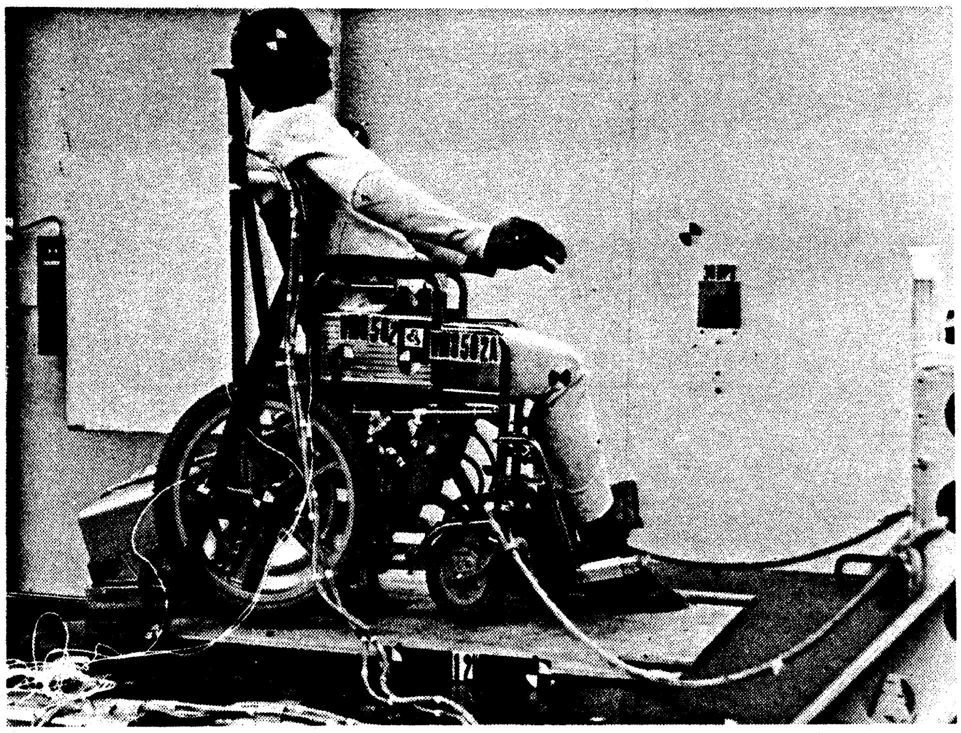


Figure 14. Side view, post-test.

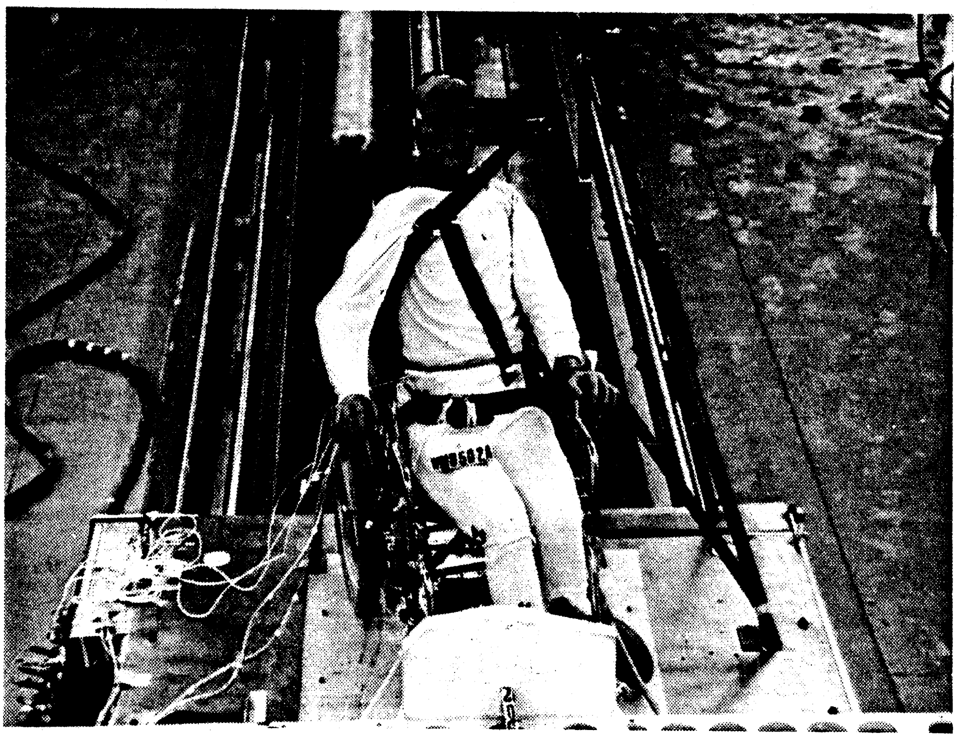


Figure 15. Front view, post-test.

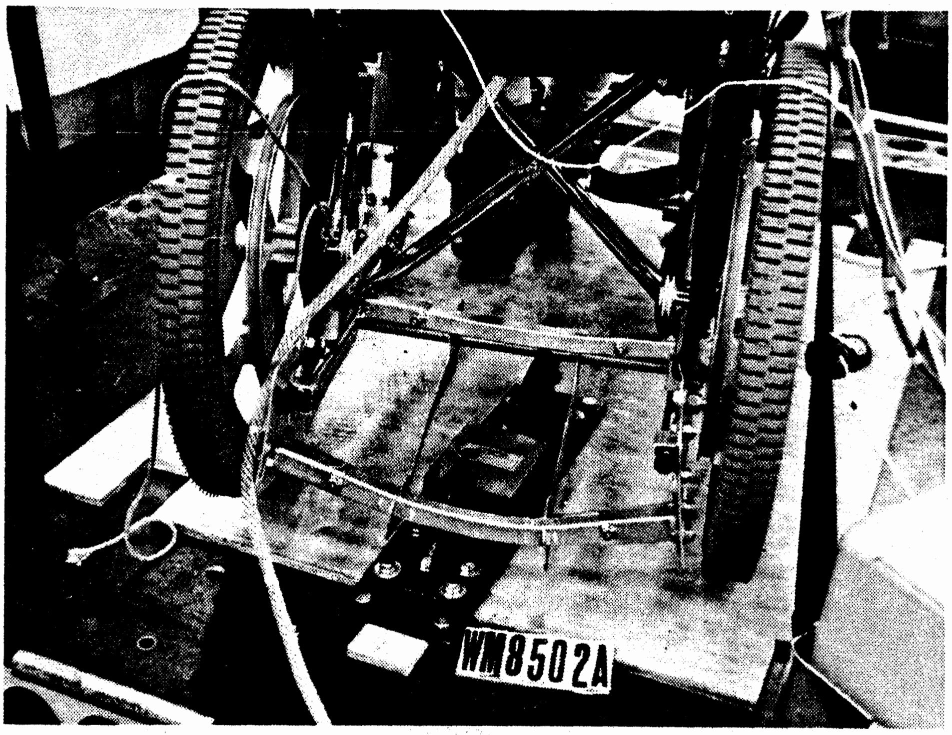


Figure 16. View of tie-down hardware after removing battery box.

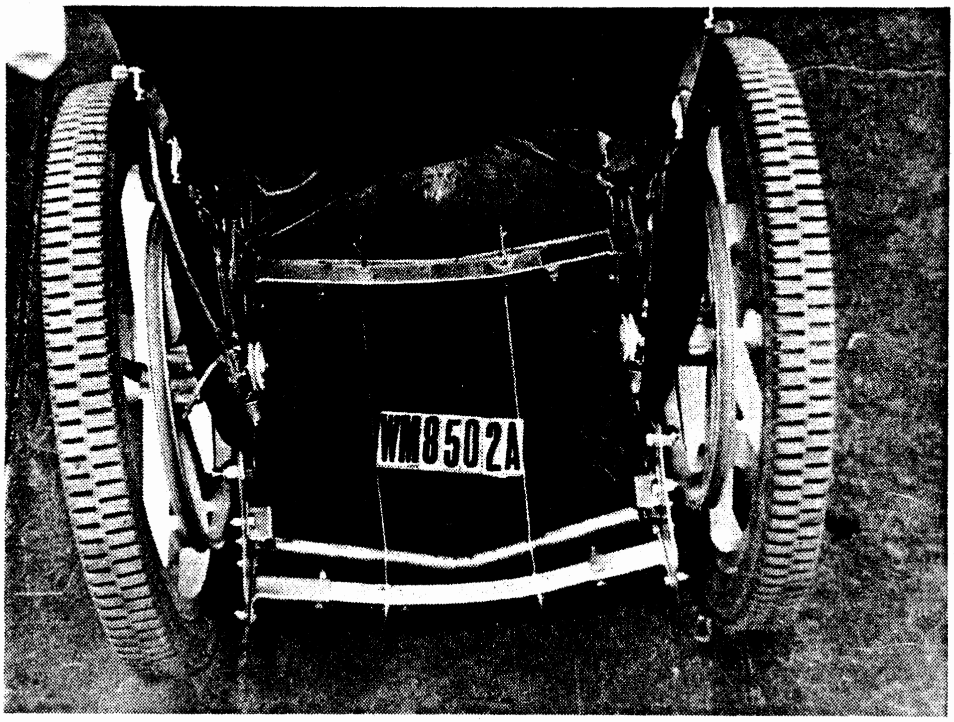


Figure 17. View of tie-down hardware, showing bending in rear bar.

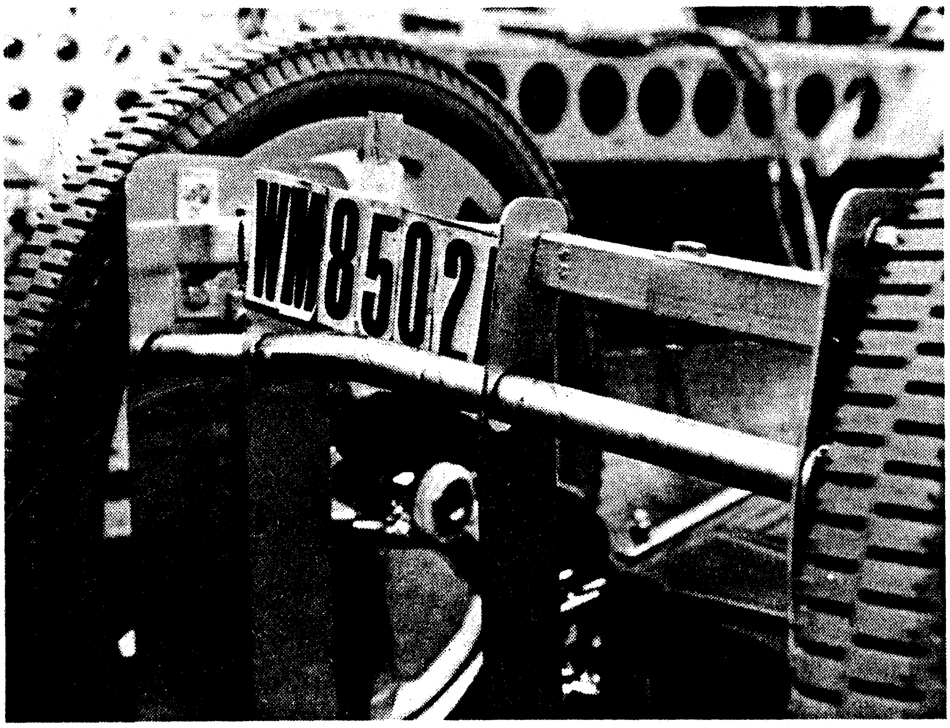


Figure 18. Close-up of rear tie-down bar and longitudinal plates, showing fractures at slots.

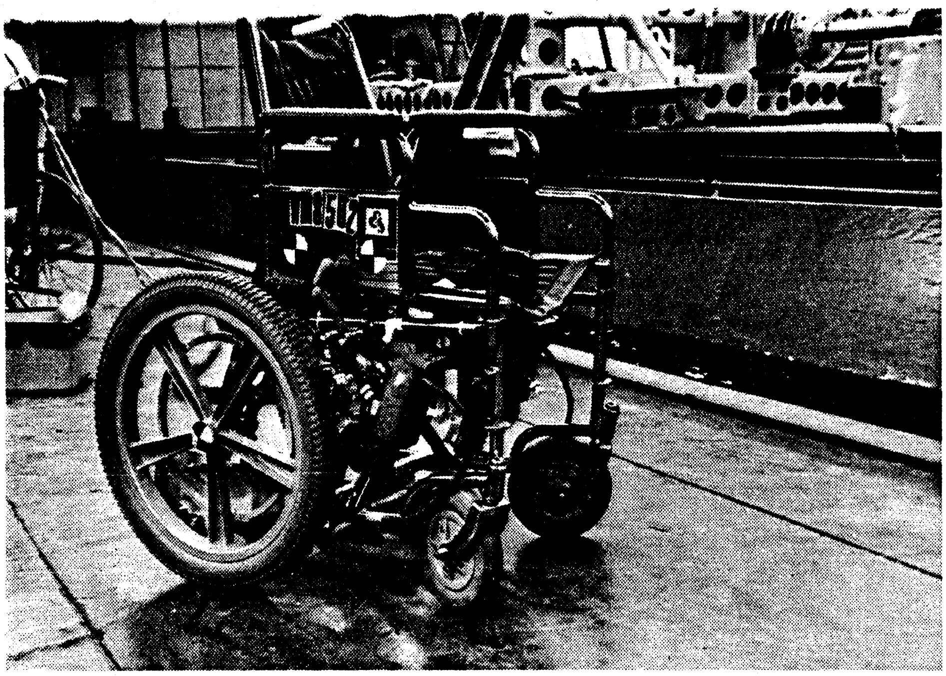


Figure 19. Wheelchair after impact test.

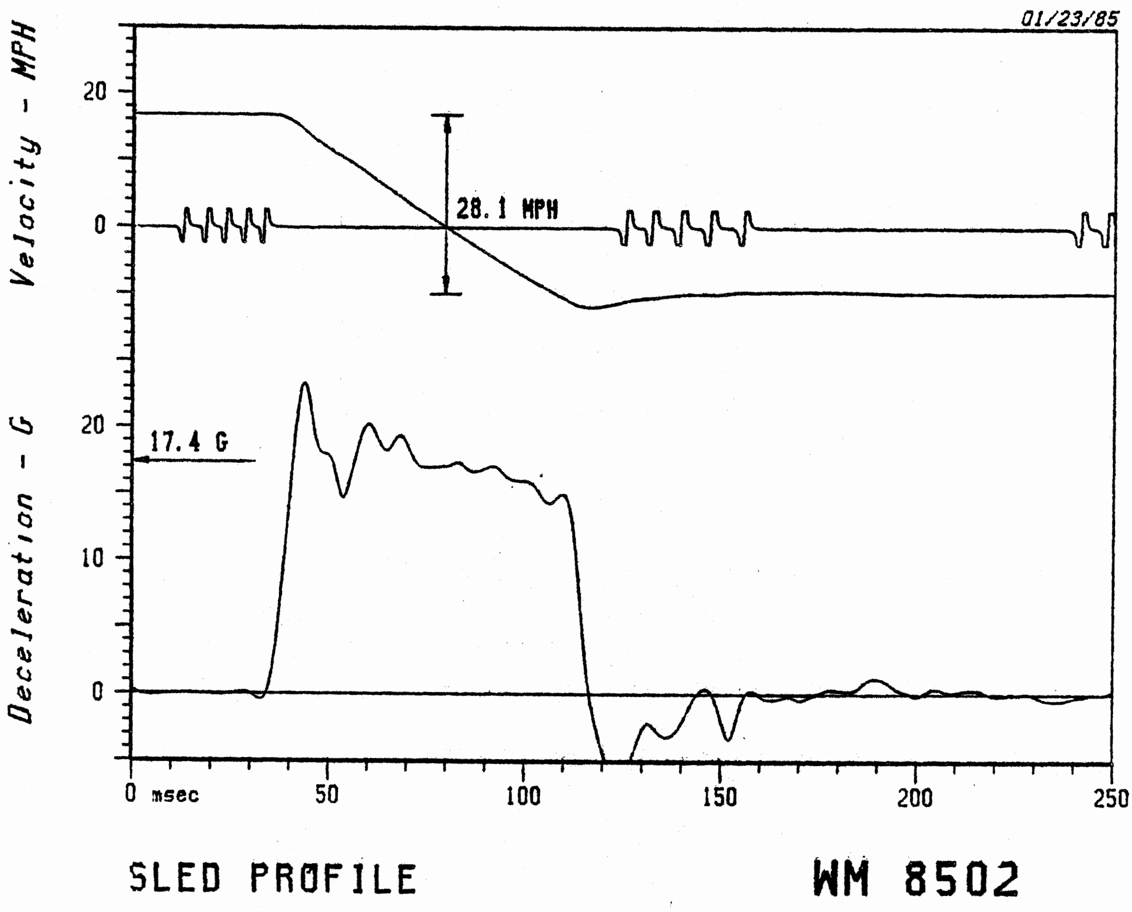


Figure 20. Sled velocity and deceleration profiles.

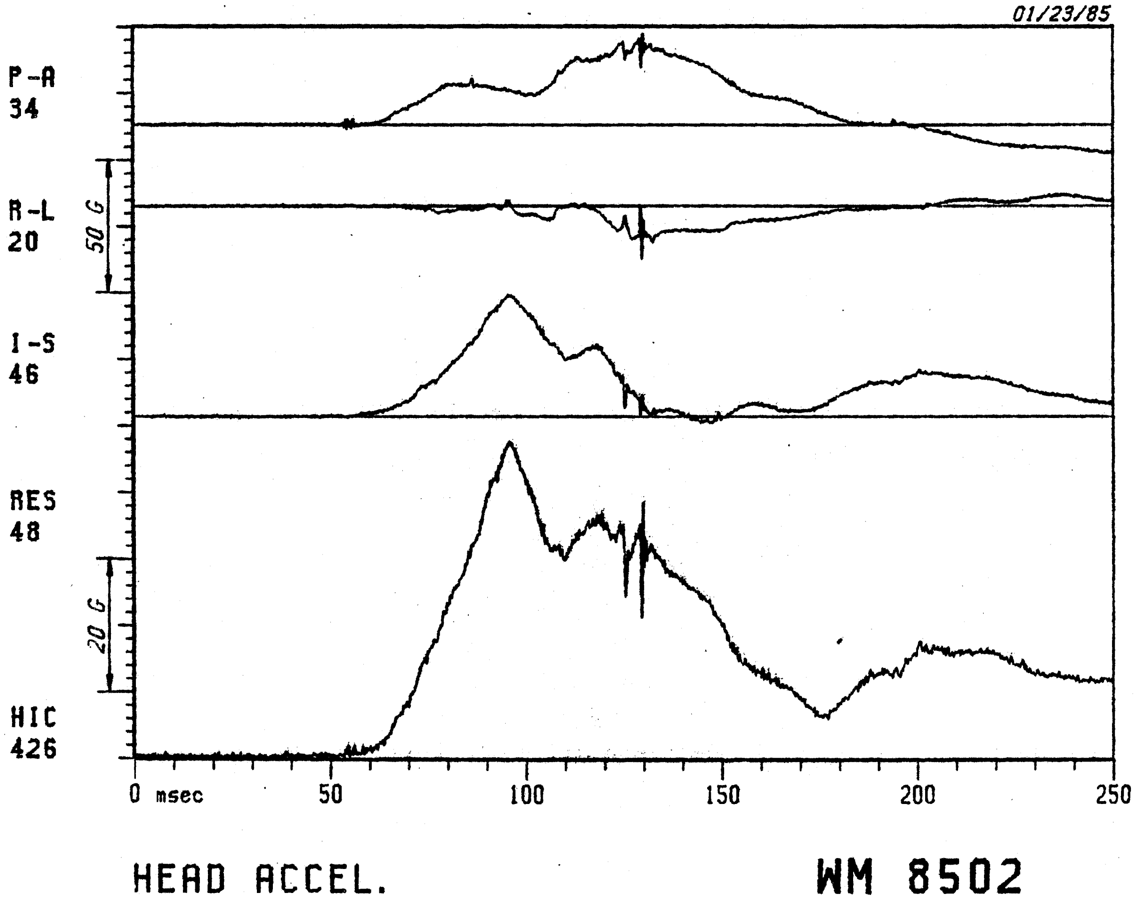


Figure 21. Head accelerations versus time.

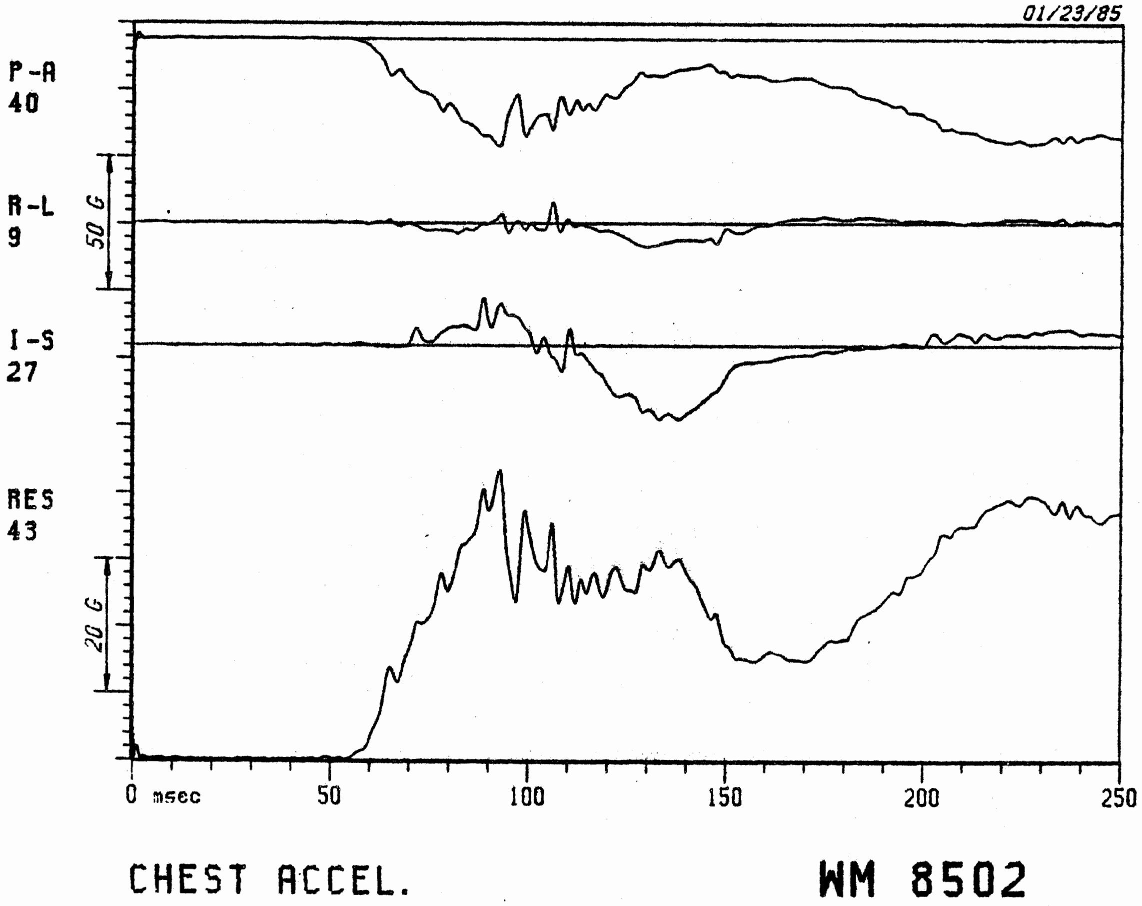


Figure 22. Chest accelerations versus time.

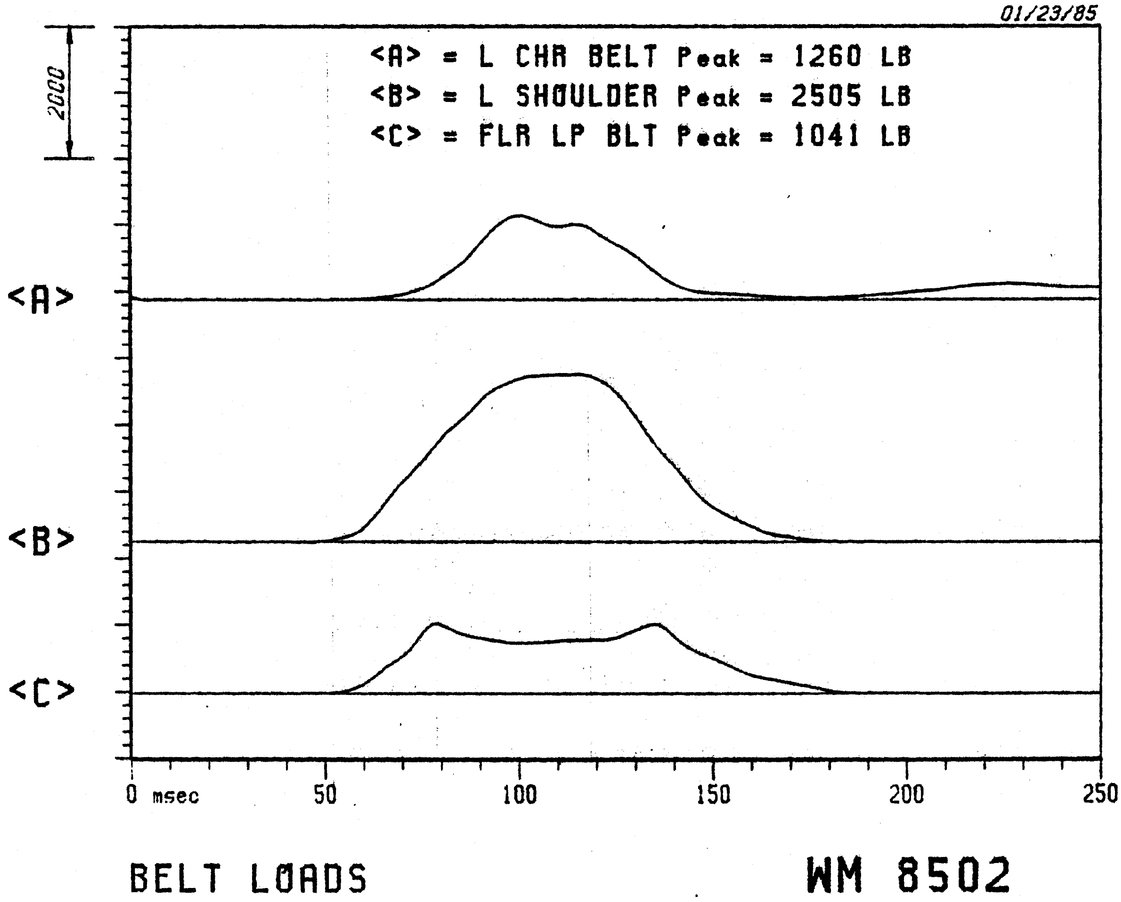


Figure 23. Belt loads versus time.

SUMMARY AND DISCUSSION

The Intex tie-down provided very good wheelchair securement during the impact test, and the dummy was well restrained in the wheelchair. The high peak load in the shoulder belt of 2505 pounds is, however, a possible indication that the shoulder belt was loaded with the wheelchair as well as the dummy (i.e., that the shoulder belt assisted in wheelchair restraint). This is an undesirable result if it did occur, since it places unnecessary and excessive force on the occupant and is one reason that previous tests of tie-downs have been without vehicle-anchored belts. If a tie-down is effective with only a lap belt to the wheelchair restraining the test dummy, one can be sure that it will be effective when a vehicle-anchored occupant restraint is used and that the occupant restraint is not assisting with wheelchair securement. This also represents a likely real-world loading condition, since many occupants may not be provided with a shoulder restraint.

UMTRI

SLED IMPACT TEST

WM8503

TARGET INDUSTRIES

WHEELCHAIR TIE-DOWN

FOR DRIVERS

Test Date:

January 23, 1985

INTRODUCTION

The purpose of this test was to evaluate the effectiveness of a production wheelchair tie-down system developed by Target Industries for handicapped drivers of vans. The system does not include a lap belt to the wheelchair, but one was added to provide comparable tie-down loading conditions to tests WM8501 and WM8502. A vehicle-anchored three-point restraint system was also used to provide occupant restraint for the 50th-percentile male anthropomorhic test dummy.

TEST SETUP

- * Wheelchair Tie-Down .... Target Industries' power tie-down system.
- * Weight of Tie-down hardware on wheelchair .... 27 lbs., 3 oz.
- * Wheelchair .... E&J 3P power wheelchair
- * Occupant Restraint .... lap belt to wheelchair plus 3-point belt to vehicle
- * Test Dummy .... 50th-percentile male (167 lbs.)
- * Orientation of Test .... Forward facing, frontal impact
- * Desired Impact Velocity ..... 30 mph
- * Desired Deceleration .... 20 g's

Figures 1 and 2 show the wheelchair with tie-down hardware attached, and Figure 3 shows the tie-down structure that bolts to the vehicle floor or power pan. The equipment is similar to previously tested "Speedlock" hardware,but the structure attached to the chair has been significantly increased in strength to decrease the amount of bending. The motorized system tested added over 27 pounds to the weight of the wheelchair. As shown in Figures 4 and 5, the front portion bolts to the lower horizontal frame members just behind the front posts and castor supports. The back cross-bar bolts to the lower horizontal frame member just forward of the rear axle posts. Attachment is by means of "U" bolts and brackets as shown. Connecting the two cross bars down the center of the wheelchair is an upside-down "U" structure which is flared at the front and which fits over the steel floor-anchored tie-down structures. The wheelchair is captured and locked into position by means of two steel pins attached to a pivoting steel bar. Movement of the pins into and out of holes in the longitudinal bracket on the wheelchair and slots in the floor-anchored tie-down structure is accomplished by an electric motor which drives the pivoting bar open or closed.

The floor-anchored structure occupies a rectangular floor space area 1-1/2 by 22-inches and the lowest clearance point of the wheelchair is 2-1/2 inches at the center of the rear tie-down cross-bar. With the tie-down hardware attached, the wheelchair cannot be folded.

Figures 6 through 10 show the wheelchair locked in position with the 50th-percentile anthropomorphic test dummy. The occupant restraint included a lap belt that was tied to the wheelchair at the junctions of the horizontal seat frame members and the seat back posts. A three-point vehicle-anchored restraint system was bolted as shown and placed between the seat back posts and the wheelchair arms to achieve appropriate positioning on the dummy. The shoulder belt anchor point was positioned 15 inches outboard of the center of the wheelchair and 9 inches back from the seat back upholstery. The right side floor belt anchorage was positioned approximately 3 inches behind and 3 inches outboard of the rear wheel hub. GSE seat belt load cells were placed on the right chair lap belt, the right side floor belt, and the shoulder belt to measure webbing tensions during impact loading. Sled pressures were set to achieve a velocity differential of 30 mph and an average deceleration of 20 g's.

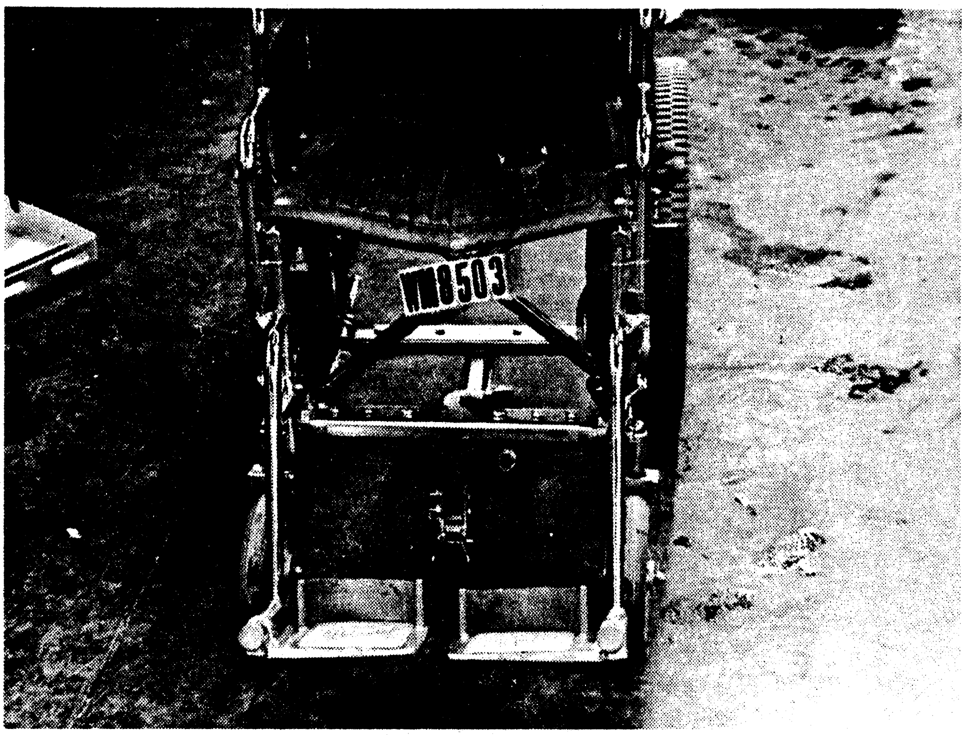


Figure 1. Front view of wheelchair, showing "Speedlock" hardware attached.

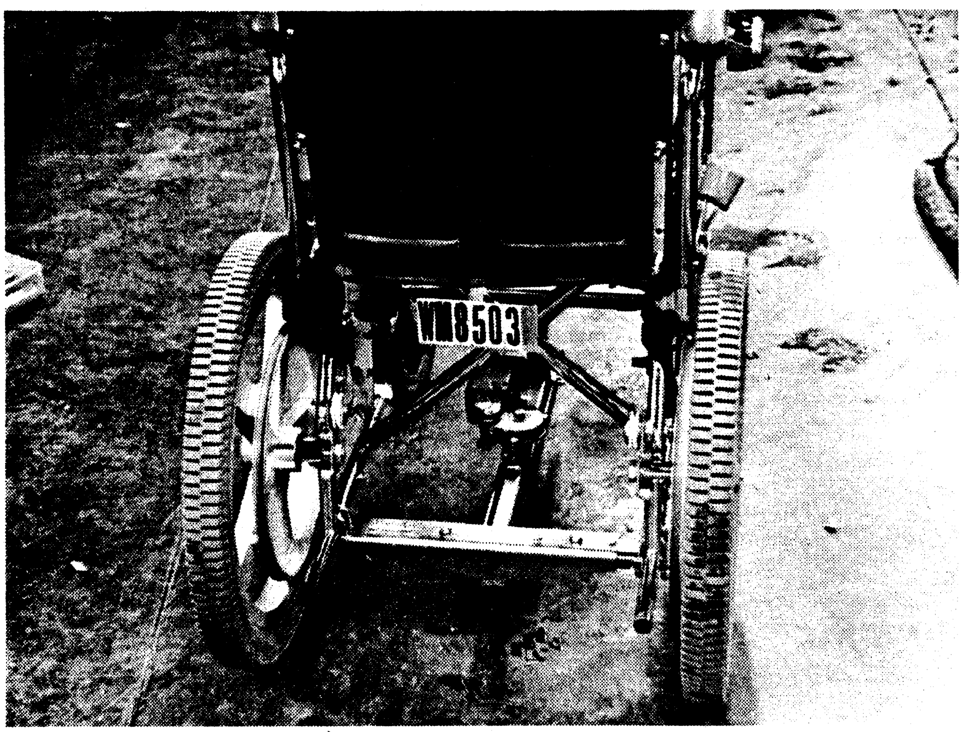


Figure 2. Rear view of wheelchair, showing "Speedlock" hardware attached.

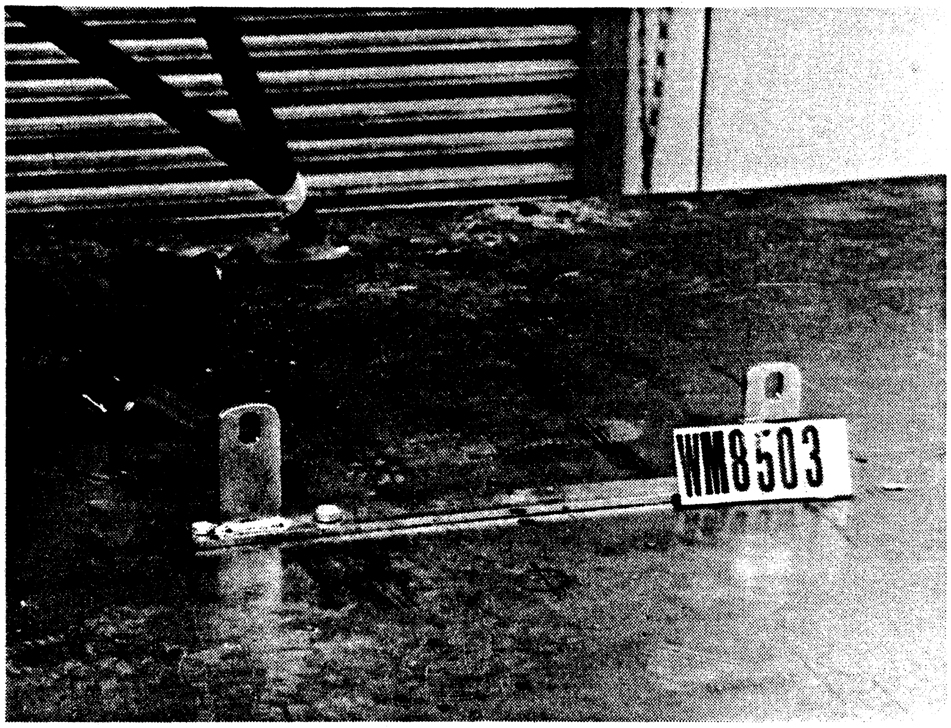


Figure 3. "Speedlock" tie-down structure attached to wheelchair.

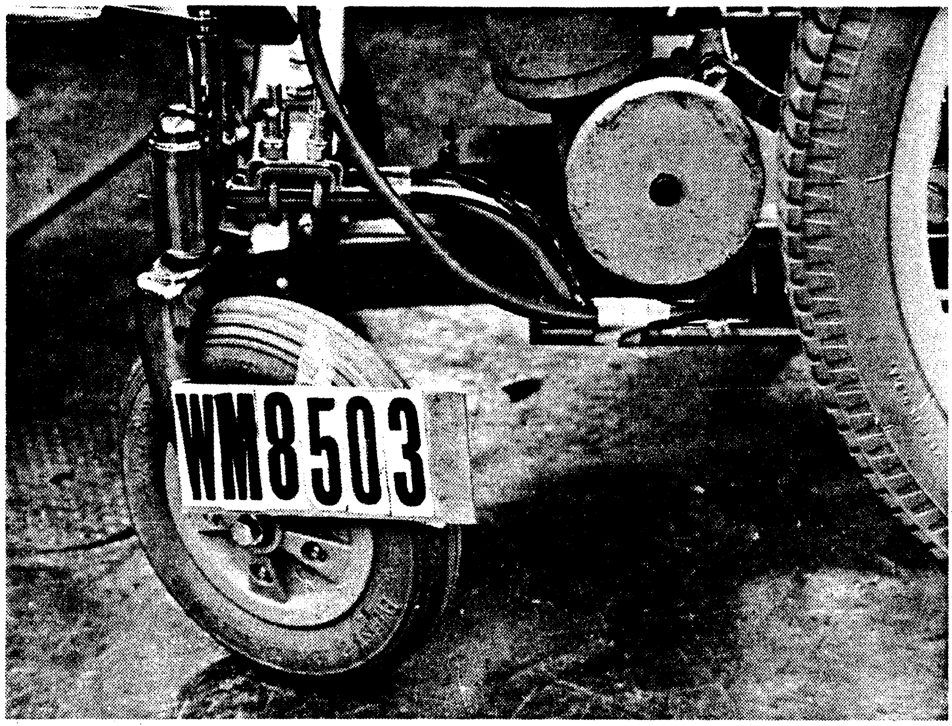


Figure 4. Close-up of "Speedlock" attachment at front of wheelchair.

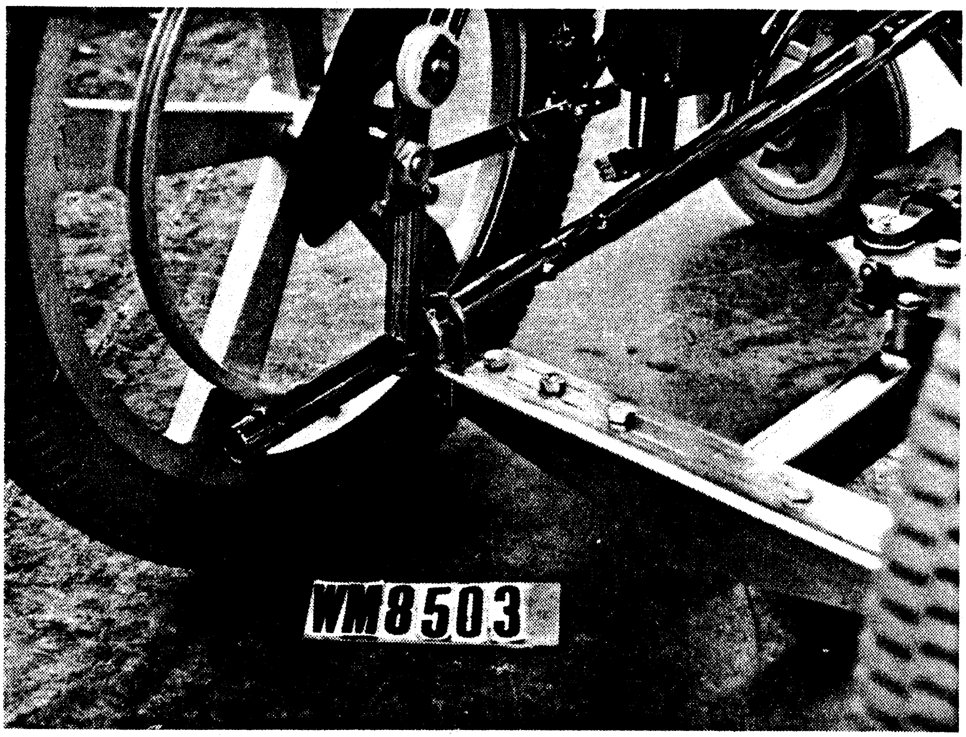


Figure 5. Close-up of "Speedlock" attachment
just forward of axle posts.

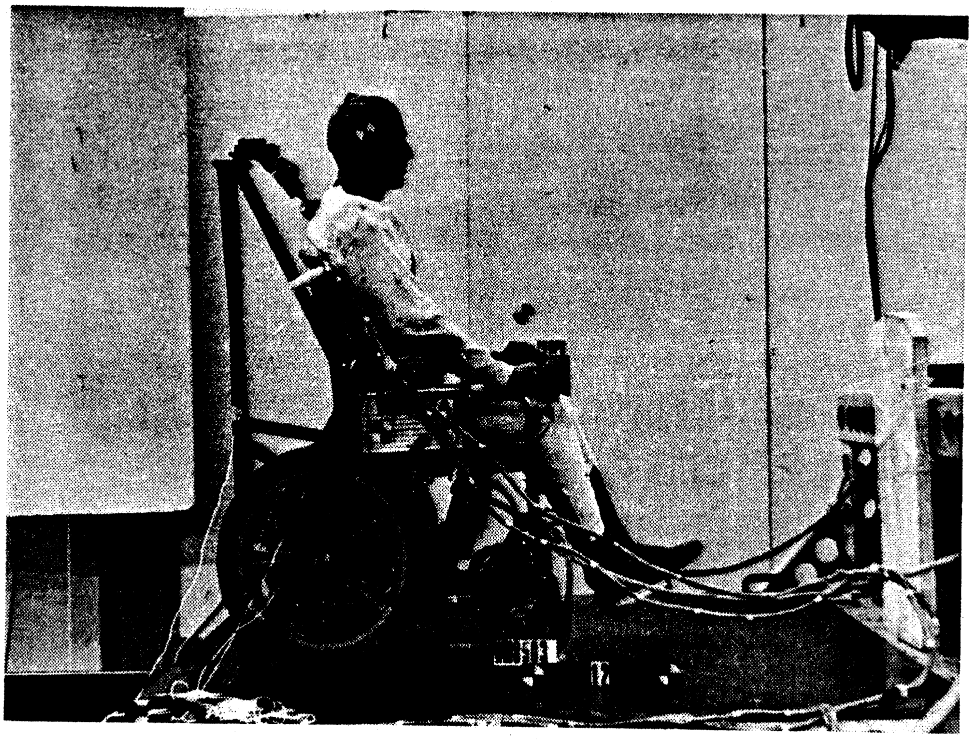


Figure 6. Side view of pre-test setup.

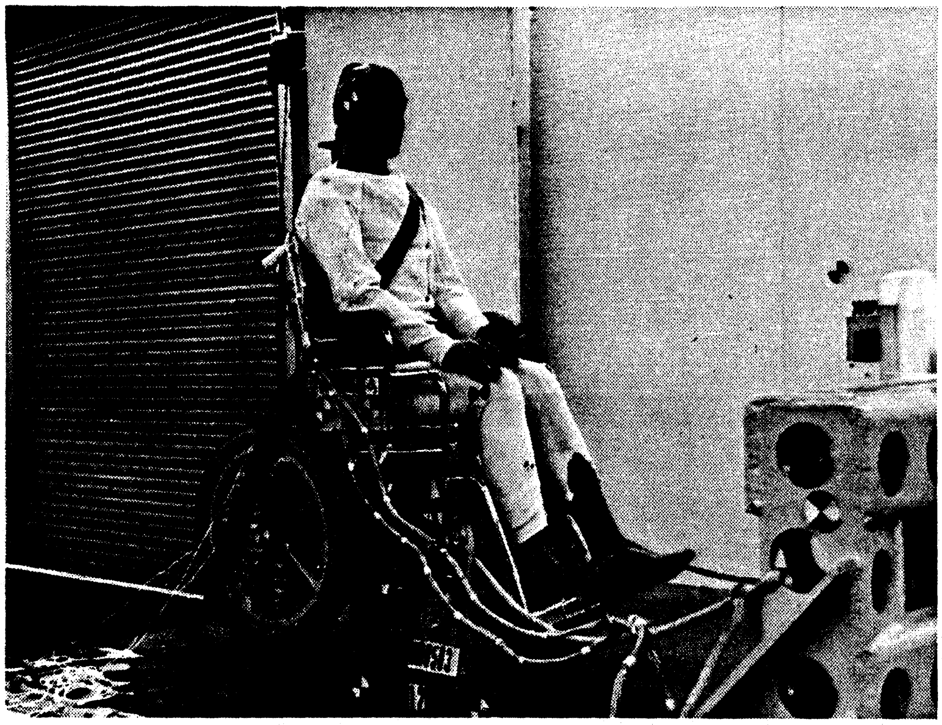


Figure 7. Oblique view of test setup.

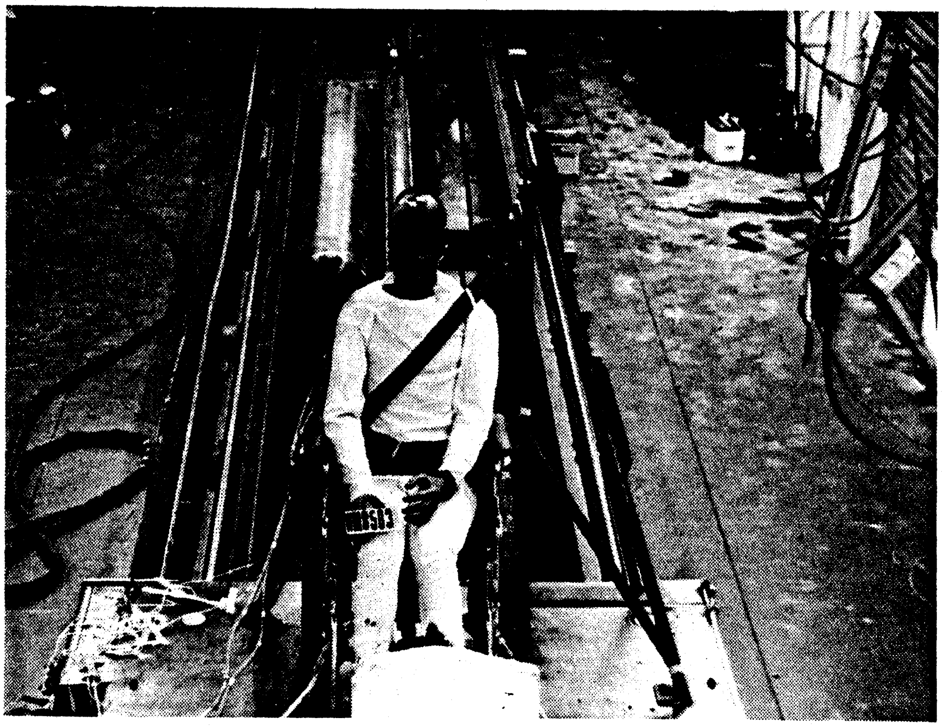


Figure 8. Front view of pre-test setup.

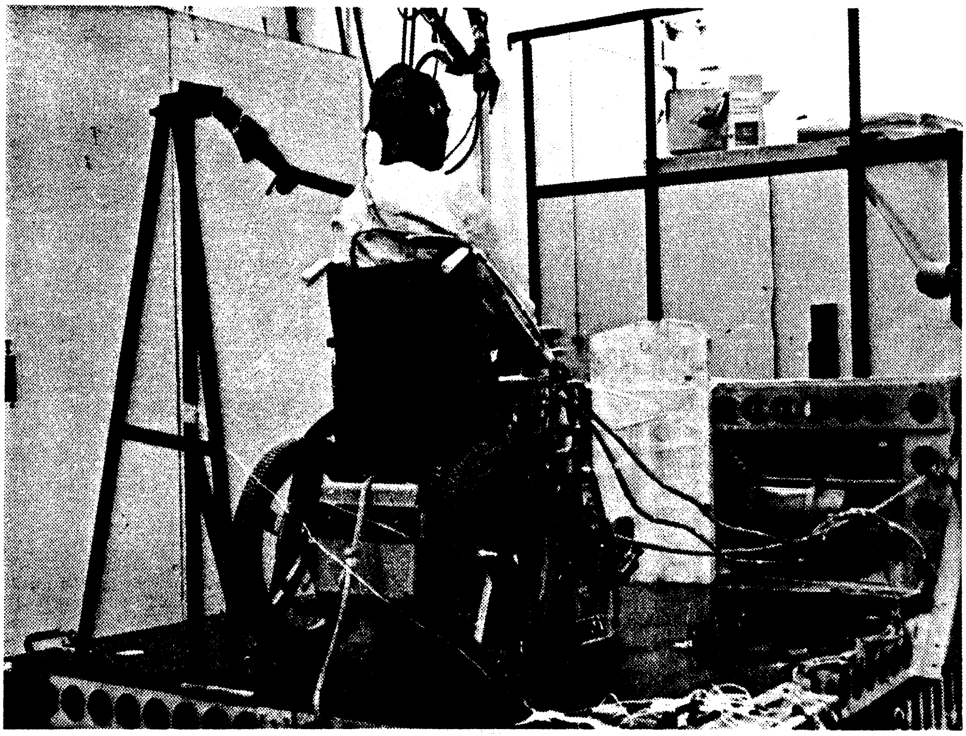


Figure 9. Rear oblique view of pre-test setup.

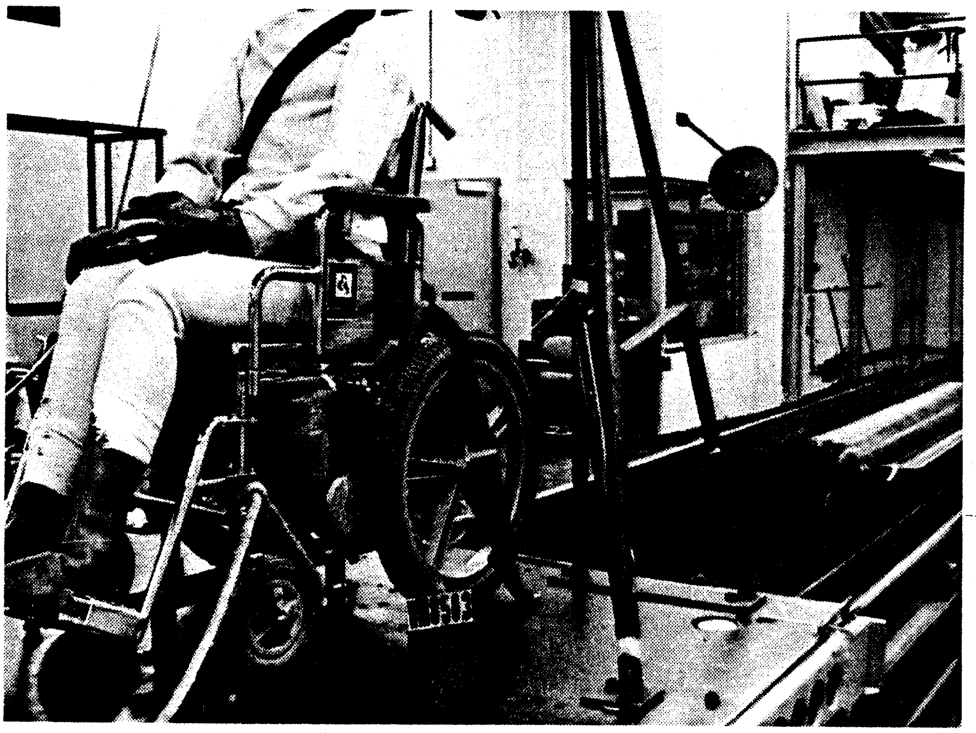


Figure 10. Right side oblique view of pre-test setup.

RESULTS

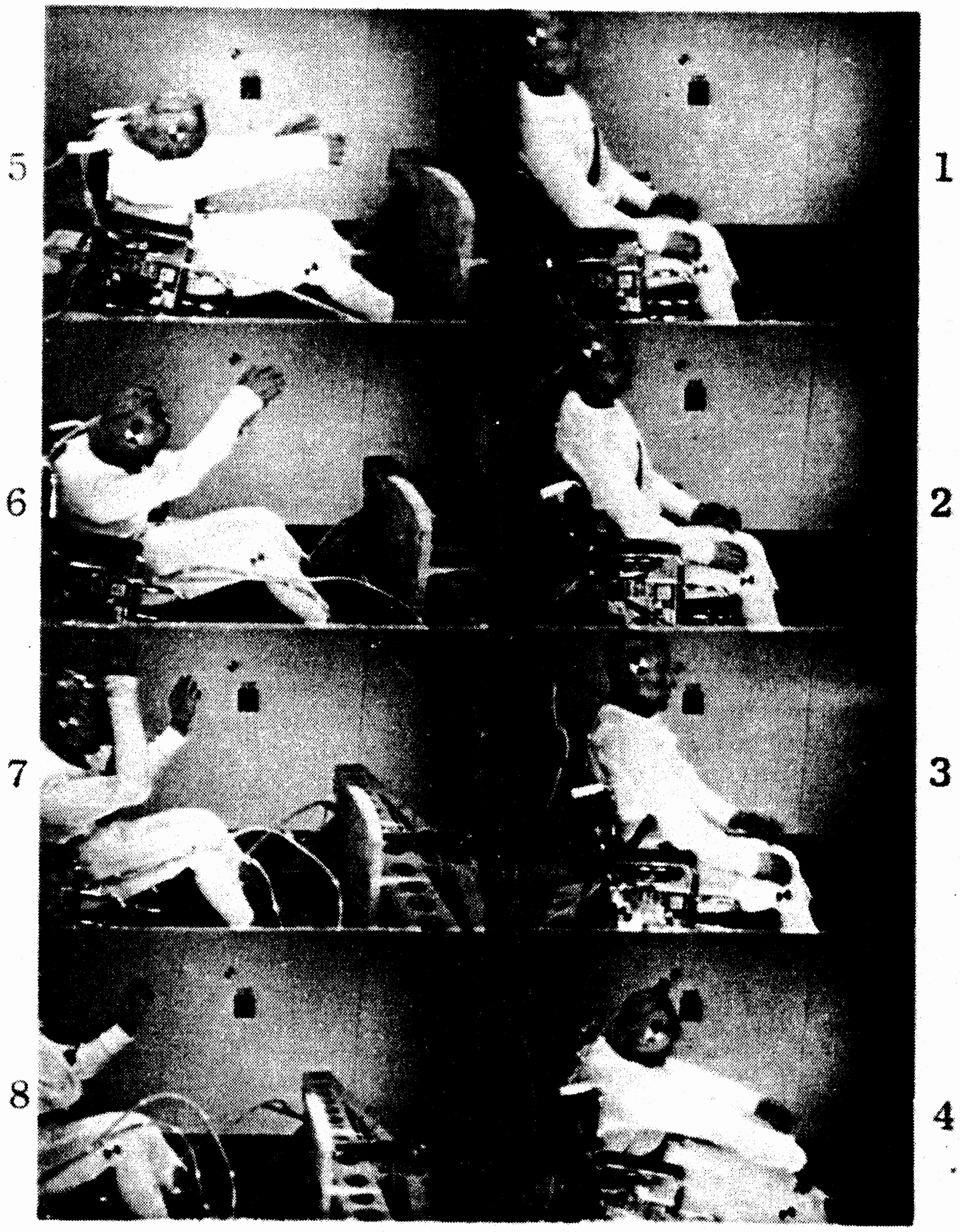
- * Actual Sled Deceleration .... 20.6 g's
- * Actual velocity .... 28.9 mph
- * Peak force right chair lap belt ..... 240 lbs.
- * Peak force left shoulder belt .... 2848 lbs.
- * Peak force right floor lap belt ..... 972lbs.
- * Peak resultant head acceleration .... 72 g's.
- * Head Injury Criteria 652
- * Peak resultant chest acceleration ... 52 g's

Figure 11 shows the Polaroid time sequence photograph of the impact test and Figure 12 shows a stop-action photograph. As revealed in these pictures and the high-speed films, the back of the wheelchair appeared to come loose during the impact, and the wheelchair pitched forward and upward. Restraint for both the dummy and wheelchair was accomplished primarily by the three-point restraint system. Near the end of sled deceleration the shoulder belt webbing broke at a peak load of 2848 pounds, allowing further excursion of the dummy's head to take place.

Figures 13 through 17 show the post-test photographs of the wheelchair, dummy, and restraint system. The dummy remained in the wheelchair, and there was relatively little damage to the wheelchair. Inspection of the tie-down revealed that the rear pin had somehow come out of the tie-down structure and was resting on top of the bracket after the test. Exactly how this occurred has not been determined since, as shown in Figure 18, the loading on the pin by the bracket should be entirely perpendicular to the direction required to push the pin out of the slot. Thus, even though the motor had not been fully powered into the locked position (it was only partially powered and this resulted in a lower lateral force required to release the pins), the loading should not have pushed the pin out. This is even more confusing, since the front pin remained in and the two pins move in and out together on the pivoting linkage.

Inspection of the shoulder belt webbing revealed that it had torn at the anchorage point due to abrasion with a knurled locking bar. Inspection of the tie-down hardware revealed no noticeable bending or damage to the cross-bars or floor mounted structure. The rear "U" bolts which attach the tie-down to the wheelchair did show some bending and appear to be a weak point in the tie-down system.

Figures 19 through 22 show the sled velocity and deceleration profiles, the head and chest accelerations, and the belt loads respectively. The chest and head accelerations are within existing tolerance values for the able-bodied population. The point of shoulder belt failure is clearly apparent, as is the consequent change in head deceleration resulting from the release of the torso at this point in time. The high peak value of shoulder belt load is clearly related to the loading of the wheelchair as well as the dummy into the restraint.



WM 8503

Figure 11. Polaroid graph sequence photograph.

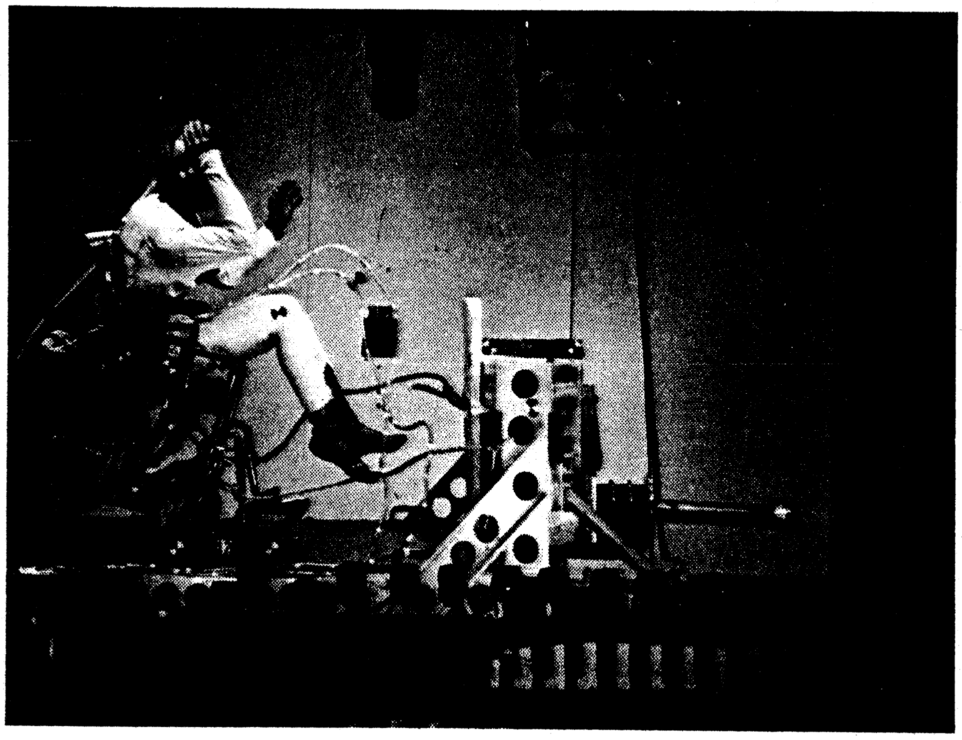


Figure 12. Stop-action photograph.

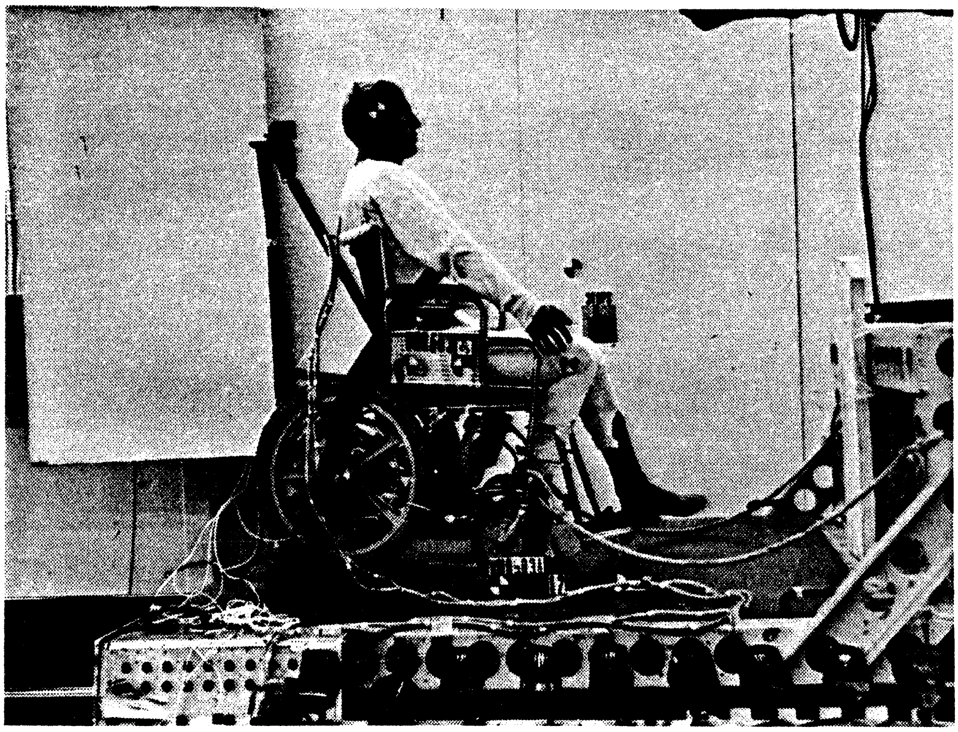


Figure 13. Side view, post-test.

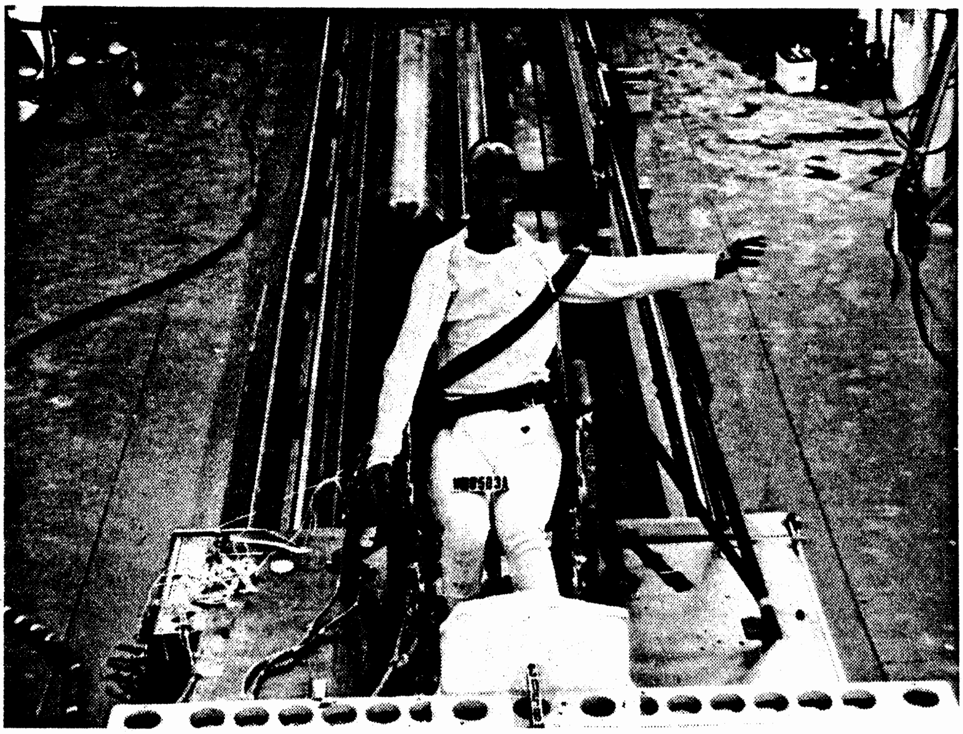


Figure 14. Front view, post-test.

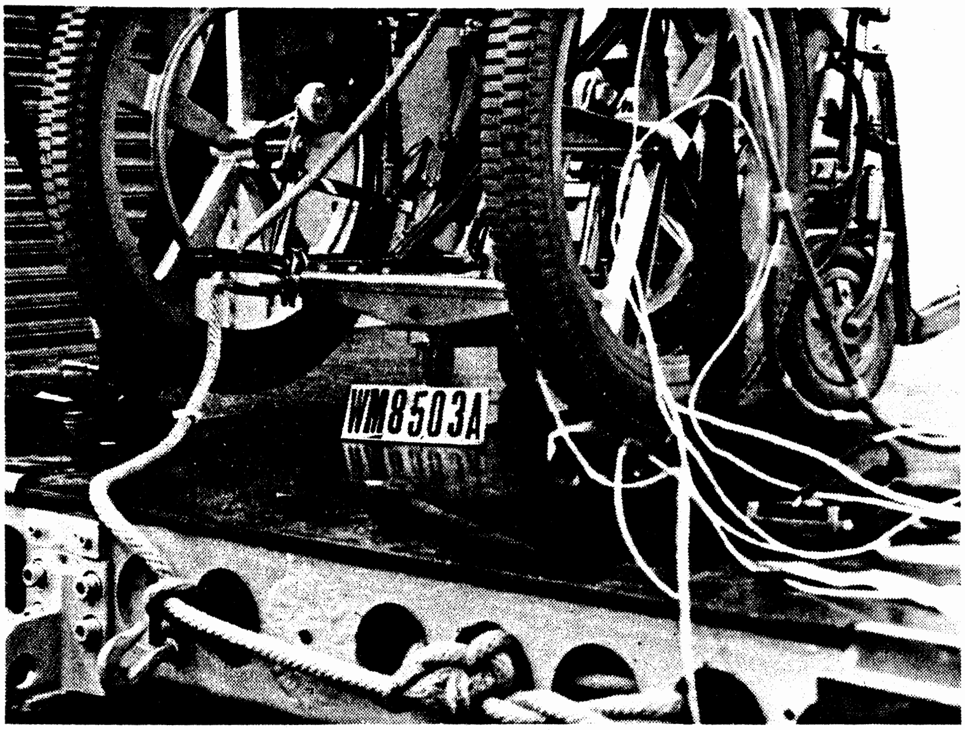


Figure 15. Close-up of rear tie-down bracket post-test showing pin out of slot.

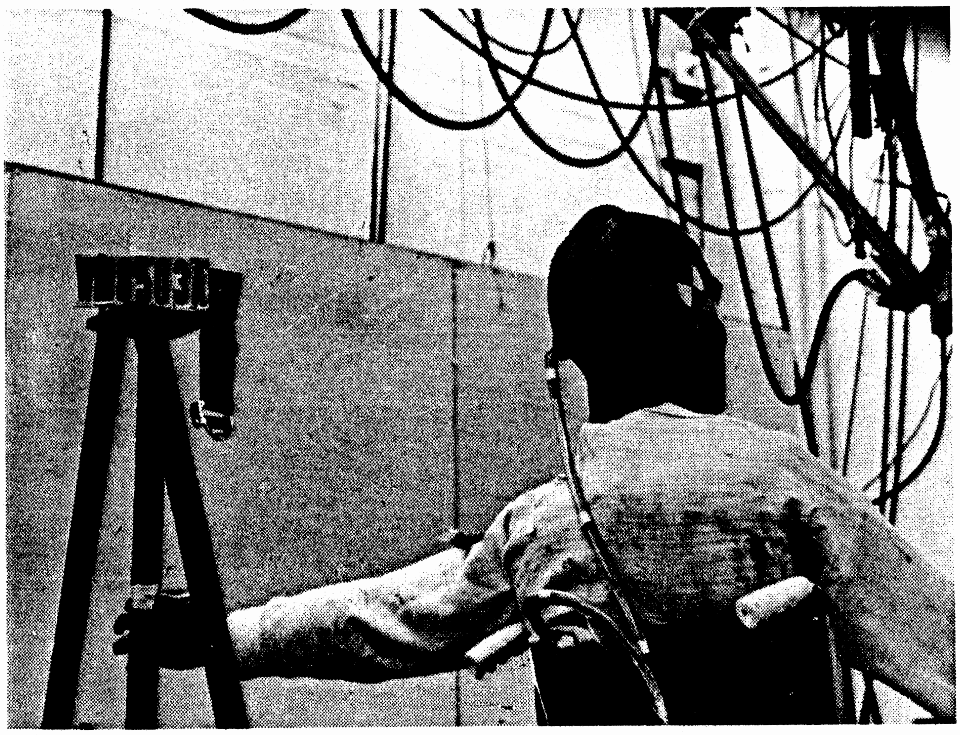


Figure 16. Post-test view of broken shoulder belt.

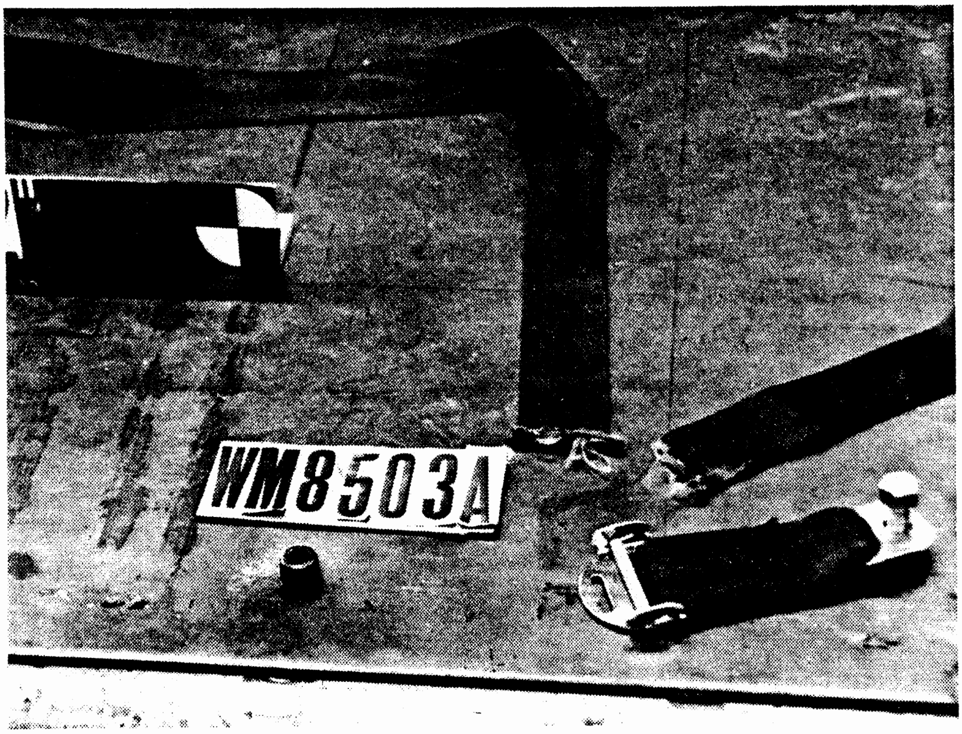


Figure 17. Torn shoulder belt webbing and anchor bracket.

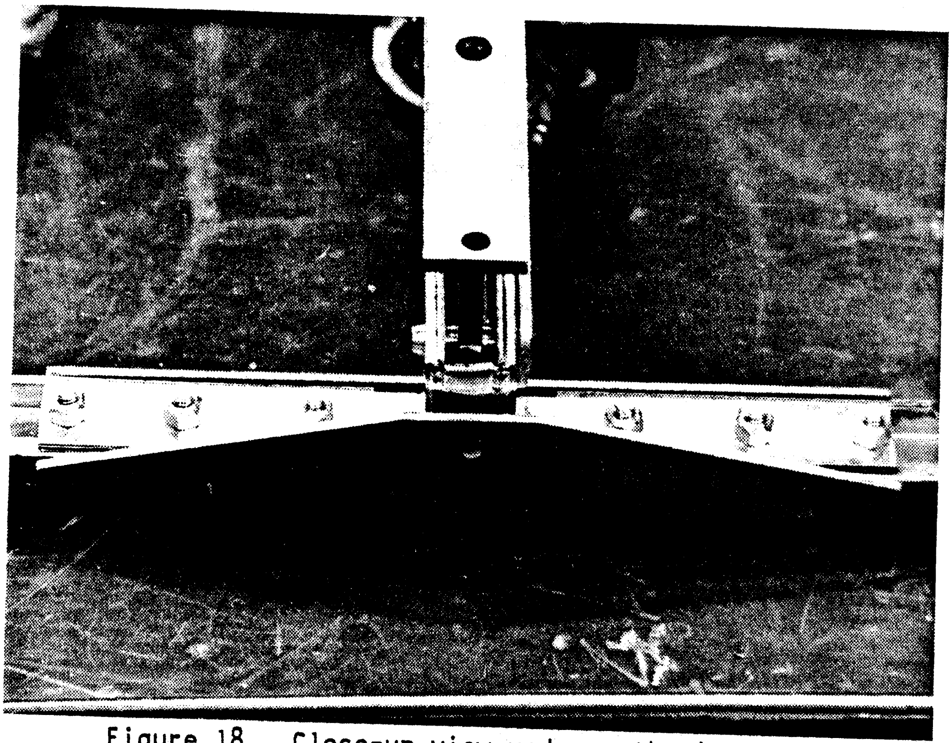


Figure 18. Close-up view underneath tie-down, showing pin through floor bracket.

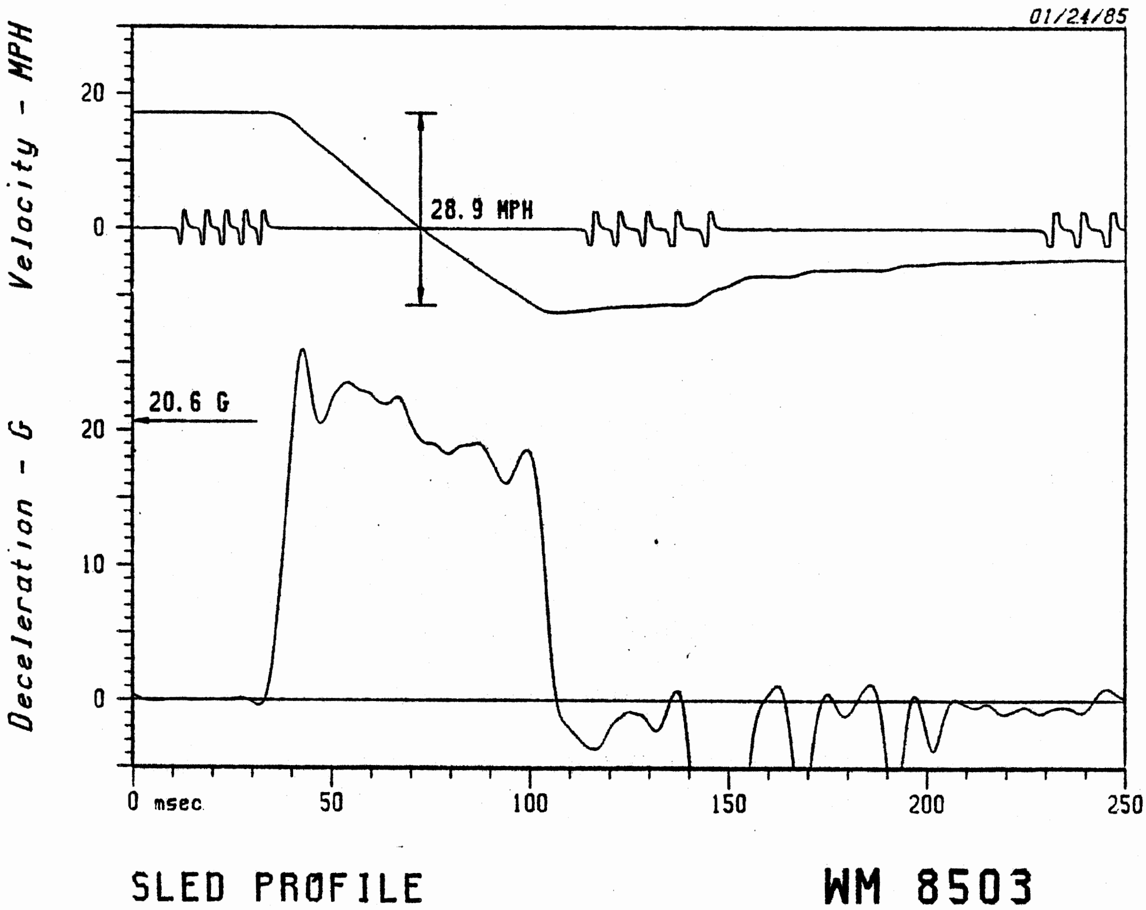


Figure 19. Sled velocity and deceleration profiles.

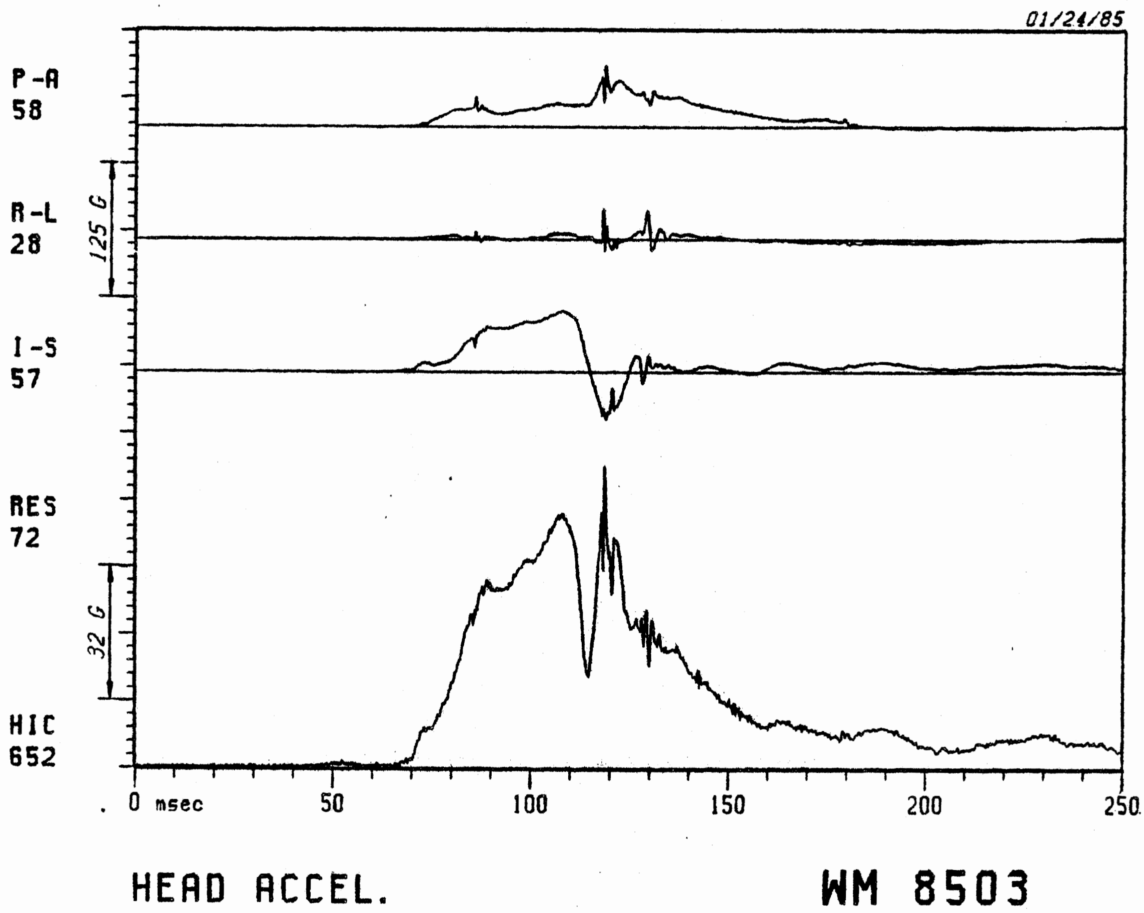


Figure 20. Head accelerations versus time.

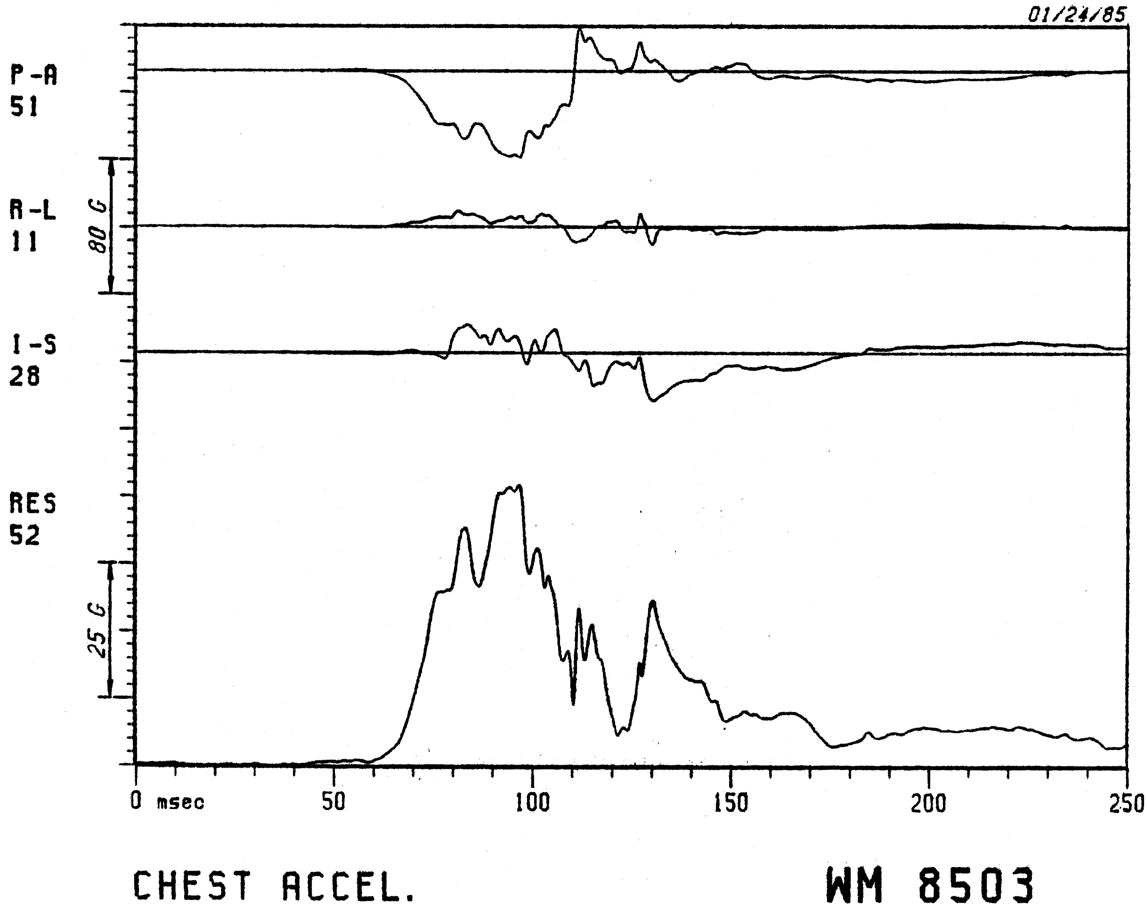


Figure 21. Chest accelerations versus time.

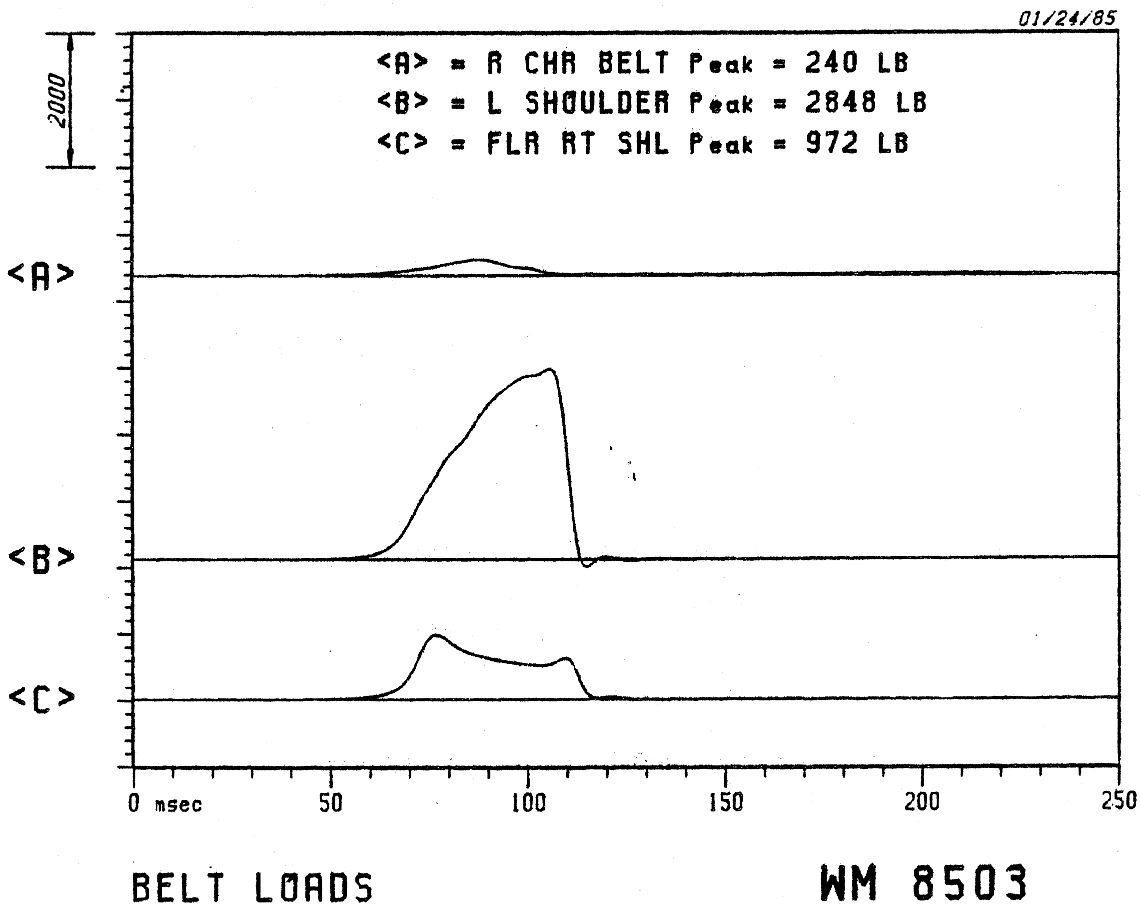


Figure 22. Belt loads versus time.

SUMMARY AND DISCUSSION

Because the rear pin came out and allowed the back part of the tie-down and wheelchair to become totally free except for the occupant restraint system, this cannot be considered a valid test of the "Speedlock" tie-down system. The reason for this mode of failure at the back of the "Speedlock" but not at the front and with the perpendicular loading that should have been on the pin is not clear. It is known that the locking spring that maintains tension on the pivot bar was not fully wound, since the drive motor had not been fully activated in the locking direction prior to the test. If this is done in a future test the pin should not disengage.

The peak shoulder belt force at failure is greater than it would have been if the wheelchair had not loaded into the restraint. The cause of failure seems to be abrasion or cutting due to the knurled locking bar. FMVSS 209 specifies that "any webbing cut by the hardware during test shall have a breaking strength of ... not less than 2,800 pounds or 1,270 kilograms at a cut in webbing of the upper torso restraint." While the peak force at failure in this test was just greater than 2800 pounds, consideration should be given to another type of adjustment and anchor mechanism that would not be as likely to cut the webbing material. It is also recommended that the "U" bolts used to anchor the "Speedlock" to the wheelchair be made of hardened steel or changed to "U" brackets that would have higher breaking strength.

UMTRI

SLED IMPACT TEST

WM8504

CREATIVE CONTROLS

WHEELCHAIR TIE-DOWN

FOR DRIVERS

(first modification)

Test Date:

March 13, 1985

INTRODUCTION

The purpose of this test was to evaluate the effectiveness of a prototype wheelchair tie-down system developed by Creative Controls, Inc. for handicapped drivers of vans. In test WM8501, a similar tie-down was tested but failed due to an excessive amount of free-play in the rear locking mechanism. This allowed the front tie-down bar to be released from the anchor hook on sled acceleration so that the wheelchair and test dummy flipped backwards prior to impact. While the test was essentially invalidated due to the orientation of the wheelchair and dummy at impact, it was also noted that the free-play in the tie-down mechanism resulted in a decoupling situation which puts excessive impact loads on the tie-down hardware.

In test WM8504, the tie-down system was modified to include a solenoid-actuated latching mechanism at the front tie-down hook which removes the free-play from the tie-down system. In addition to a lap belt attached to the tie-down hardware, a vehicle-anchored shoulder belt was used to provide upper torso restraint for the 50th-percentile male anthropomorhic test dummy.

TEST SETUP

*	Wheelchair Tie-Down	Creative Controls prototype with modified front latching mechanism.
*	Weight of Tie-down hardware on wheelchair	18 lbs.
*	Wheelchair	E&J 3P power wheelchair.
*	Occupant Restraint	lap belt to wheelchair plus vehicle shoulder belt.
*	Test Dummy	50th percentile male (167 lbs.)
*	Orientation of Test	Forward facing, frontal impact
*	Desired Impact Velocity	30 mph
*	Desired Deceleration	20 g's

Figures 1 through 8 show the tie-down hardware and test setup which is described in test WM8501 and is essentially the same except for the modified front latching mechanism and the use of a vehicle-anchored shoulder belt instead of the three-point belt. Figures 1 through 3 show the front latching mechanism in close-up. When the wheelchair is moved into position the front tie-down bar pushes on the pivoting steel latch bar which comes up behind the bar and captures it in the hook. As the latch pivots up, a spring-loaded "wedge" moves under the latch mechanism to lock it in position. The front latch is released by means of a wire cable attached to the spring-loaded wedge, which can be actuated manually or by an electrically powered solenoid. As in the previous version, the rear tie-down bar presses down on a spring-loaded plate as the wheelchair moves into position and is captured under the steel retaining structure.

Four GSE seat belt load cells were installed to measure forces in the upper shoulder belt, the right floor belt, and the left and right sides of the lap belt. The wheelchair, with batteries, motors and tie-down hardware, weighed about 160 pounds, of which the tie-down hardware accounted for about 18 pounds. Sled pressures were set to achieve a velocity differential of 30 mph and a sled deceleration of 20 g's during impact.

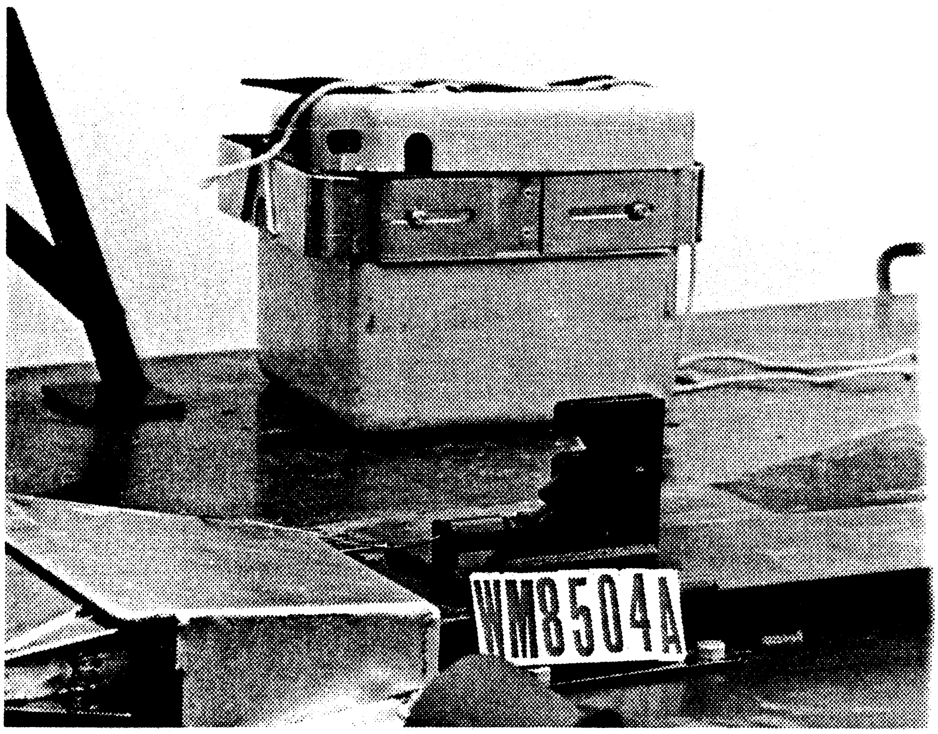


Figure 1. Floor-mounted tie-down structure - front retaining latch open.

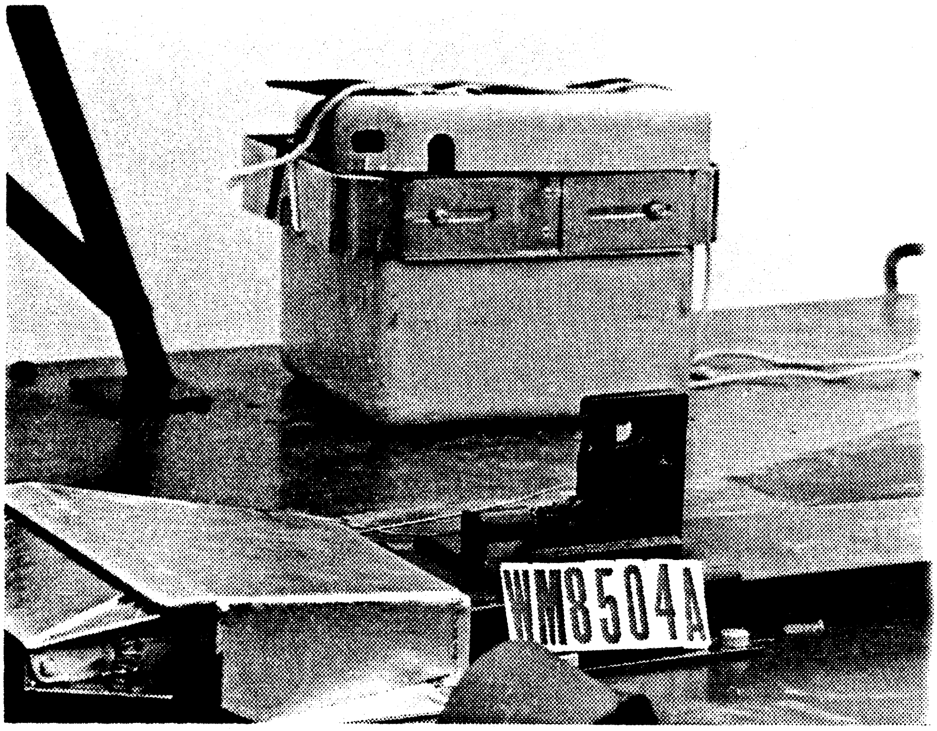


Figure 2. Floor-mounted tie-down hardware - front retaining latch closed.

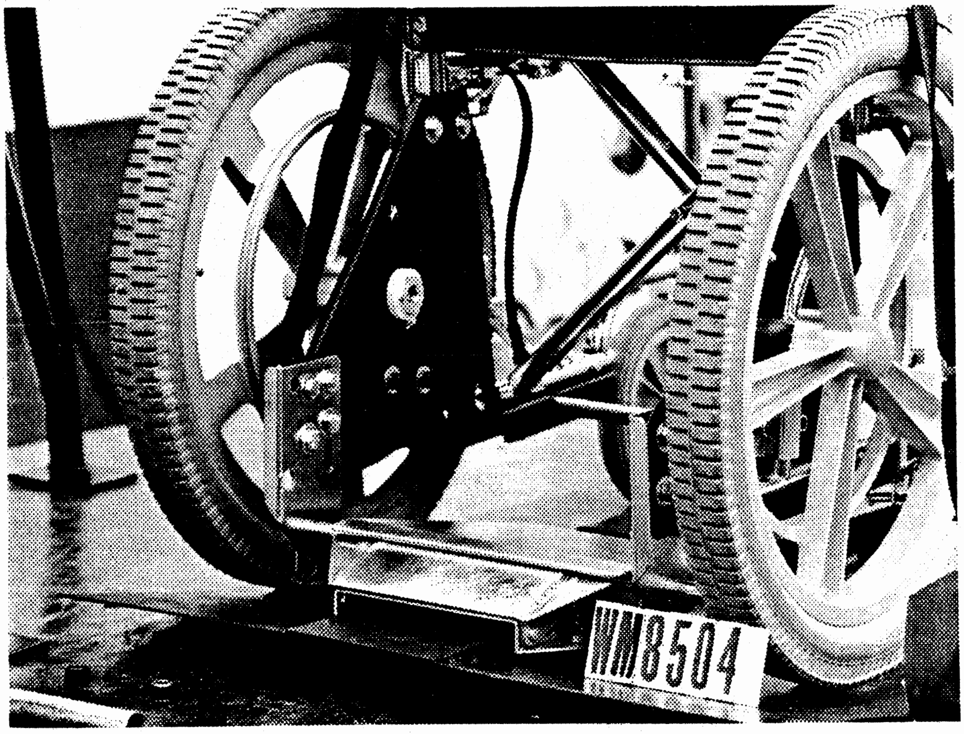


Figure 3. Wheelchair with triangular plates and steel retaining bars locked in tie-down mechanism. Note lap belt anchor point.

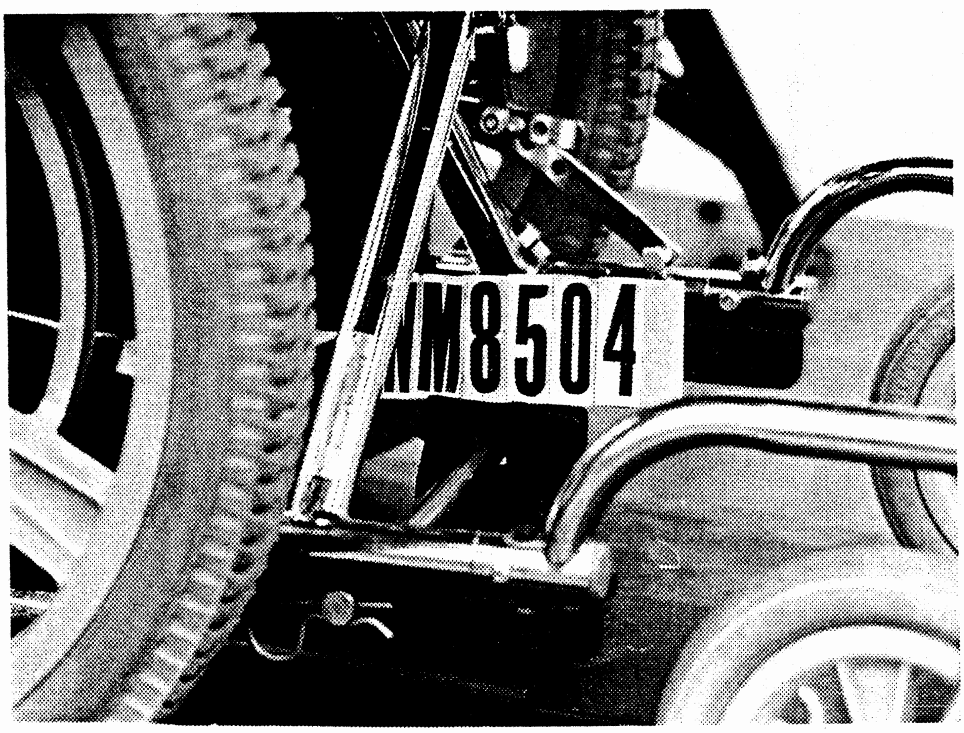


Figure 4. Front retaining bar captured in lock-down mechanism.

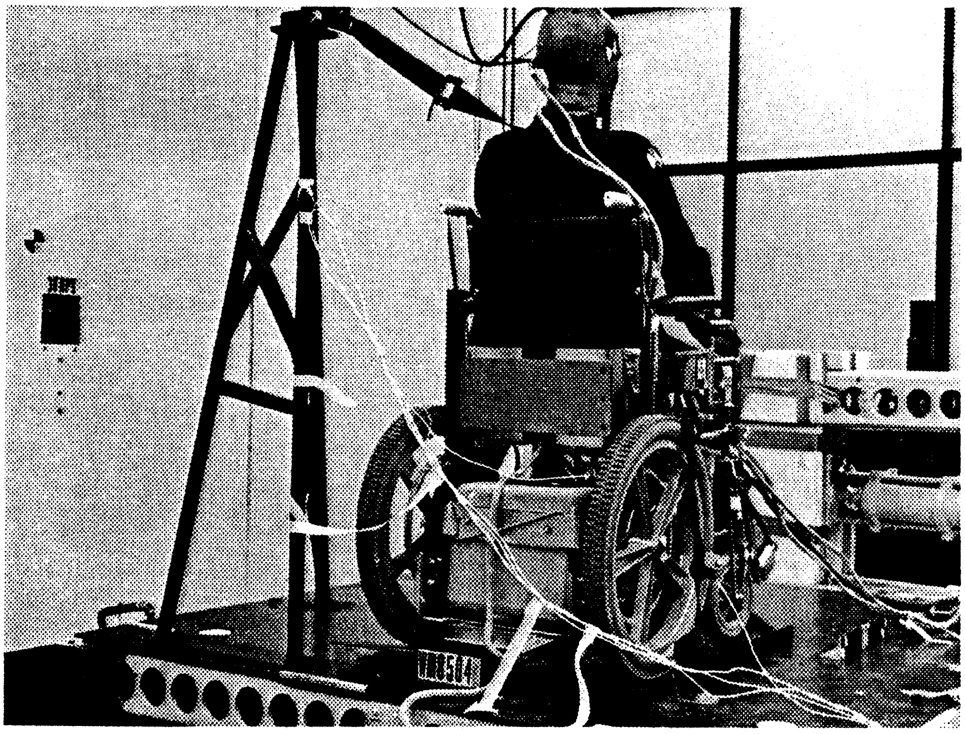


Figure 5. Rear view of test setup. Shoulder belt was placed between chair arm and chair back prior to test.

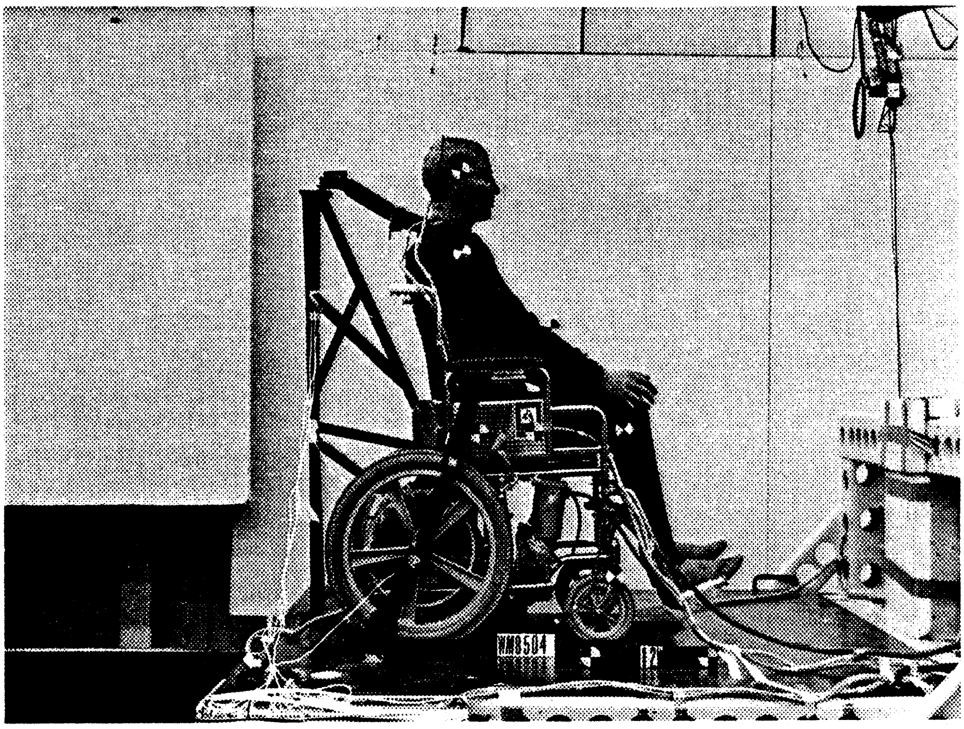


Figure 6. Side view of test setup. Shoulder belt was placed between chair arm and chair back prior to test.

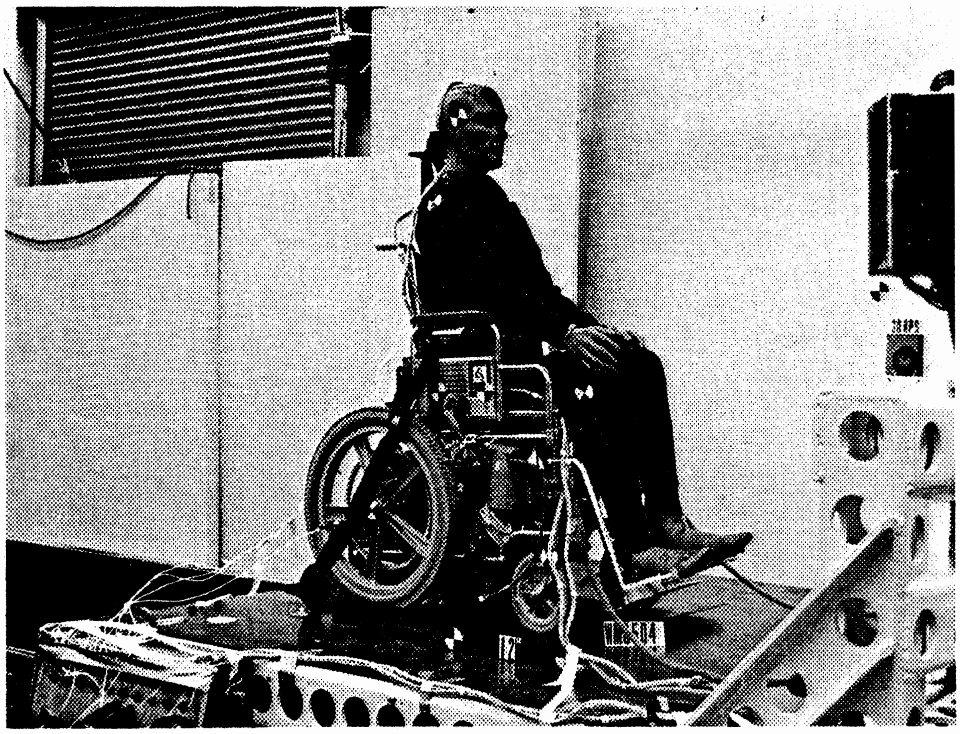


Figure 7. Oblique view of test setup.

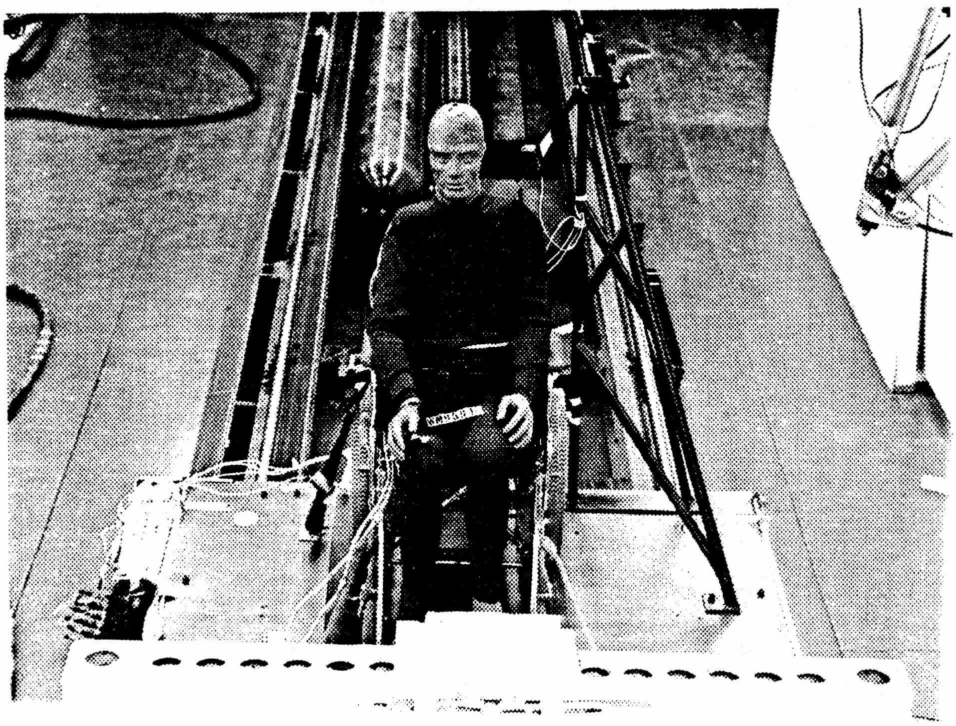


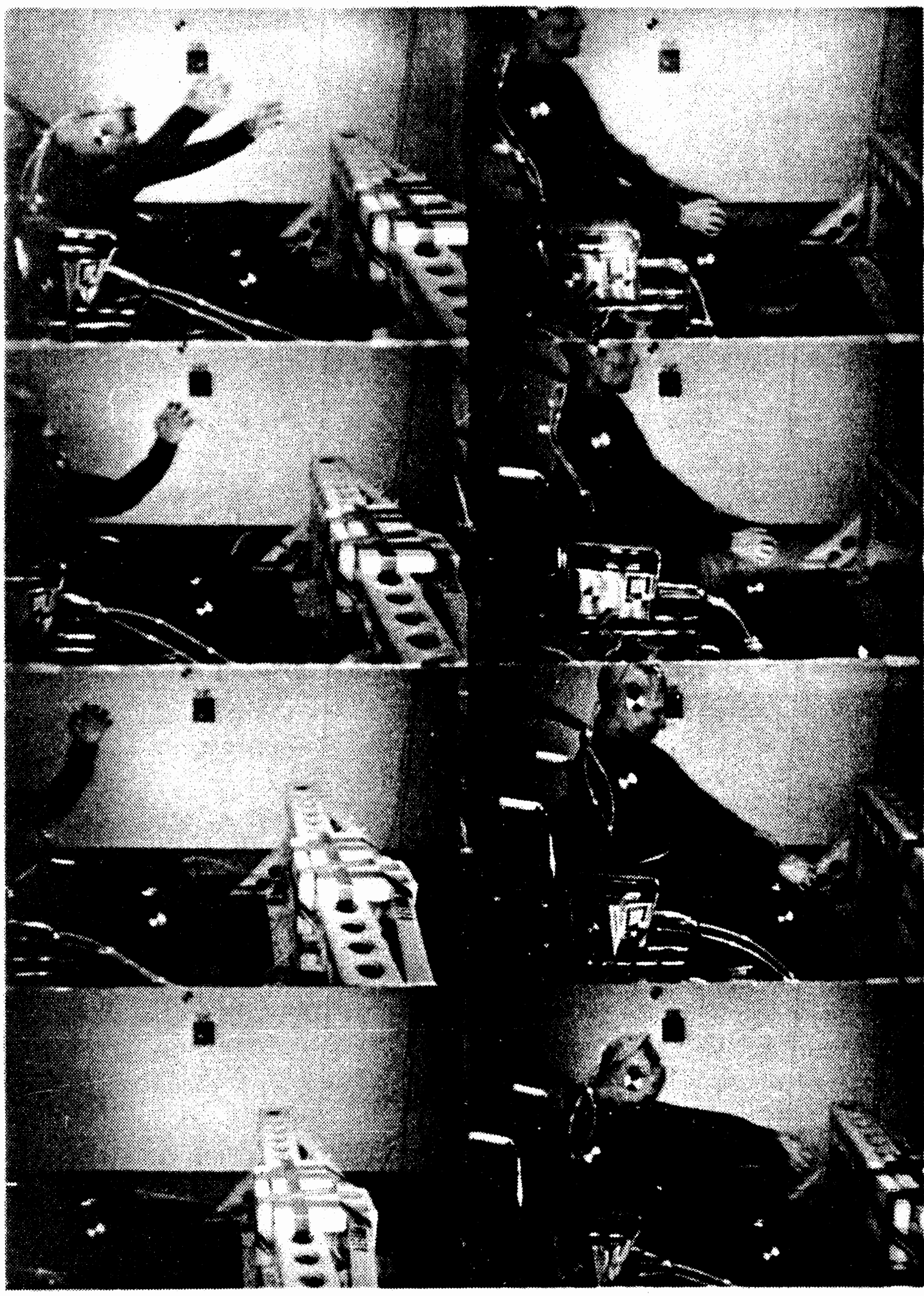
Figure 8. Front view of test setup.

RESULTS

* Actual Sled Deceleration .... 21.0 g's
* Actual velocity .... 27.4 mph
* Peak force right chair lap belt ..... 959 lbs.
* Peak force left chair lap belt ...... 1623 lbs.
* Peak force upper shoulder belt ...... 1727 lbs.
* Peak force lower shoulder belt ...... 1185 lbs.
* Peak resultant head acceleration .... 35.9 g's.
* Head Injury Criteria 539
* Peak resultant chest acceleration ... 26.2 g's

Figure 9 shows the polaroid sequence photographs of the impact event, and Figures 10 through 13 show the post-impact conditions. The tie-down appeared to provide good restraint for the wheelchair throughout the deceleration although the rear retaining bar was found out of the tie-down locking mechanism after the test, as shown in Figure 13. A review and analysis of the high-speed films indicates that the tie-down bar did not come out during the primary impact deceleration but on rebound after the primary impact loading was over. A peak wheelchair excursion of about 3.5 inches was measured at the hub of the large wheel.The front bar remained captured in the front locking mechanism but showed a significant amount of bending.

Figure 14 shows the sled velocity and deceleration profiles which indicated a velocity differential of 27.4 mph and an average deceleration of 21.0 g's. Figures 15 through 17 show the head and chest accelerations and belt loads. The shoulder belt loads are not excessively high, indicating that the tie-down system provided good restraint of the wheelchair and that the rear bar did not come out of the retaining structure until rebound after impact. The peak resultant head and chest accelerations and the Head Injury Criteria are well within accepted tolerance limits for the able-bodied population.



5 1

6 2

7 3

8 4

WM 8504

Figure 9. Polaroid graph sequence photograph.

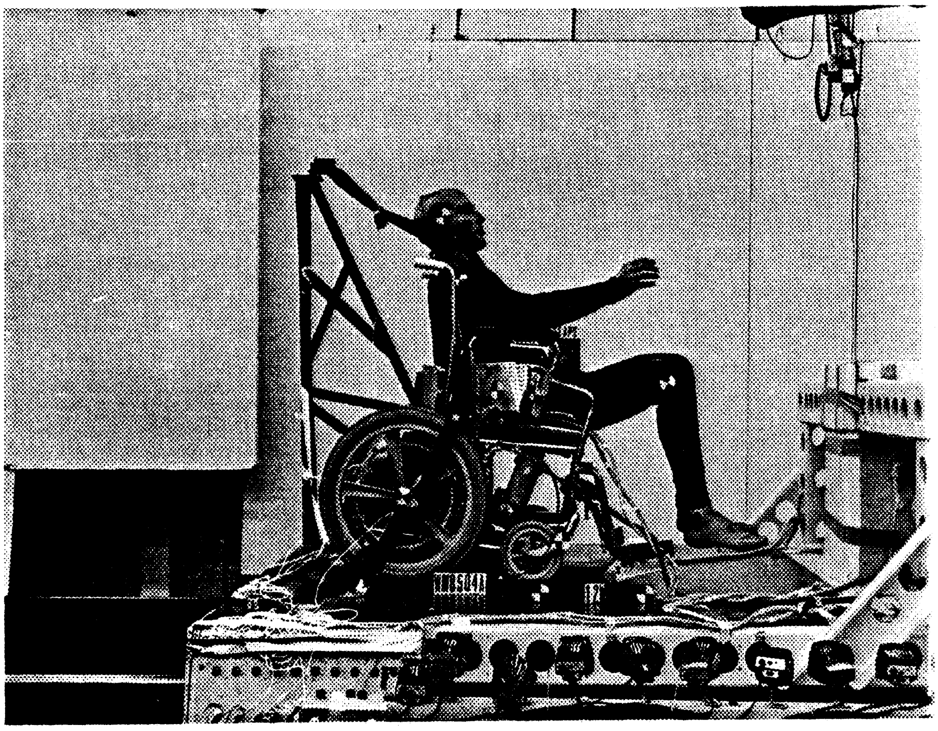


Figure 10. Side view after impact.

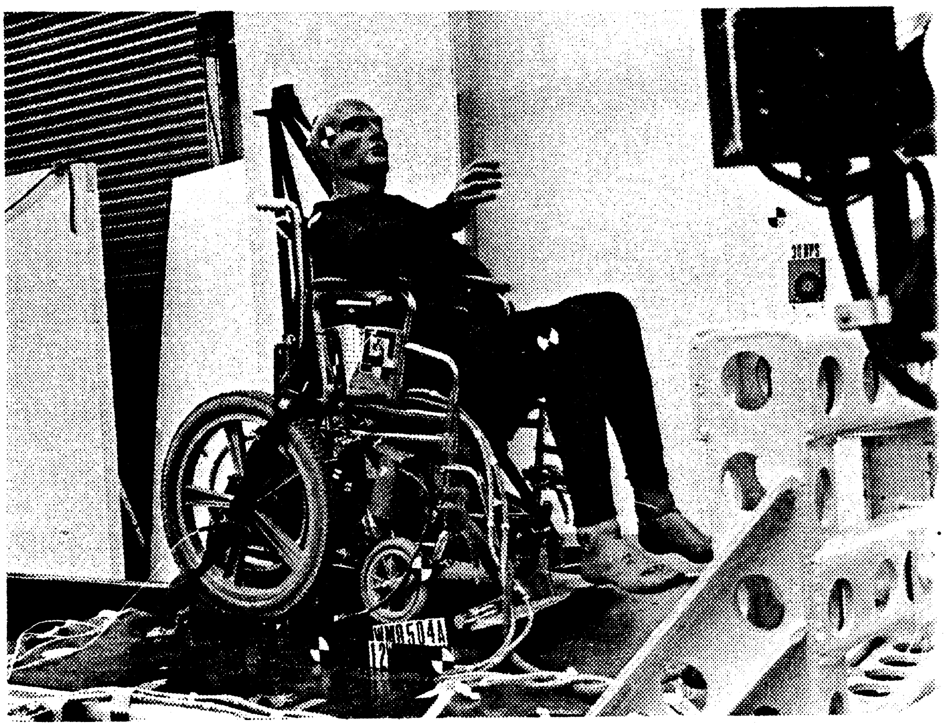


Figure 11. Oblique view after impact.

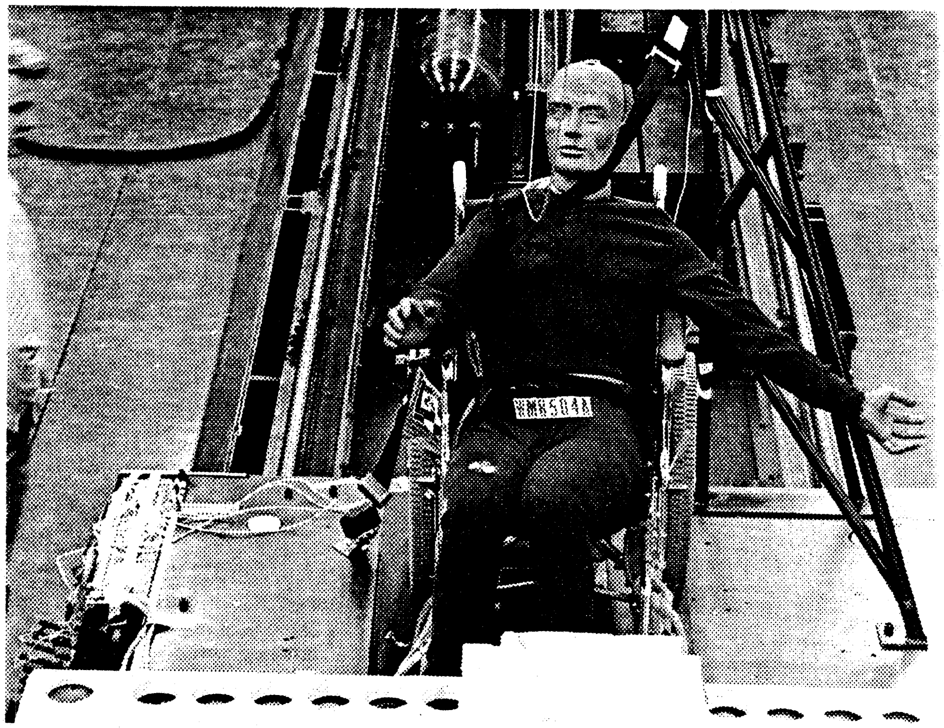


Figure 12. Front view after test.

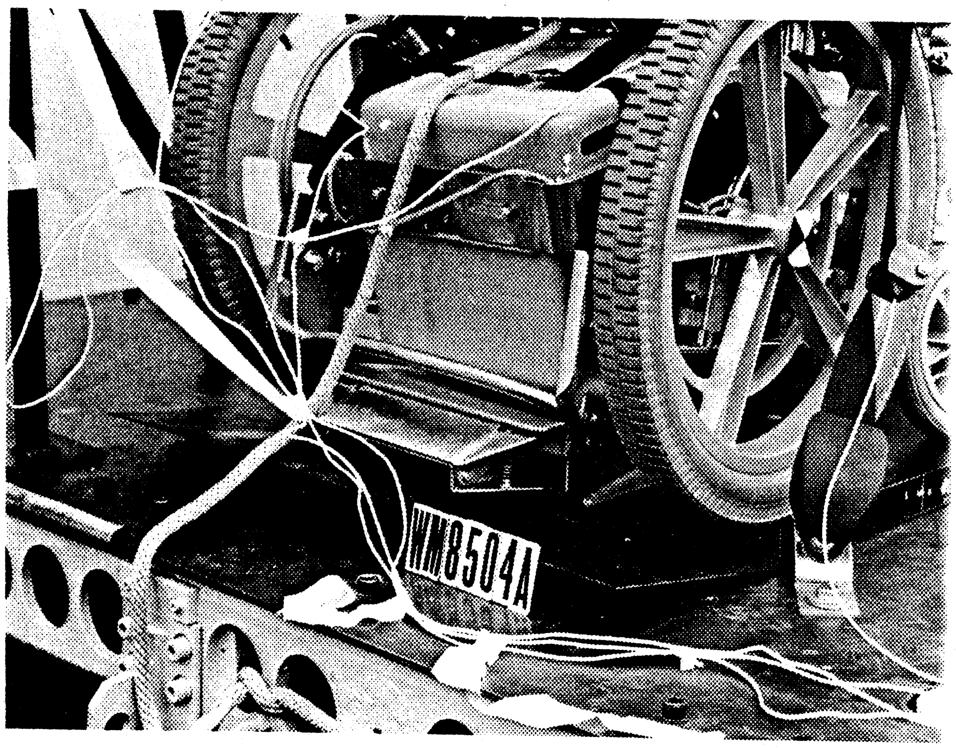


Figure 13. Rear view close up after test, showing steel bar out of tie-down.

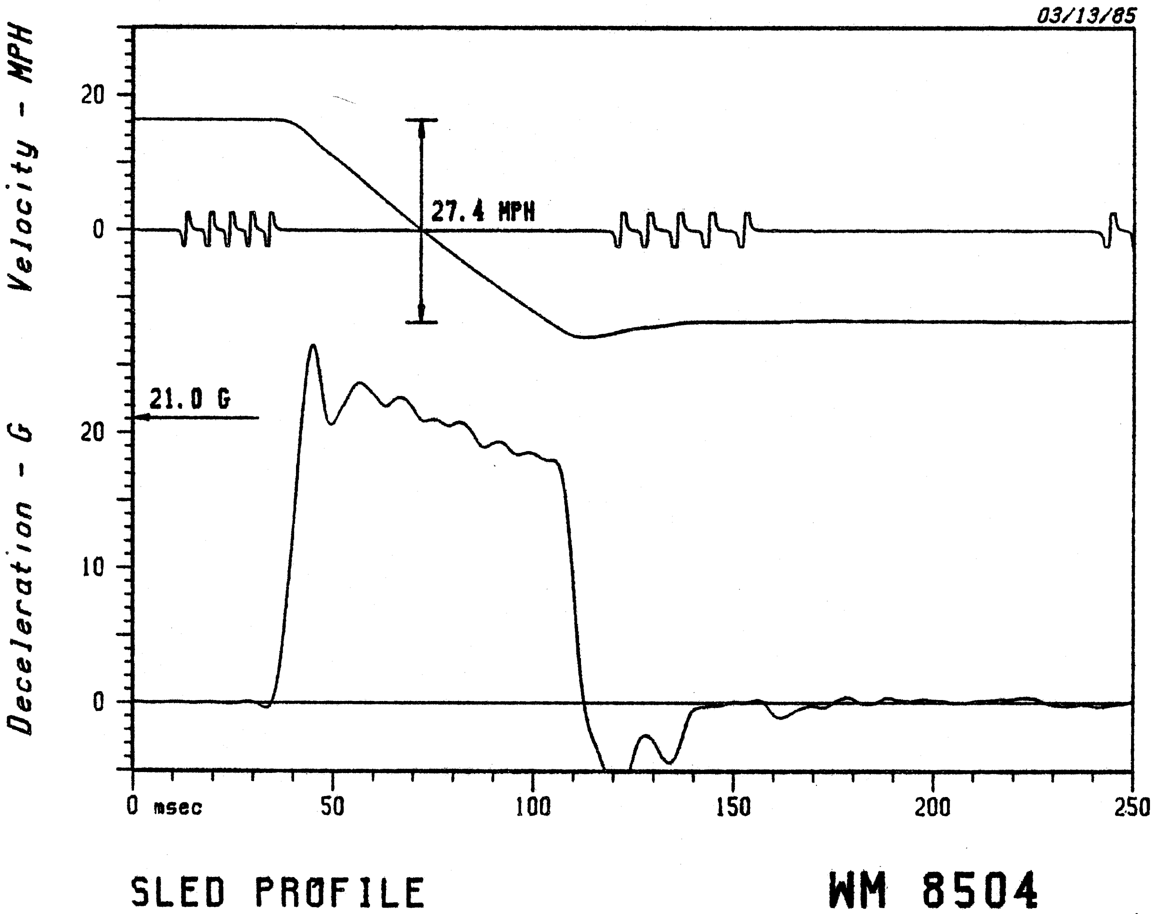


Figure 14. Sled velocity and deceleration profiles.

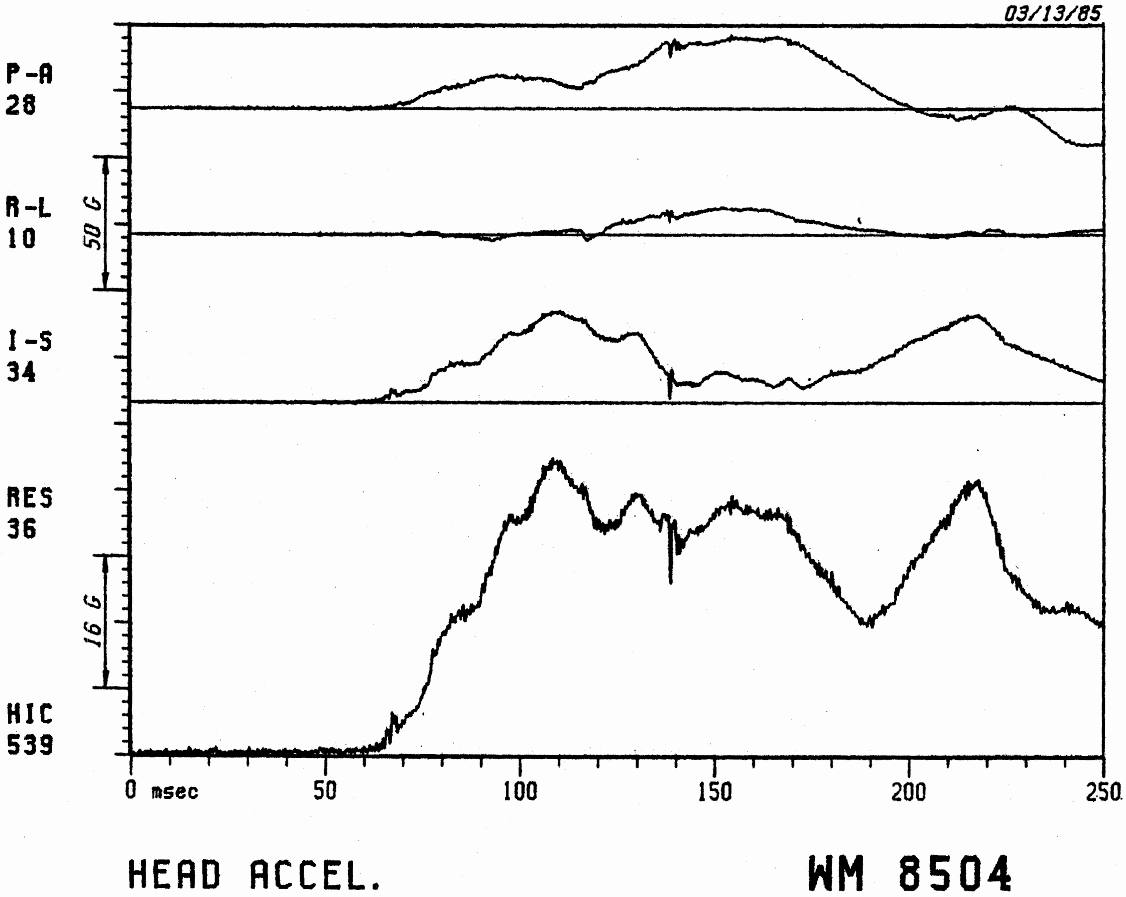


Figure 15. Head accelerations versus time.

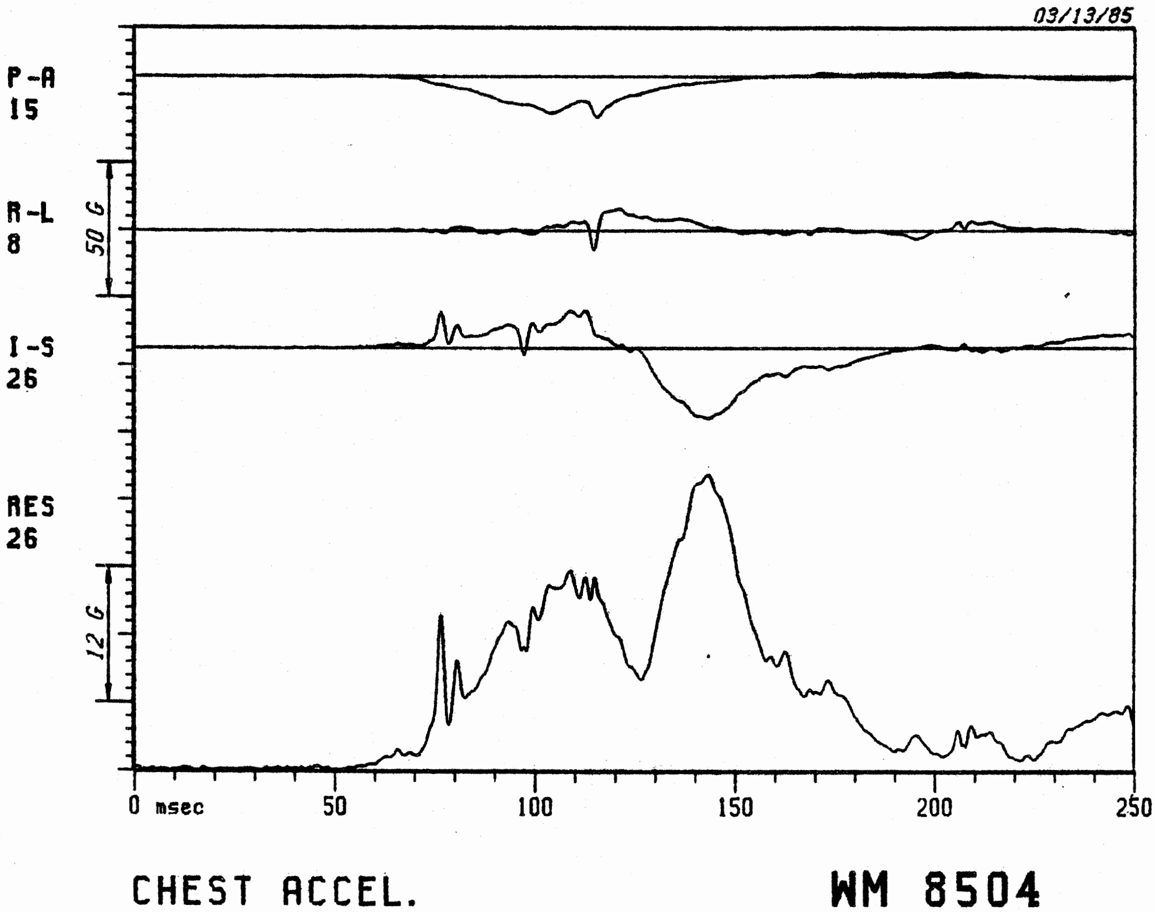


Figure 16. Chest accelerations versus time.

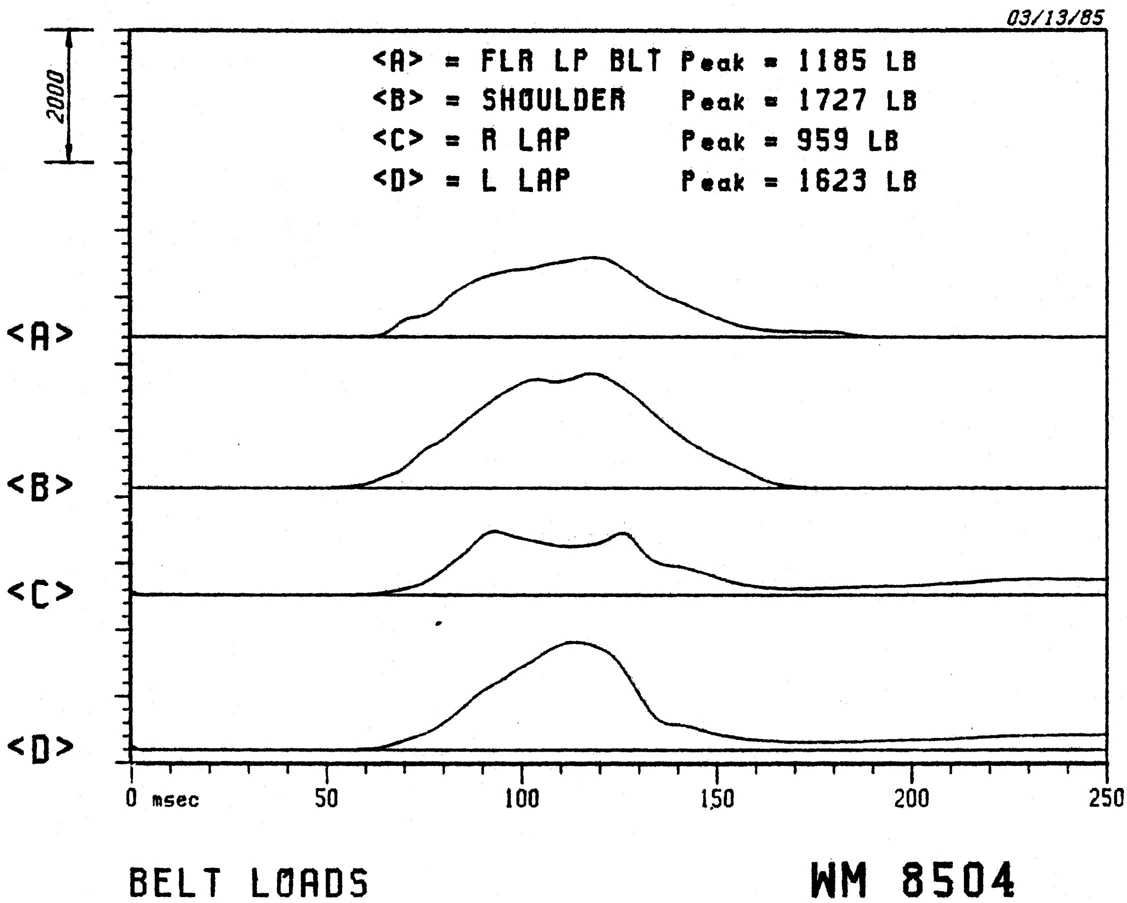


Figure 17. Belt loads versus time.

SUMMARY AND DISCUSSION

This version of the Creative Controls, Inc. tie-down system showed a significant improvement over the system evaluated in test WM8501. During the primary impact deceleration, the tie-down provided excellent wheelchair restraint, allowing only about 3.5 inches of wheelchair excursion measured at the wheel hub. The fact that the rear tie-down bar came out of the tie-down retaining mechanism is, however, unacceptable for real-world application, where multiple and complex impact decelerations can be expected.

It appears that the spring-loaded plate which pivots down when the rear tie-down bar moves forward into its captured position was also caused to pivot down during impact by inertial forces generated by the mass of the plate. This action, combined with the bending of the rear bar, was sufficient to allow the bar to pop out from under the steel retaining lip as the wheelchair moved rearward after impact. It is recommended that the rear locking mechanism be modified to prevent this possibility. If this is done, the CCI tie-down system should offer excellent wheelchair securement for frontal vehicle impacts equal to or less than the 30-mph, 20-g impact conditions of this test.

UMTRI

SLED IMPACT TEST

WM8505

TARGET INDUSTRIES

WHEELCHAIR TIE-DOWN

FOR DRIVERS

(second test)

Test Date:

March 13, 1985

INTRODUCTION

The purpose of this test was to re-evaluate the improved "Speedlock" wheelchair tie-down system developed by Target Industries. In test WM8503 the identical tie-down system did not successfully restrain the wheelchair due to the rear tie-down pin popping out of the tie-down structure. The motor which moves the pins into the lock-down position by rotating the steel pivot arm and winding up a coil spring had only been partly activated prior to the test. The spring tension holding the pivot arm and pins in place was therefore less than maximum. In the current test, the tie-down motor was fully powered with a 12 volt battery prior to the test, so that the spring was fully tensioned.

The Target tie-down system does not include a lap belt anchored to the wheelchair, but one was added to represent what is believed to be typical real-world conditions and to provide comparable loading conditions to impact tests of other tie-down systems intended for use by wheelchair-seated drivers. A vehicle-ahchored three-point restraint system was also used to provide occupant restraint for the 50th-percentile male anthropomorhic test dummy.

TEST SETUP

*	Wheelchair Tie-Down	Target Industries' power tie-down system.
*	Weight of Tie-down hardware on wheelchair	27 lbs., 3 oz.
*	Wheelchair	E&J 3P power wheelchair
*	Occupant Restraint	lap belt to wheelchair plus 3-point belt to vehicle
*	Test Dummy	50th percentile male (167 lbs.)
*	Orientation of Test	Forward facing, frontal impact
*	Desired Impact Velocity	30 mph
*	Desired Deceleration	20 g's

Figures 1 through 4 show the wheelchair secured in the tie-down system on the sled prior to dynamic testing. The setup and equipment are identical to that of test WM8503. A detailed description of the "Speedlock" tie-down system is contained in the report for that test. A steel structure consisting of front and rear cross members and a center longitudingal inverted "U" structure is bolted to the lower frame of the chair by means of "U" bolts and brackets. The wheelchair is captured and locked in position by means of two steel pins attached to a pivoting steel bar. Movement of the pins in and out of holes in the inverted "U" structure on the wheelchair and slots in the floor-anchored tie-down structure is accomplished by an electric motor which drives the pivoting steel bar open or closed and winds up a coil spring which applies tension to hold the pivot bar in the closed position. In test WM8503 the motor was not fully powered prior to the test and therefore the spring was not fully tensioned. In this test, a 12 volt battery was used to apply full power to the motor and thereby apply full spring tension on the pivot bar to keep the pins in position during impact.

A three-point vehicle-anchored restraint system was anchored to the sled and "B" pillar structure and placed between the seat back posts and the wheelchair arms to achieve appropriate positioning on the dummy. The shoulder belt anchor point was positioned 15 inches outboard of the center of the wheelchair and 9 inches back from the seat back upholstery. The right side floor belt anchorage was positioned approximately 3 inches behind and 3 inches outboard of the rear wheel hub. GSE seat belt load cells were placed on the right chair lap belt, the right side shoulder belt down near the floor, the upper left part of the shoulder belt, and the right side of the vehicle-anchored lap belt near the floor. As previously mentioned, a lap belt was also tied to the wheelchair structure at the junctions of the seat back posts and the horizontal seat frame members. Sled pressures were set to achieve a velocity differential of 30 mph and an average deceleration of 20 g's.

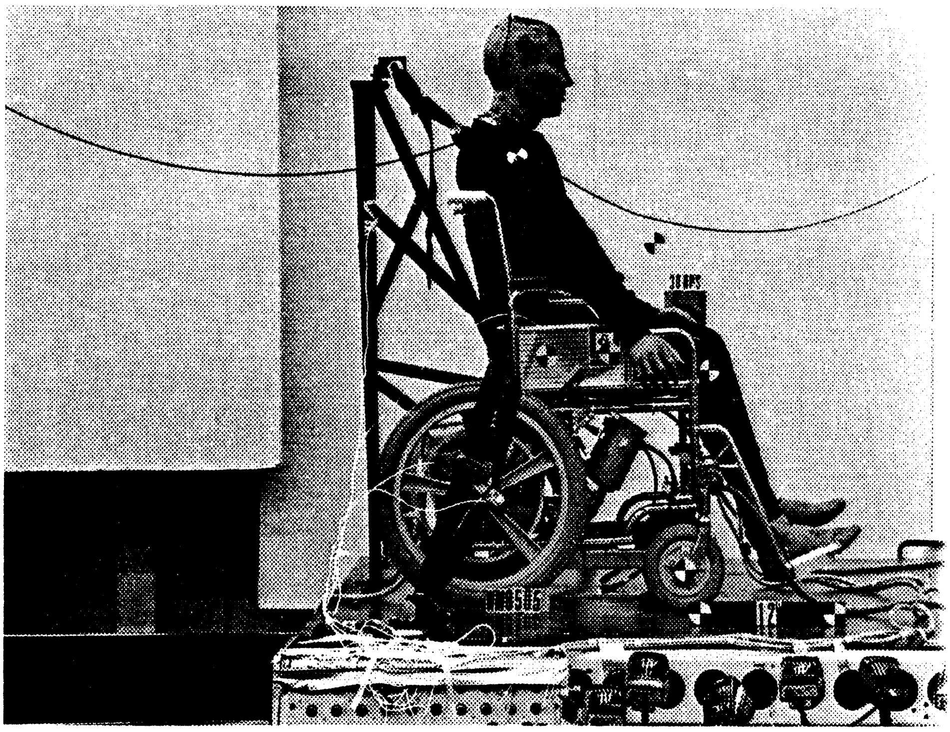


Figure 1. Side view of test setup.

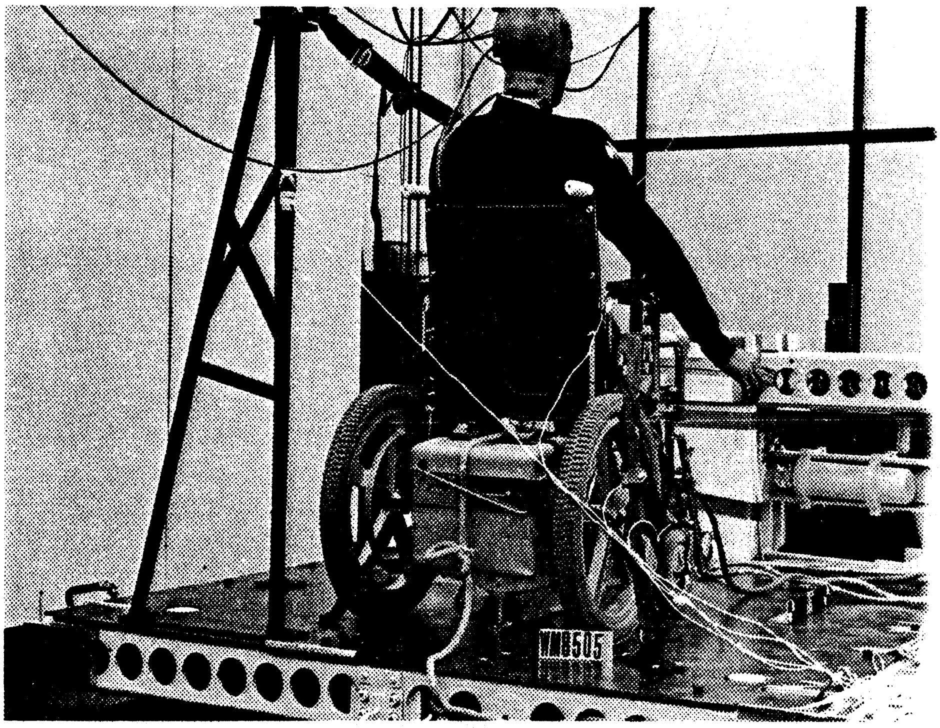


Figure 2. Rear view of test setup.

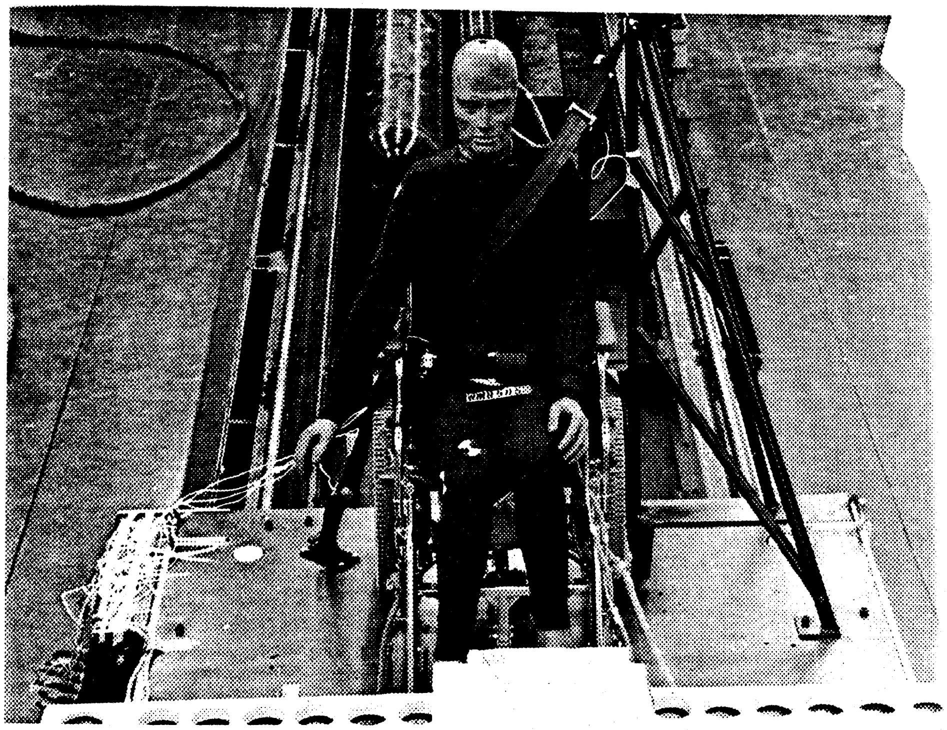


Figure 3. Front view of test setup.

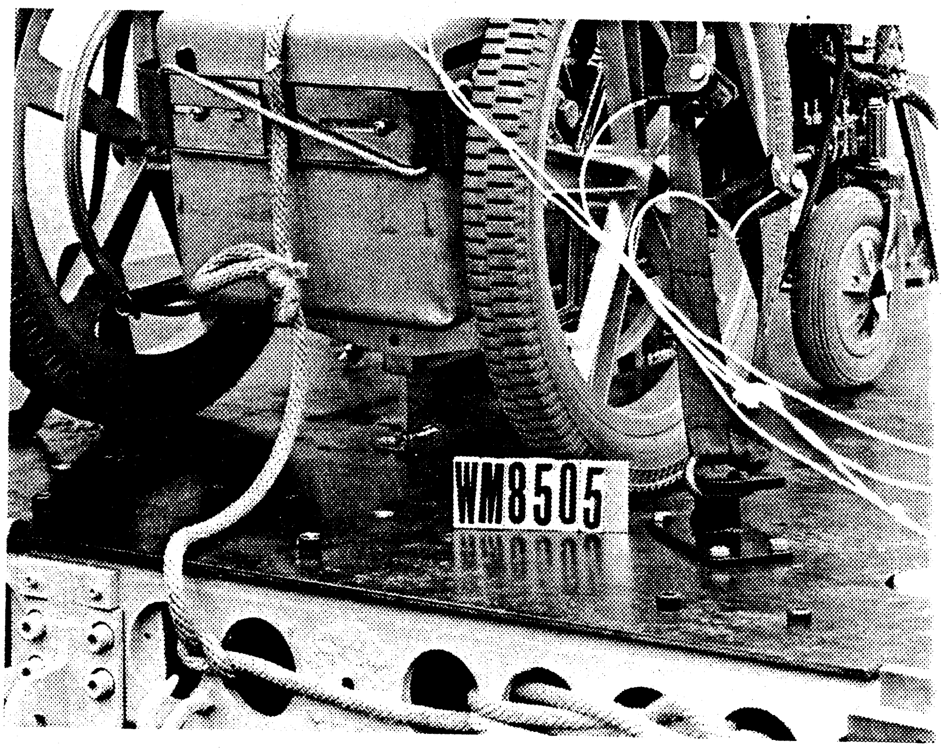


Figure 4. Rear view close-up of tie-down structure in locked position.

RESULTS

* Actual Sled Deceleration .... 20.1 g's
* Actual velocity .... 29.2 mph
* Peak force right chair lap belt ..... 374 lbs.
* Peak force left shoulder belt .... 2124 lbs.
* Peak force right floor lap belt ..... 2043 lbs.
* Peak force right vehicle lap belt ... 1192 lbs.
* Peak resultant head acceleration .... 60 g's.
* Head Injury Criteria .... ?
* Peak resultant chest acceleration ... 53 g's

Figure 5 shows the Polaroid time sequence photograph of the impact test, and Figures 6 through 10 show the wheelchair and test dummy after the impact. During the impact the retaining pins remained in place and the tie-down did an excellent job of securing the frame of the wheelchair in place. Analysis of the high-speed films indicates a peak wheelchair excursion measured at the wheel hub of just over three inches. Inspection of the tie-down structure attached to the wheelchair revealed no visible damage or bending in the cross members. The "U" bolts attaching the hardware to the wheelchair frame were bent but not broken or loosened. The tie-down structure attached to the sled showed no damage at all.

As shown in Figure 10, the wheelchair sideframes underwent significant deformation, and this allowed the chair mass to load the shoulder belt, resulting in the peak shoulder belt loads in excess of 2000 pounds. As in the previous test, the shoulder belt broke at this force level due to abrasion of the webbing material on the knurled roller at the upper anchor point, leading to further wheelchair deformation due to downward loading of the dummy on the wheelchair.

Figures 11 through 14 show the sled velocity and deceleration profiles, the head and chest accelerations, and the belt loads, respectively. The peak resultant head acceleration reported is an artifact due to the impact of the dummy's head with his knees at about 200 msecs as a result of shoulder belt failure. Ignoring this, head and chest accelerations are well within existing tolerance values for the able-bodied population. The point of shoulder belt failure is clearly apparent,as is the consequent change in head deceleration resulting from the release of the torso at this point in time. The low value for peak lap belt load indicates the "softness" of this anchor point for occupant restraint when the wheelchair tie-down points are a significant distance from the occupant restraint anchor points.

WM 8505

Figure 5. Polaroid graph sequence photograph.

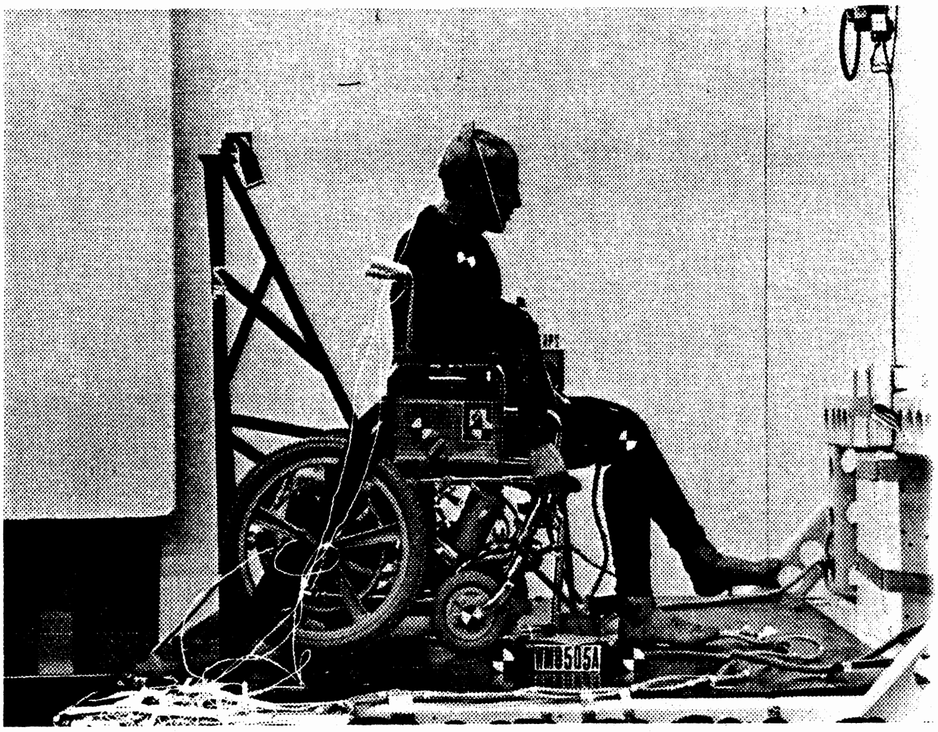


Figure 6. Side view after impact.

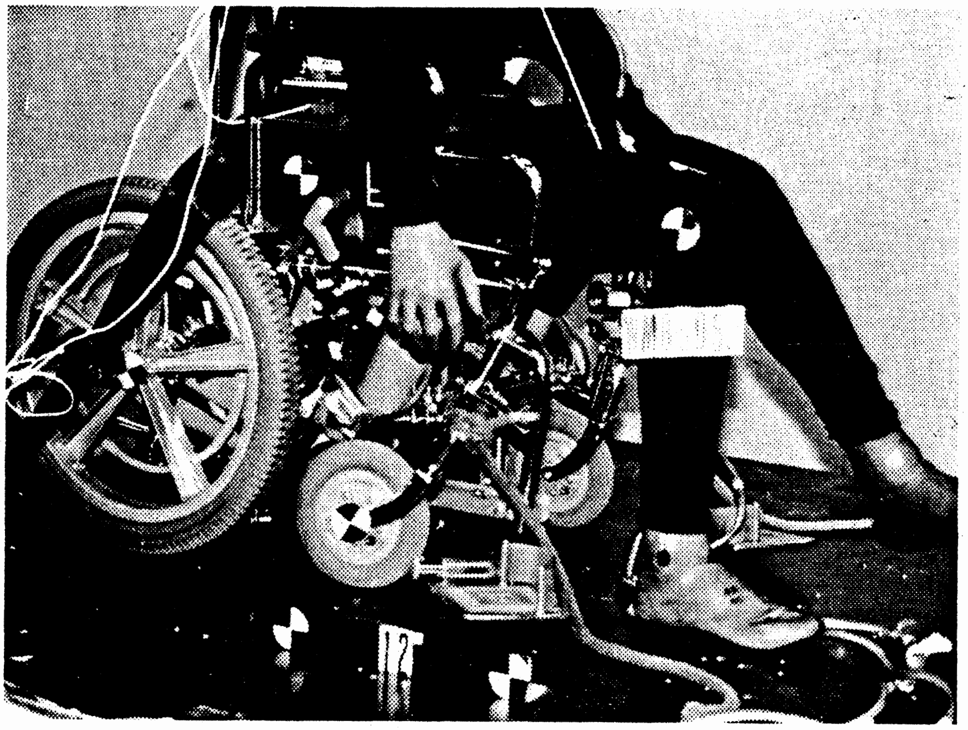


Figure 7. Close-up of front of wheelchair after impact.

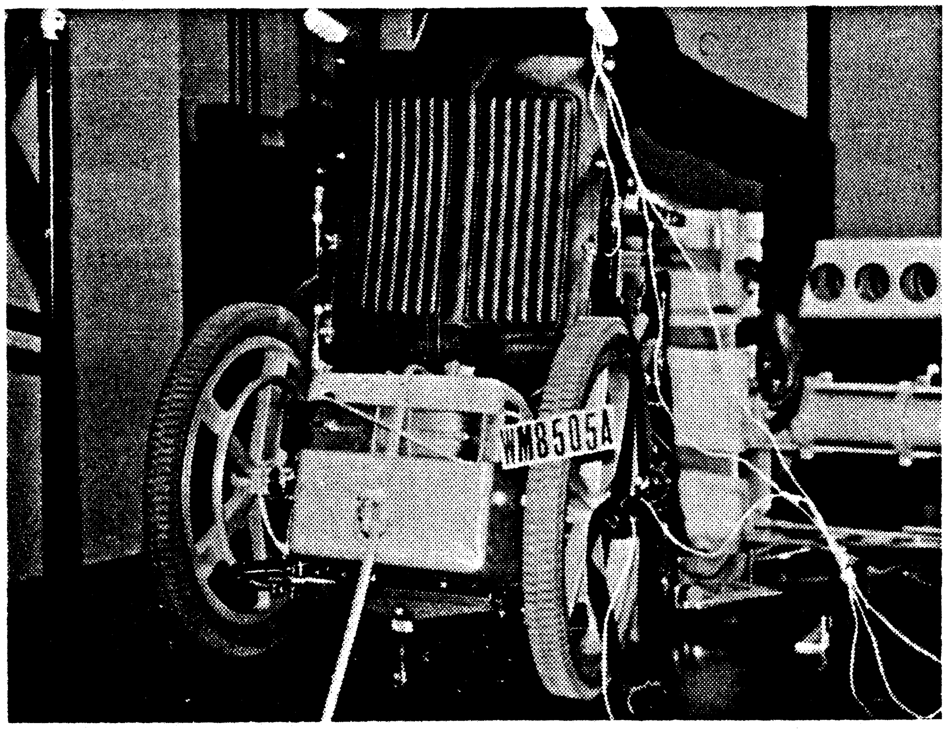


Figure 8. Rear view after impact.

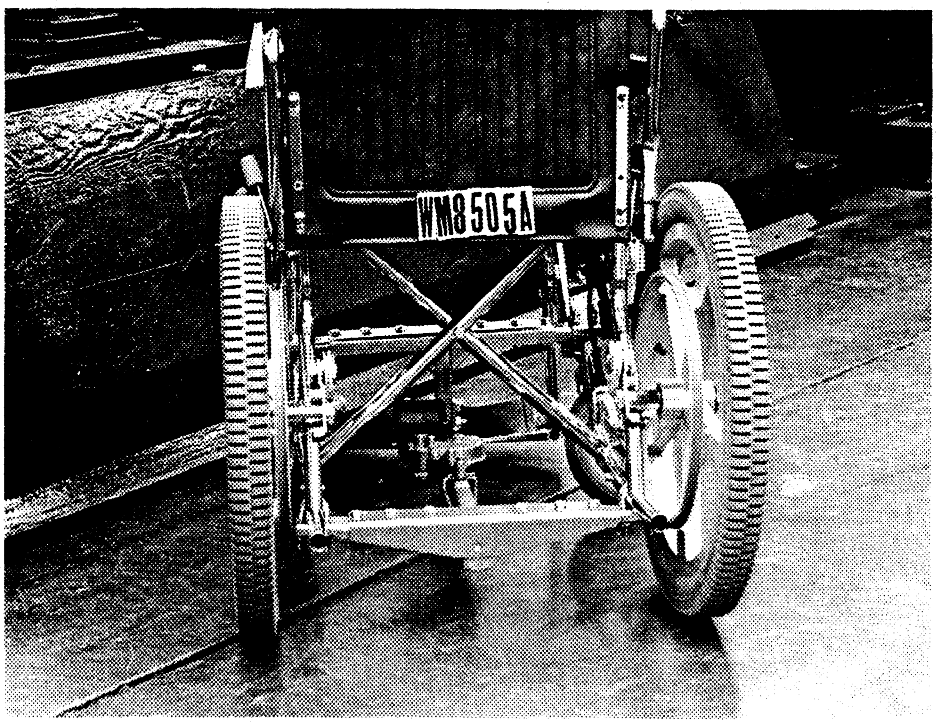


Figure 9. View of tie-down hardware on wheelchair after impact.

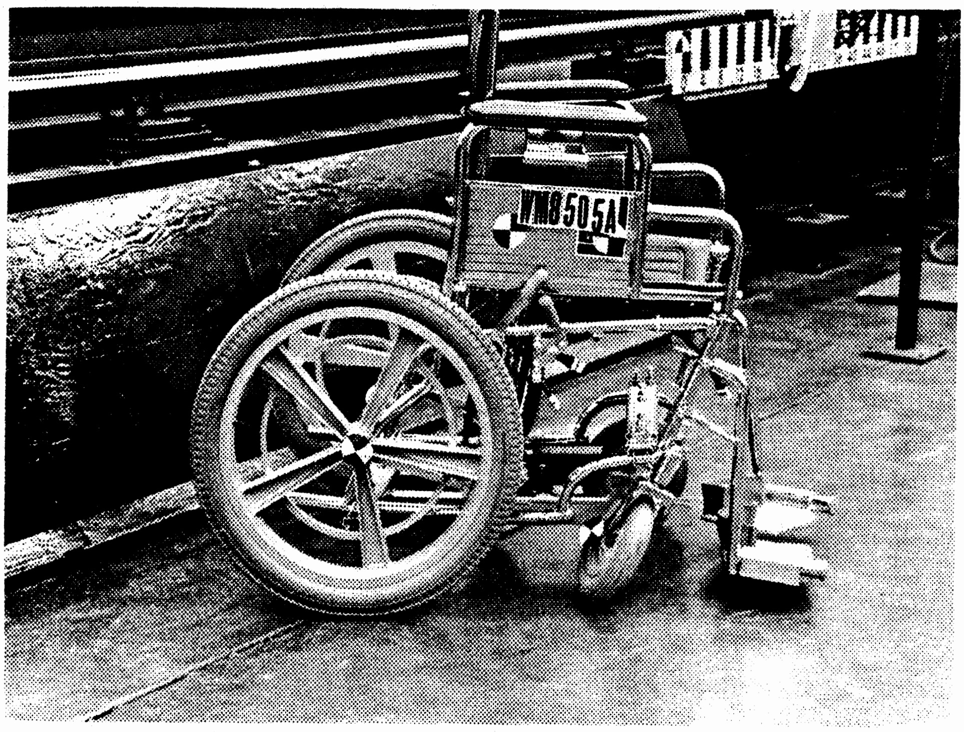


Figure 10. Collapsed wheelchair frame after impact.

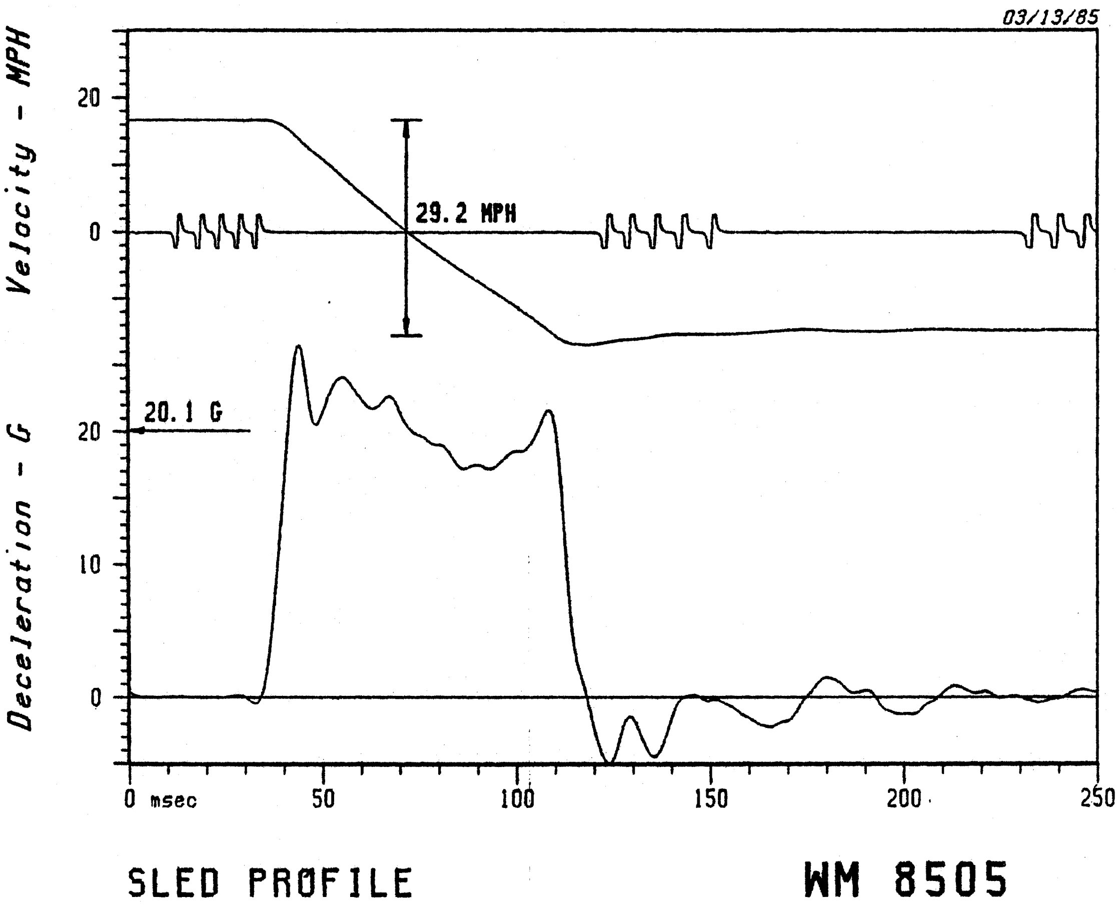


Figure 11. Sled velocity and deceleration profiles.

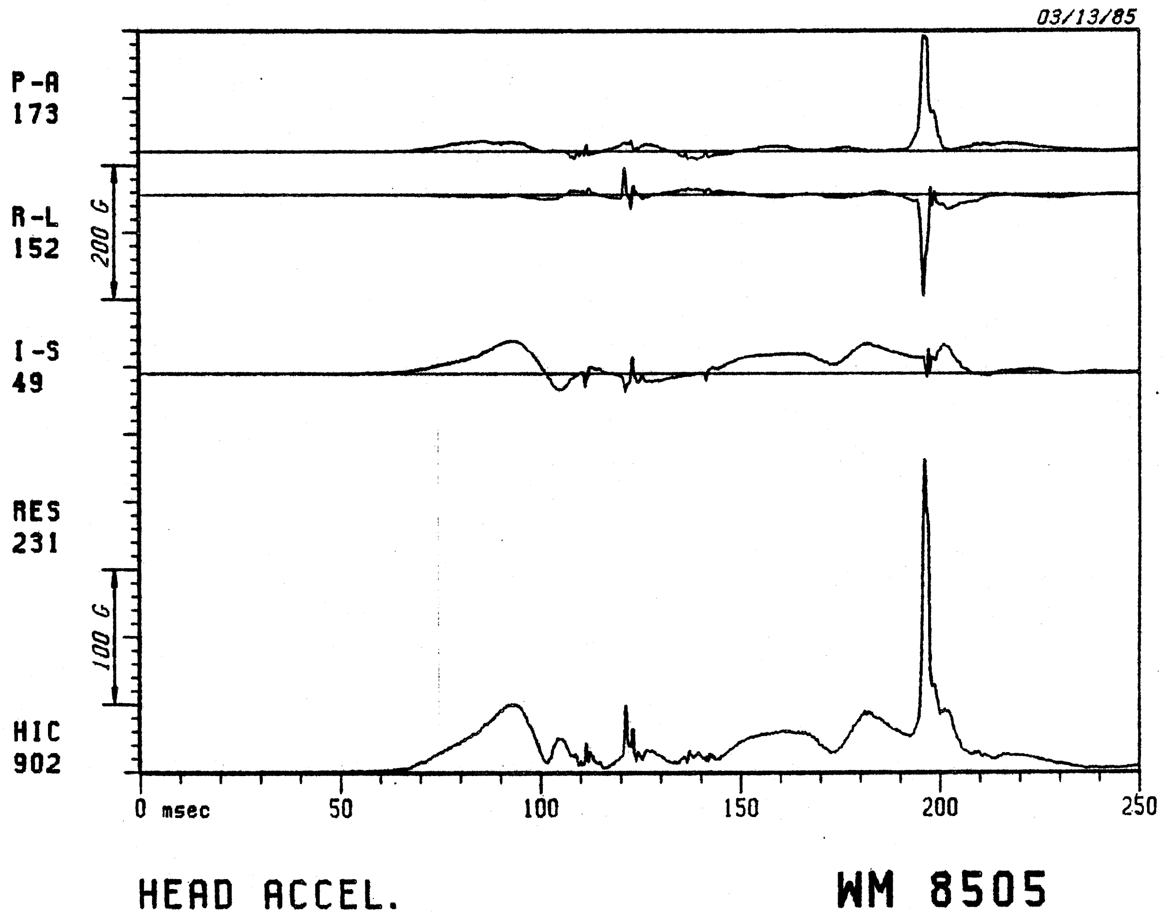


Figure 12. Head accelerations versus time.

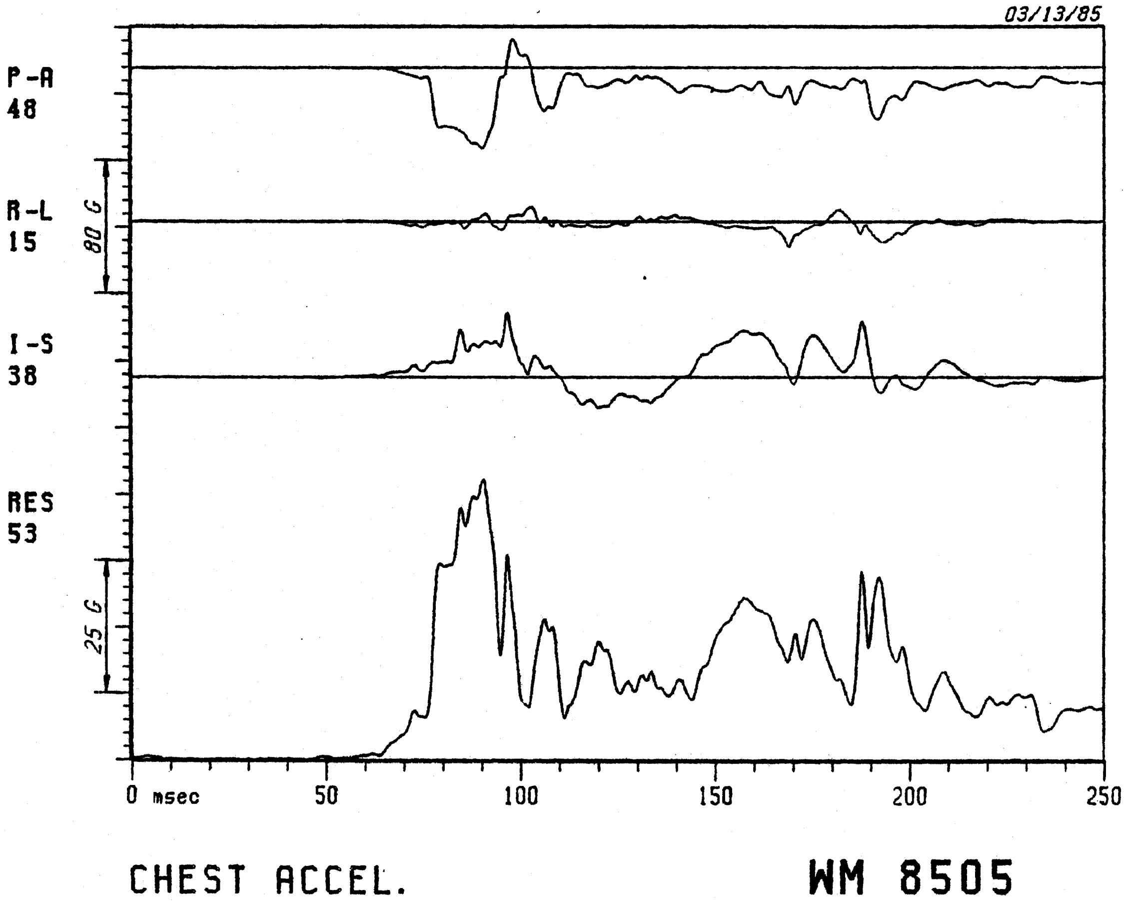


Figure 13. Chest accelerations versus time.

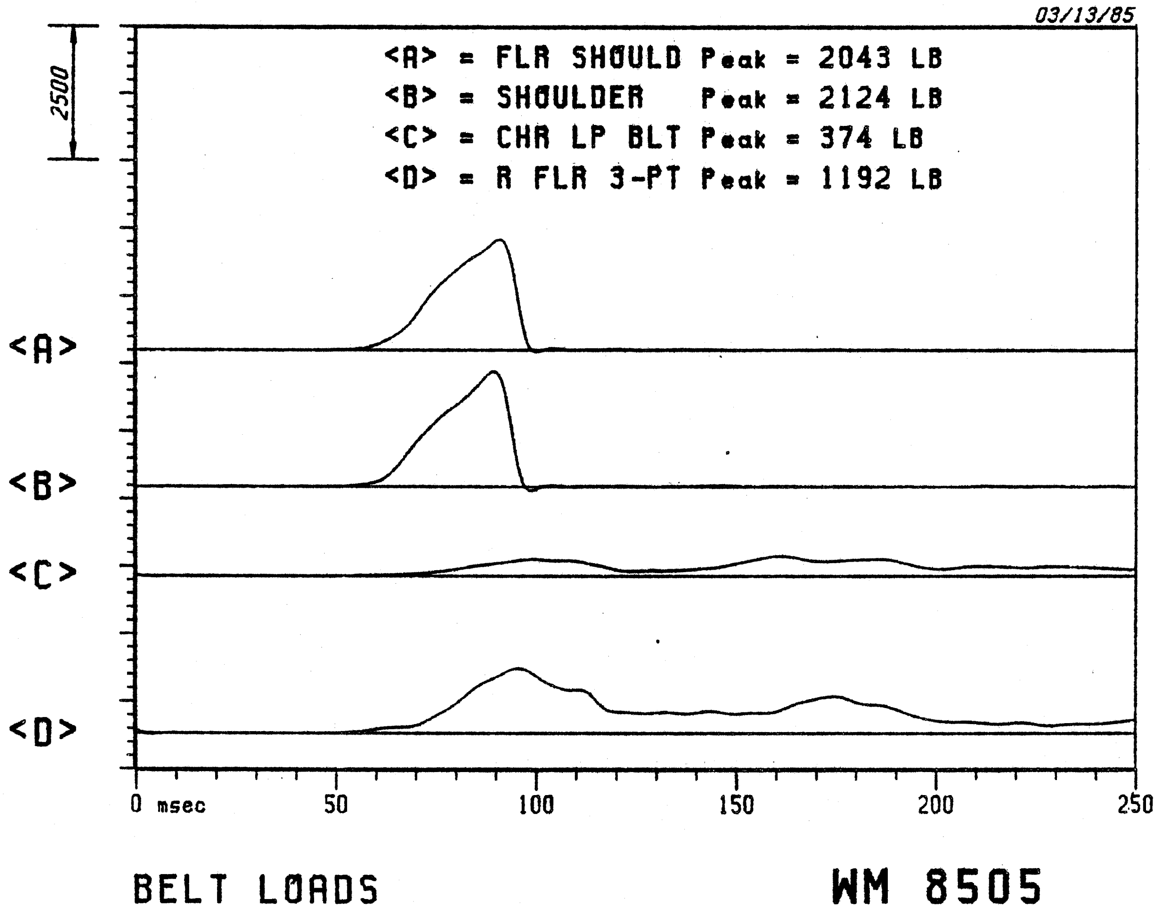


Figure 14. Belt loads versus time.

SUMMARY AND DISCUSSION

The "Speedlock" tie-down system did an excellent job of securing the wheelchair in place during the 30 mph, 20 g impact of this test. Because the lap belt was attached to the wheelchair frame some distance from the tie-down hardware, however, the torques applied to the wheelchair due to restraint forces on the dummy resulted in significant wheelchair deformation, which seems to have resulted in additional loading on the vehicle-anchored shoulder belt than would have resulted from the mass of the dummy alone. This suggests a need to provide wheelchair lap belt anchor points on the tie-down hardware for those situations where occupants desire to have a chair-anchored lap belt in addition to the vehicle-anchored restraint system. If this is done, the loads on the tie-down hardware would be increased (i.e., in this test the wheelchair frame absorbed the occupant restraint loads in undergoing deformation) and while it would appear that the "Speedlock" tie-down system could handle these additional loads, such a modification should be dynamically tested.

While shoulder belt forces would generally not exceed 2000 pounds in a 30 mph test, the failure in the shoulder belt webbing should not have occurred at the load it did, and it is recommended that this aspect of the restraint system be improved to withstand greater forces.

UMTRI

SLED IMPACT TEST

WM8506

CREATIVE CONTROLS

WHEELCHAIR TIE-DOWN

FOR DRIVERS

(second modification)

Test Date:

April 1, 1985

INTRODUCTION

The purpose of this test was to evaluate the effectiveness of a prototype wheelchair tie-down system developed by Creative Controls, Inc. for handicapped drivers of vans. In test WM8501, a similar tie-down was tested but failed due to an excessive amount of free-play in the rear locking mechanism. In test WM8504, a modified version of this tie-down was tested with significant improvement in performance as a result, eliminating the free-play but the rear tie-down bar came out of the tie-down structure on rebound after the primary impact deceleration. In this test (WM8506), the rear retaining mechanism was modified to prevent this from happening.

In addition to a lap belt attached to the tie-down hardware, a vehicle-anchored shoulder belt was used to provide upper torso restraint for the 50th-percentile male anthropomorhic test dummy.

TEST SETUP

*	Wheelchair Tie-Down	Creative Controls prototype with modified rear tie-down mechanism.
*	Weight of Tie-down hardware on wheelchair	18 lbs.
*	Wheelchair	E&J 3P power wheelchair.
*	Occupant Restraint	lap belt to wheelchair plus vehicle shoulder belt.
*	Test Dummy	50th percentile male (167 lbs.)
*	Orientation of Test	Forward facing, frontal impact
*	Desired Impact Velocity	30 mph
*	Desired Deceleration	20 g's

Figures 1 through 3 show the wheelchair and test dummy prior to testing,and Figure 4 shows the modified tie-down structure with the rear tie-down bar locked in position. The bar is captured tightly in position by two steel latches which pivot up behind the bar as it moves into position under the main retaining lip. As with a similar mechanism at the front of the tie-down structure (i.e., the modification in test WM8504), a spring-loaded steel "wedge" moves into position under each latch to keep it in the up position. Two steel cables attached to these steel wedges provide the means for tie-down release by manual or solenoid action.

Four GSE seat belt load cells were installed to measure forces in the vehicle-anchored shoulder belt and wheelchair anchored lap belt. Sled pressures were set to achieve a velocity differential of 30 mph and a sled deceleration of 20 g's during impact.

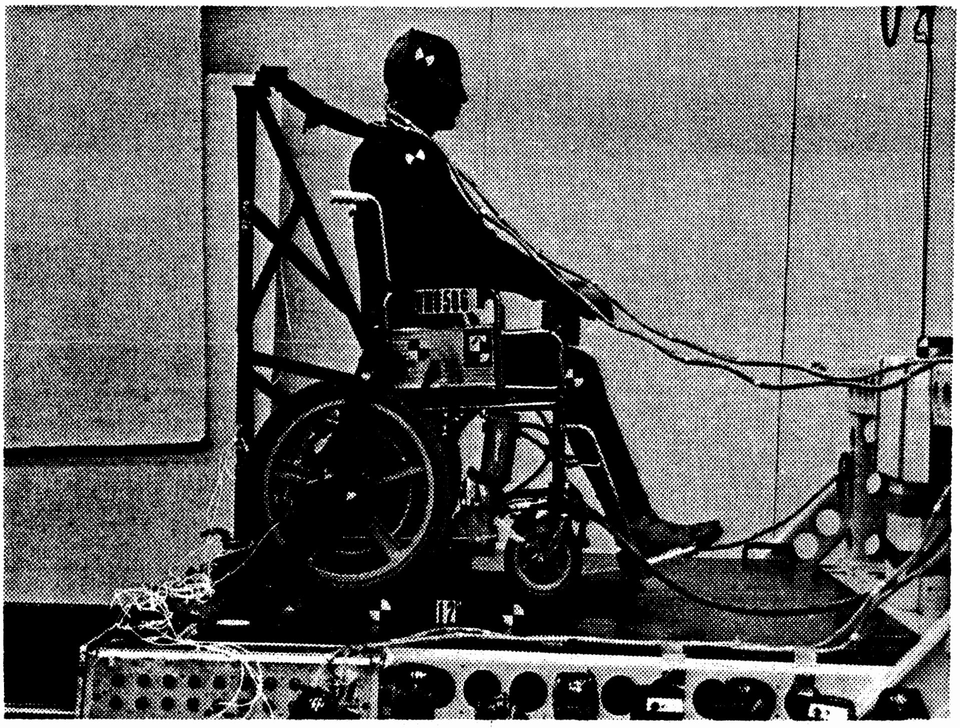


Figure 1. Side view of test setup.

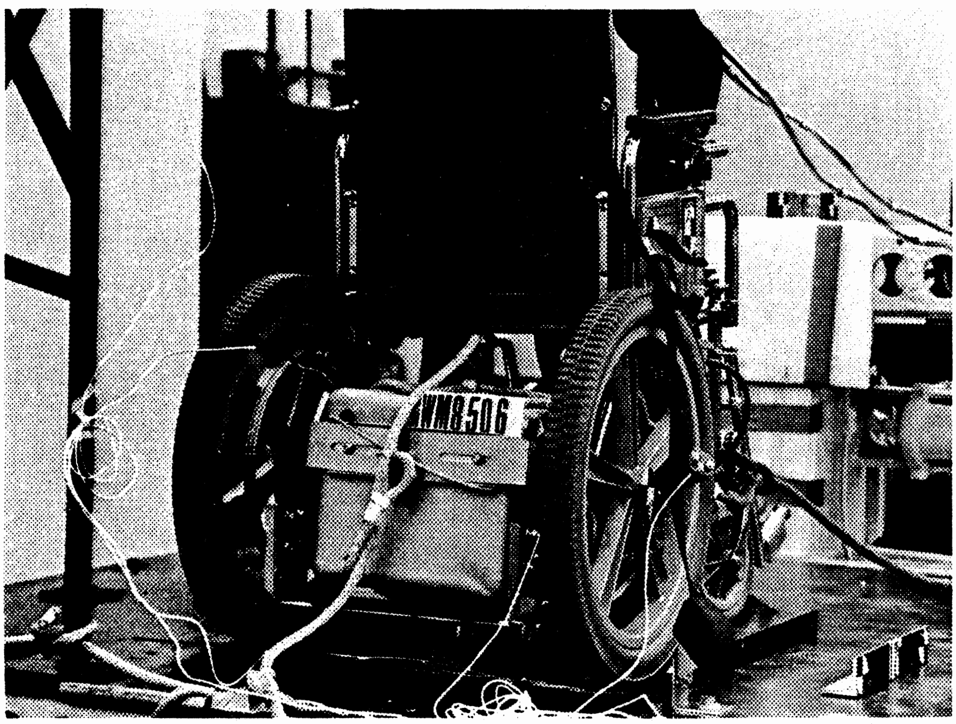


Figure 2. Rear view of test setup.

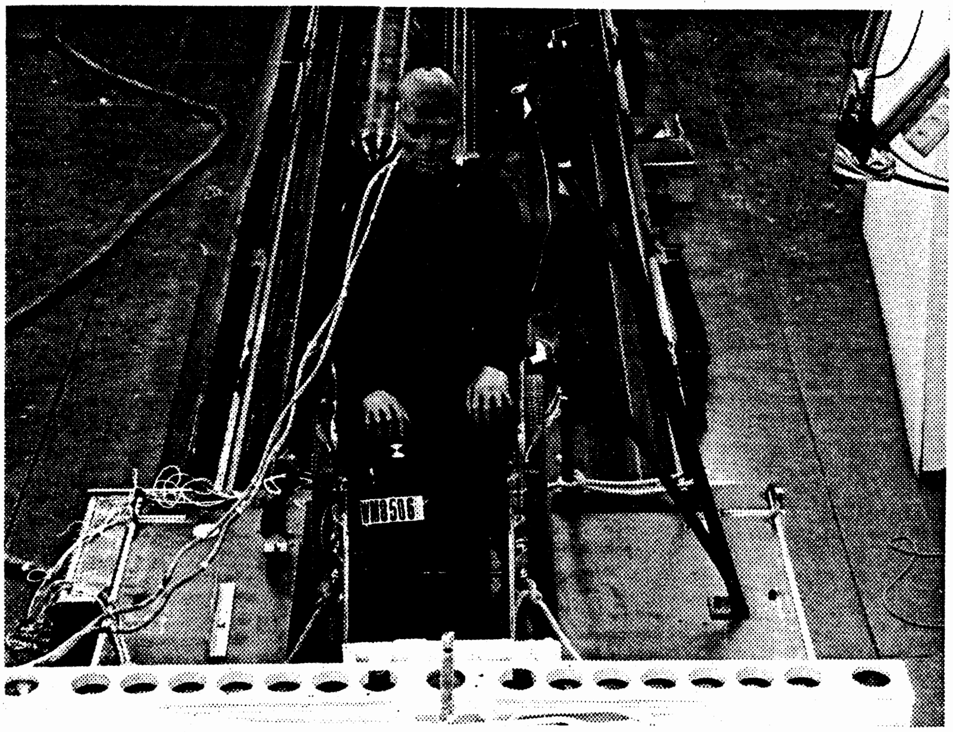


Figure 3. Front view of test setup.

Figure 4. Close-up of modified rear tie-down mechanism.

RESULTS

* Actual Sled Deceleration .... 20.6 g's
* Actual velocity .... 28.6 mph
* Peak force right chair lap belt ..... 1745 lbs.
* Peak force left chair lap belt ...... 1638 lbs.
* Peak force upper shoulder belt ...... 1931 lbs.
* Peak force lower shoulder belt ...... 882 lbs.
* Peak resultant head acceleration .... 41 g's.
* Head Injury Criteria 349
* Peak resultant chest acceleration ... 32 g's

Figure 5 shows the polaroid sequence photographs of the impact event, and Figure 6 shows a stop-action photograph early into the deceleration pulse. Figures 7 through 12 show the conditions of the wheelchair, test dummy, and tie-down hardware after the impact. The tie-down provided excellent retraint of the wheelchair, allowing the shoulder belt and lap belt to provide effective restraint for the test dummy. Analysis of the high-speed films indicates a peak wheelchair excursion of about four inches. As shown in Figure 12, both steel tie-down bars underwent significant bending during the impact, and the front of the wheelchair frame underwent moderate deformation.

Figure 13 shows the sled velocity and deceleration profiles, which indicated a velocity differential of 28.6 mph and an average deceleration of 20.6 g's. Figures 14 through 16 show the head and chest accelerations and belt loads. The shoulder belt loads are not excessively high, indicating that the wheelchair did not add to the load of the occupant restraint system. Head and chest accelerations are well within the currently accepted tolerance limits for the able-bodied population.

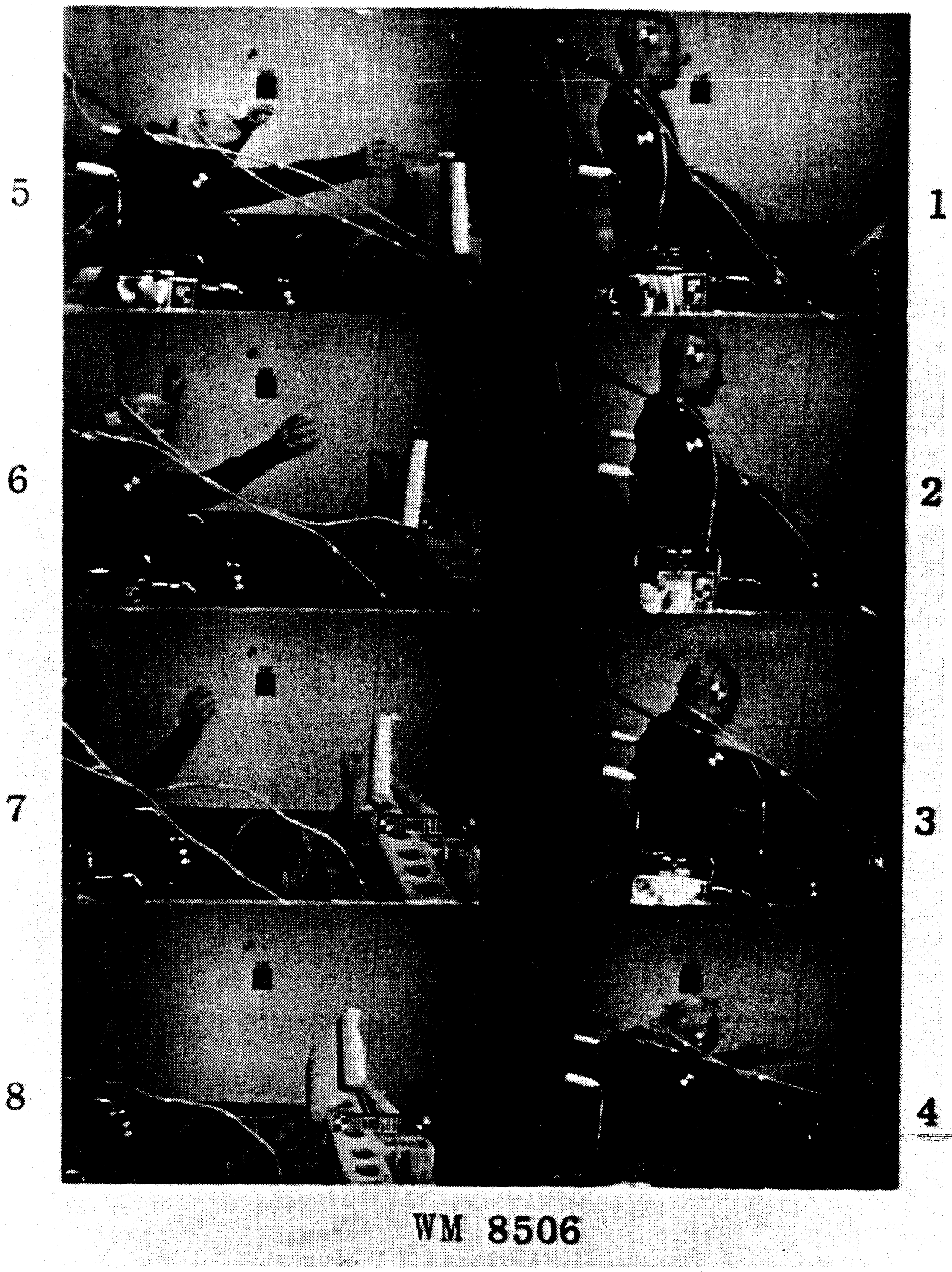


Figure 5. Polaroid graph sequence photograph.

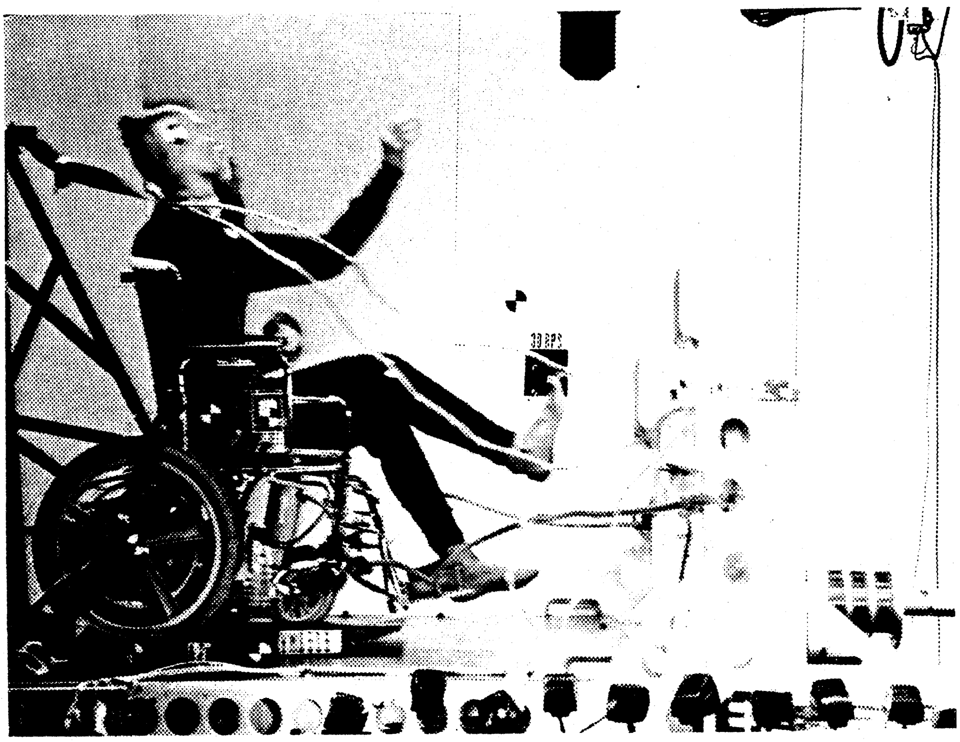


Figure 6. Stop-action photograph during impact.

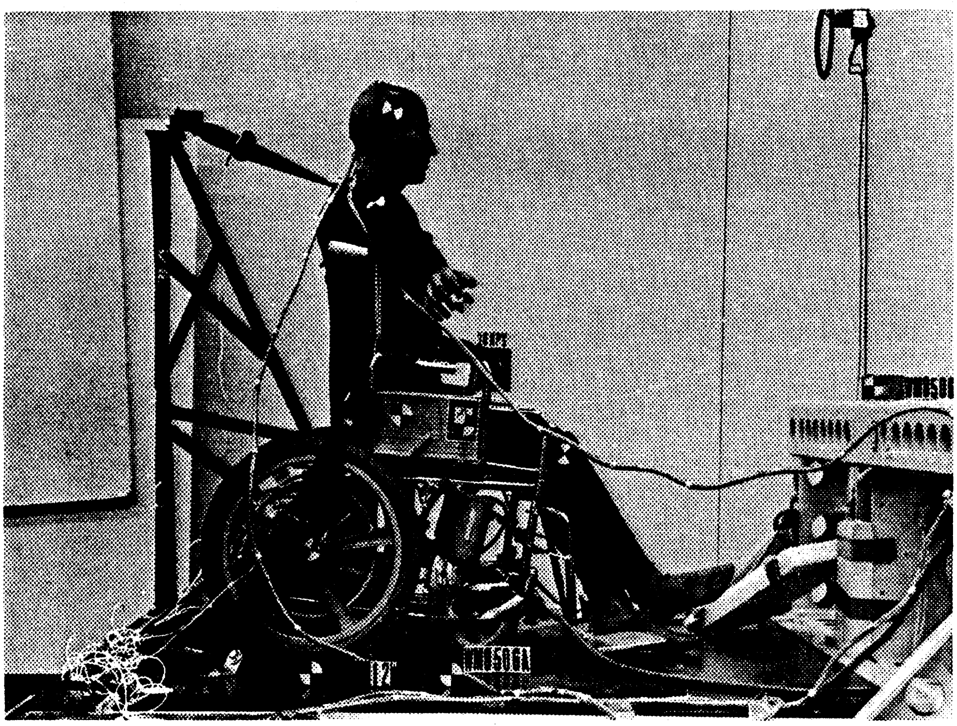


Figure 7. Side view after impact.

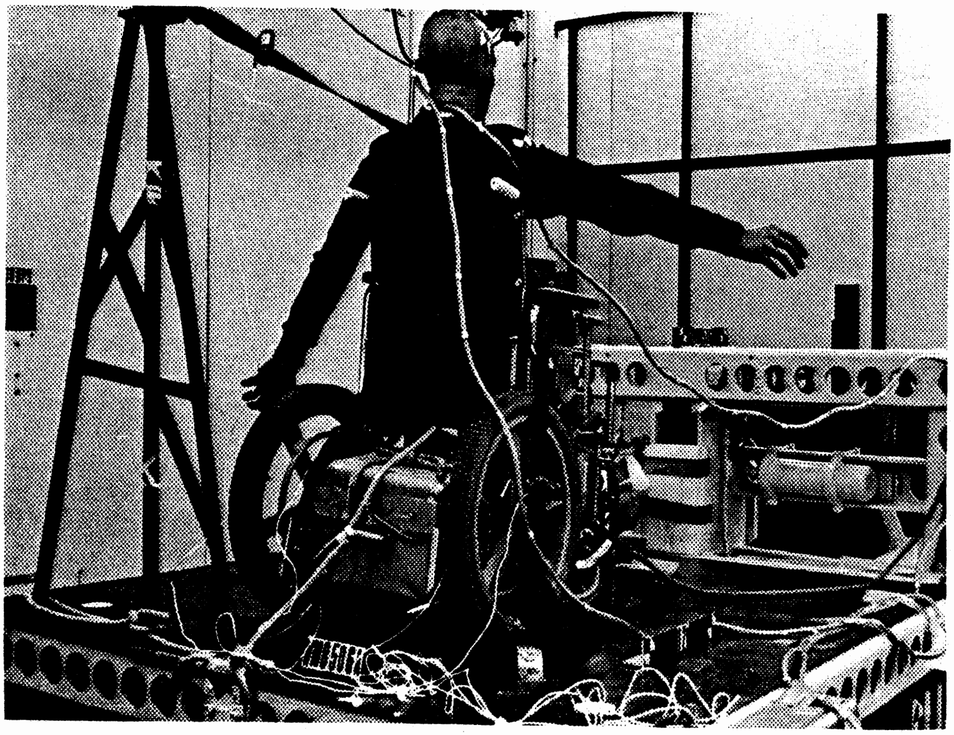


Figure 8. Rear view after test.

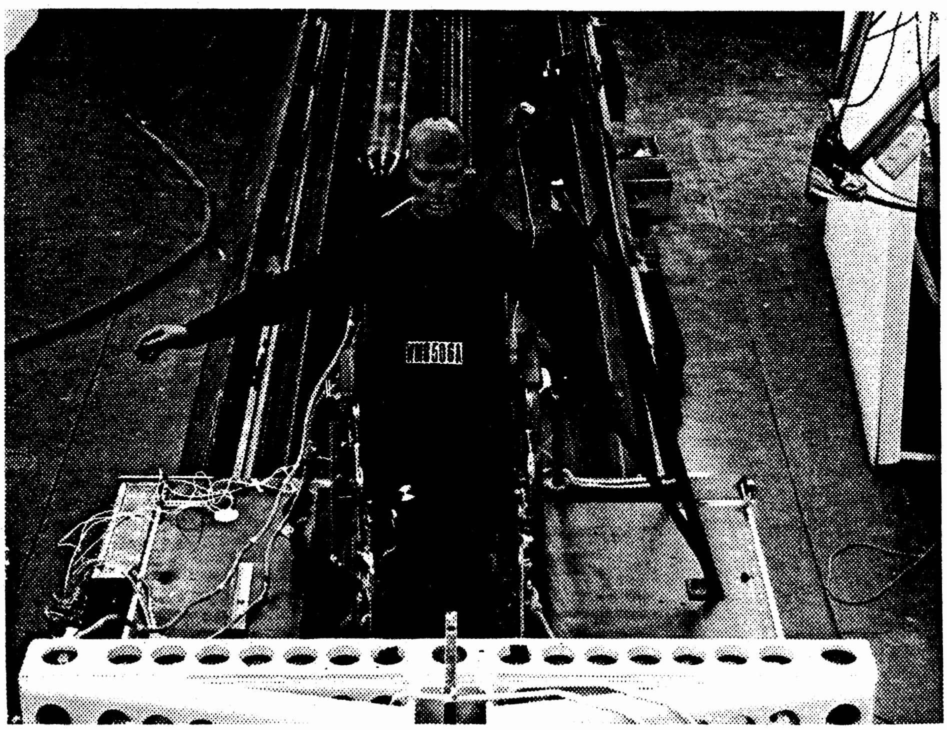


Figure 9. Front view after impact.

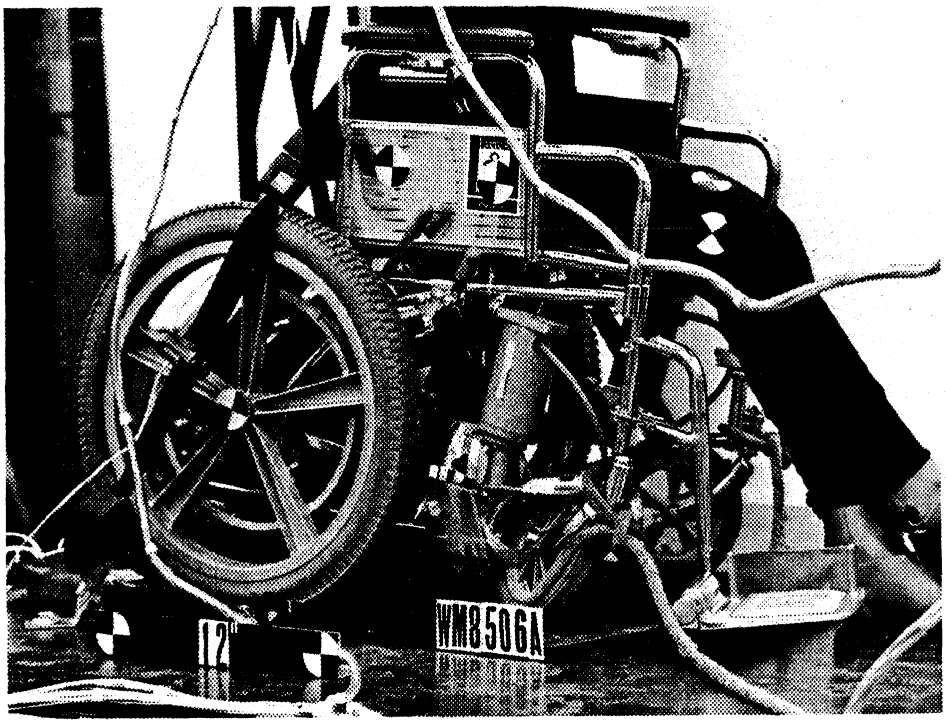


Figure 10. Close-up of front of wheelchair after impact.

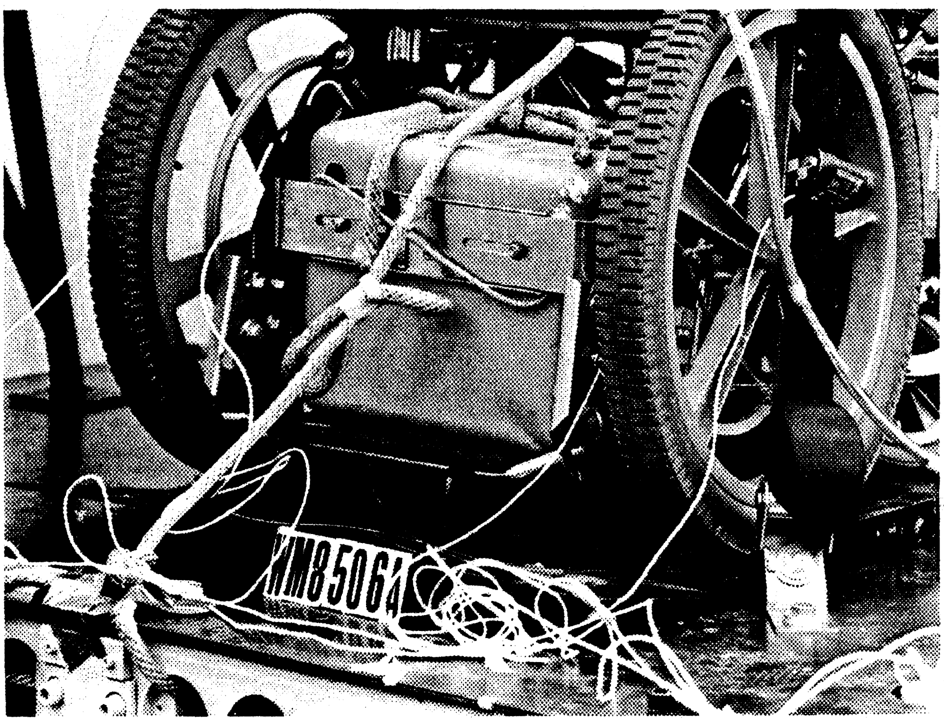


Figure 11. Rear view close-up after impact.

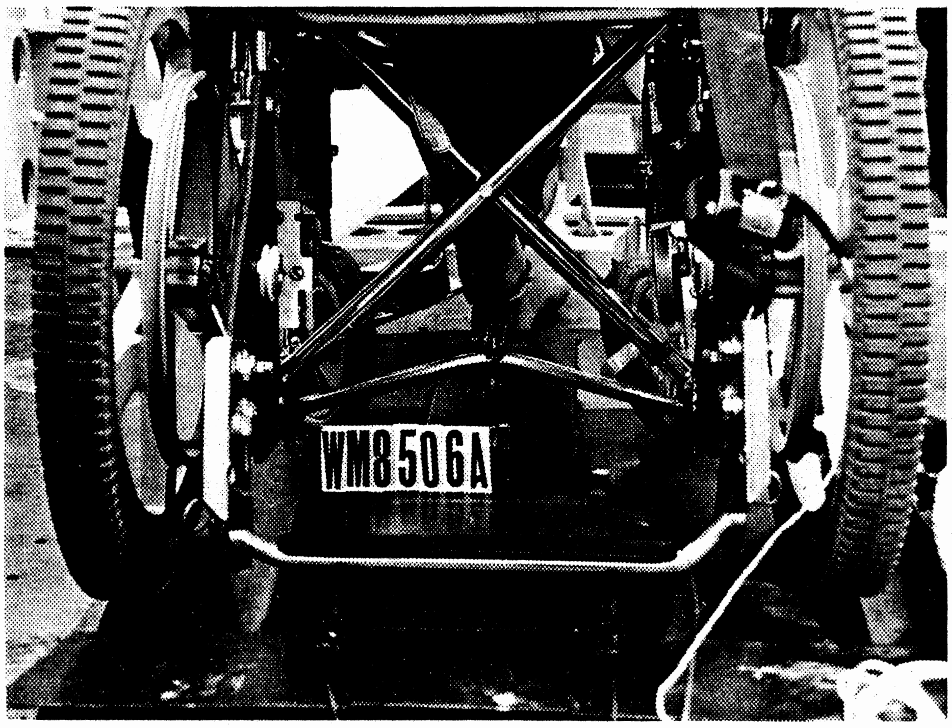


Figure 12. View of tie-down bars after impact.

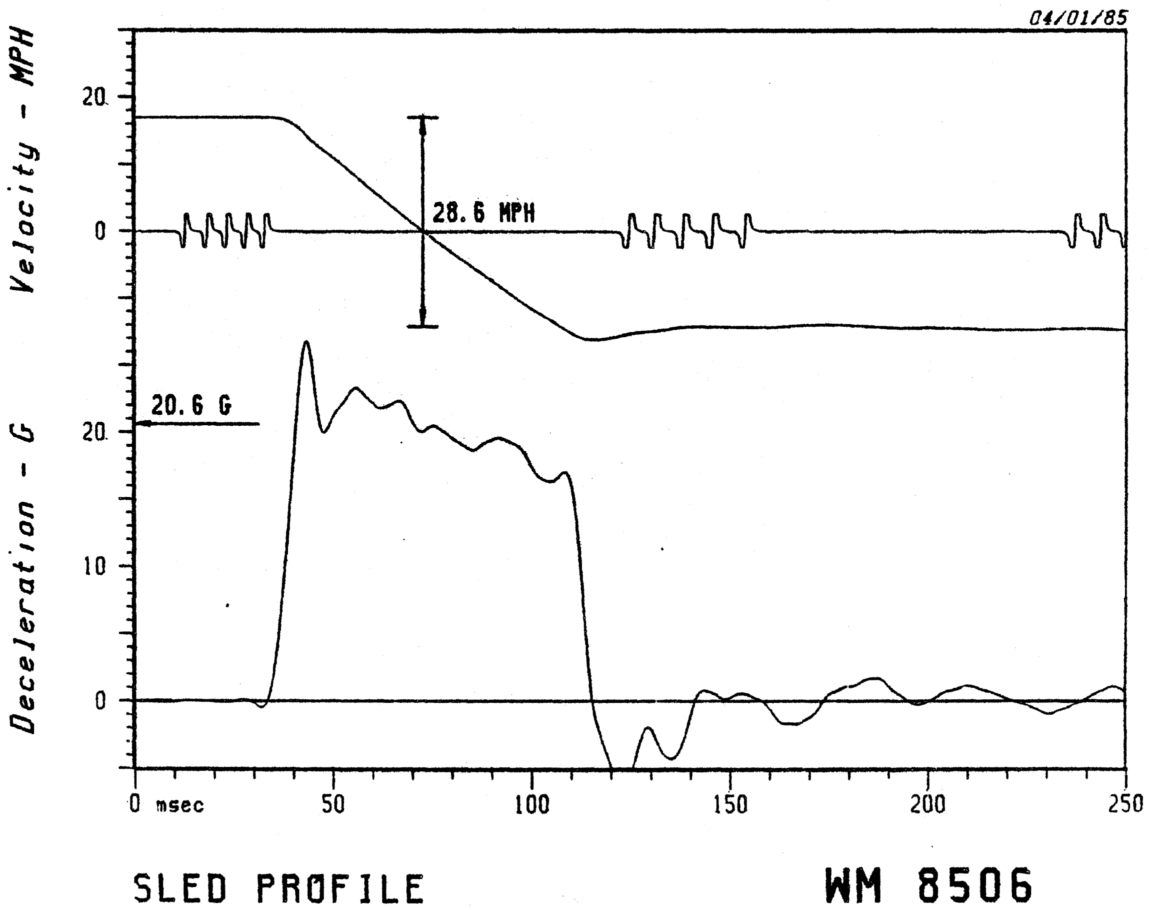


Figure 13. Sled velocity and deceleration profiles.

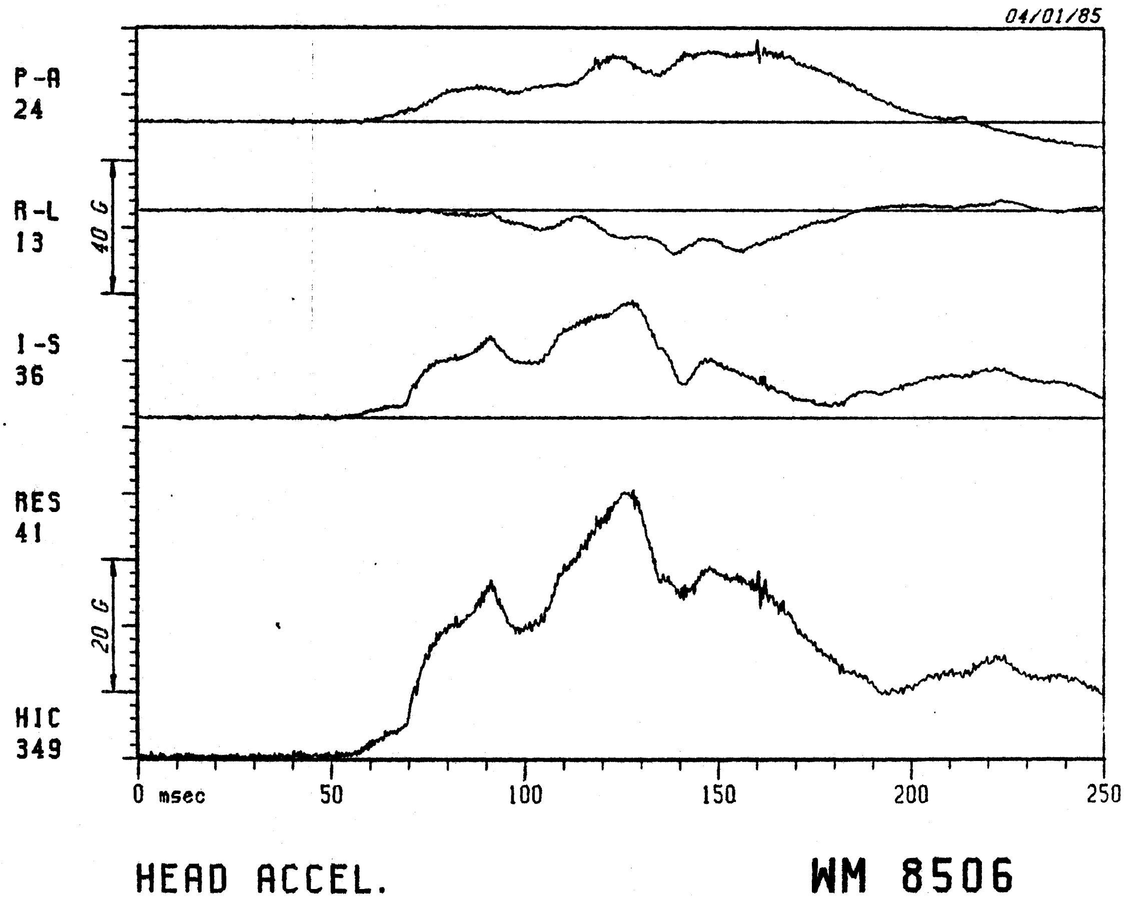


Figure 14. Head accelerations versus time.

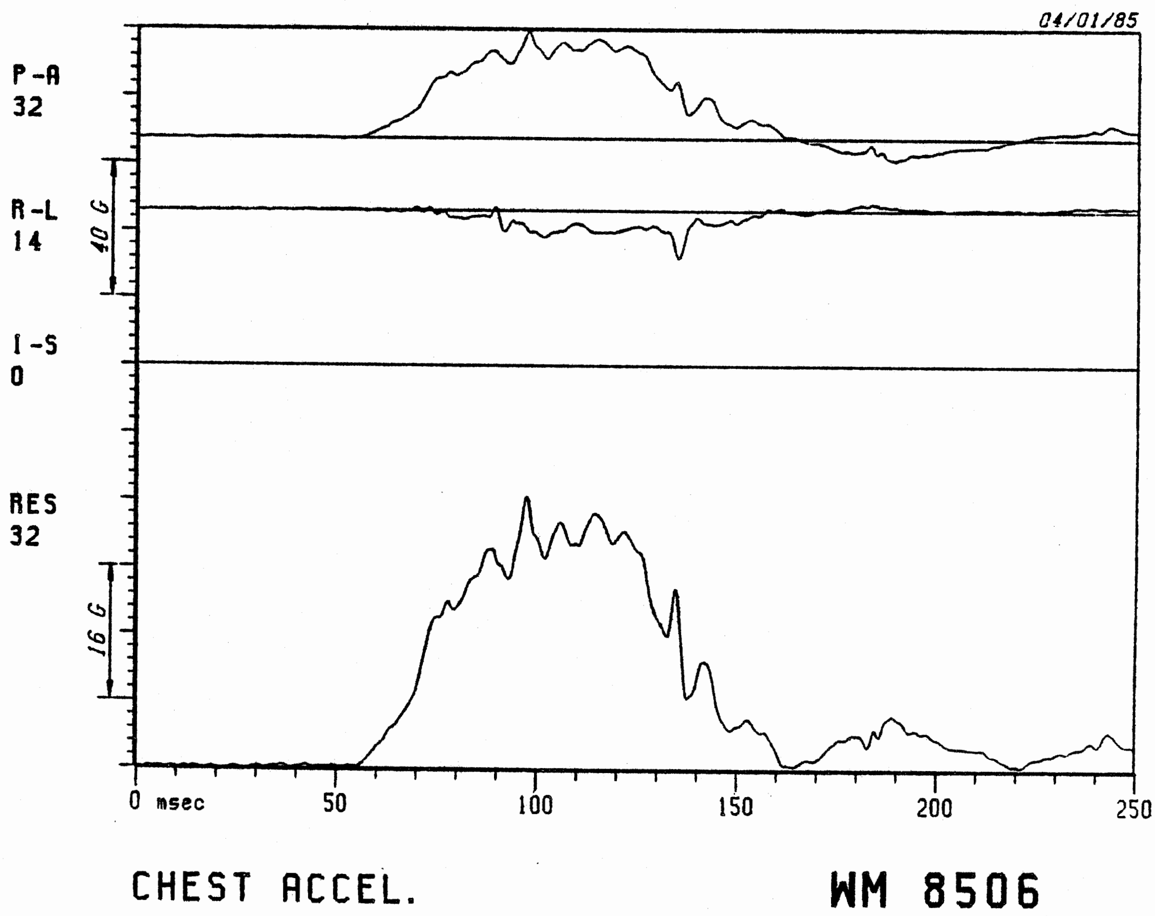


Figure 15. Chest accelerations versus time.

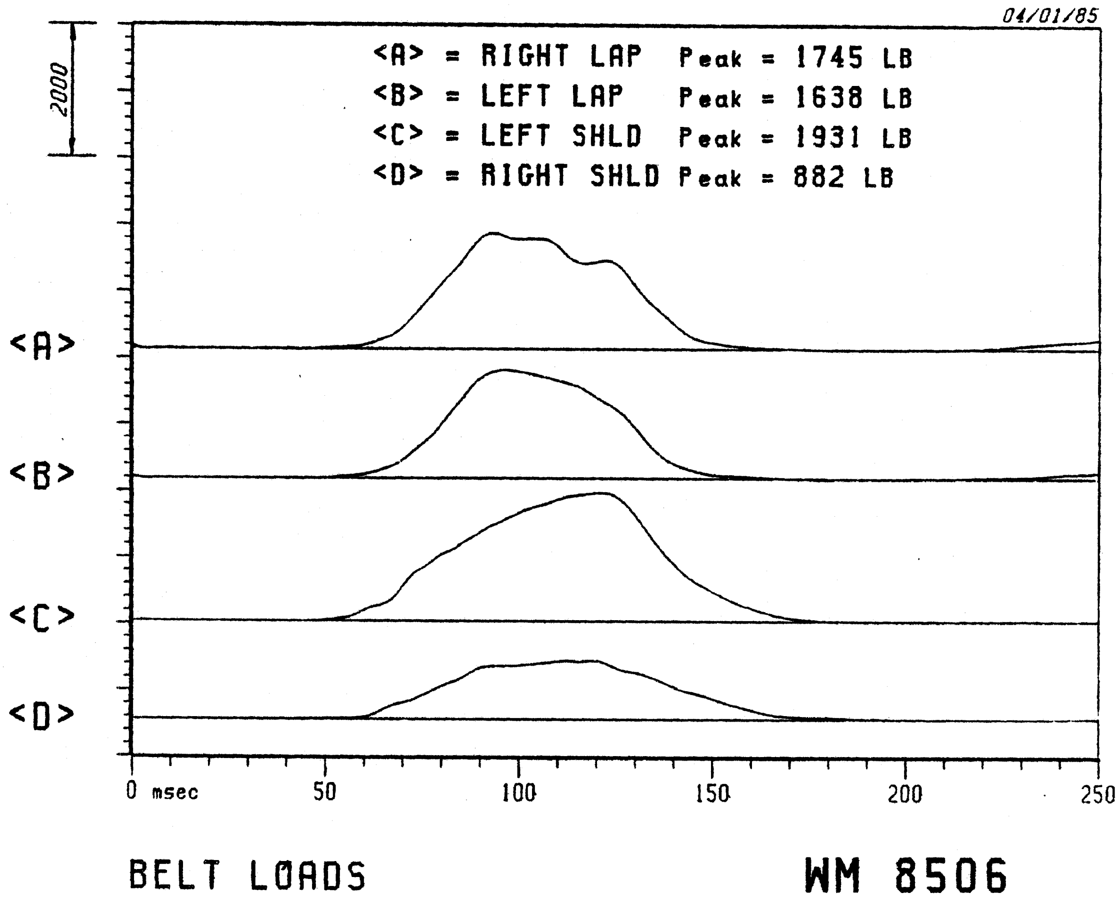


Figure 16. Belt loads versus time.

SUMMARY AND DISCUSSION

This version of the Creative Controls, Inc. wheelchair tie-down system provided excellent wheelchair securement during the 30 mph impact of this test. The only improvement that can be suggested is an increase the diameter or material properties of the steel tie-down bars to reduce the amount of wheelchair excursion due to bar deformation.