DYNAMIC TESTING OF RESTRAINT SYSTEMS AND TIE-DOWNS FOR USE WITH VEHICLE OCCUPANTS SEATED IN POWERED WHEELCHAIRS

INTERIM REPORT

to

Massachusetts Rehabilitation Commission
Statler Office Building
20 Providence Street
Boston, Massachusetts 02116

by

Lawrence W. Schneider
The Highway Safety Research Institute
The University of Michigan
Ann Arbor, Michigan 48109

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16. Abstract

Twenty-two of thirty planned sled tests of wheelchair tie-downs and restraint systems have been conducted using Everest and Jennings power wheelchairs and a 50th percentile male dummy. All tests were for a sled velocity differential of 20 mph and a 16G deceleration pulse. This report describes the results of these tests as observed from high-speed films taken at 1000 frames per second.

17. Key Words	18. Distribution Statement
Wheelchair Impact testing Restraint Tie-down	

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I. INTRODUCTION

The Biomedical and Biomechanics Departments at the Highway Safety Research Institute (HSRI) are currently conducting a series of thirty (30) sled impact tests of wheelchair tie-down and wheelchair occupant restraint systems for the Massachusetts Rehabilitation Commission. The purpose of this interim report is to describe the results of the first twenty-two (22) of these tests which have been completed to date.

II. PROCEDURES

All tests are being run on the HSRI impact sled facility illustrated in Figure 1. The sled itself is a 975-lb. test platform which is driven from one end of a 45-foot track by a compressed-gas-powered ram. An adjustable pneumatic decelerator at the opposite end of the track stops the sled abruptly and rebounds the sled in the opposite direction at a speed nearly equal to its speed prior to impact. Thus, from a pre-impact velocity of 10 mph, an impact velocity differential of nearly 20 mph is achieved.

For the tests reported on here, all pressures were set to achieve an impact velocity differential of 20 mph at a rectangular deceleration pulse of 16 G's (i.e., sixteen times the pull of gravity). Each test used an Everest and Jennings powered wheelchair frame (Model 3P) with appropriate masses attached to simulate a complete powered chair with batteries, motors, etc. weighing approximately 110 lbs. The wheelchair occupant was simulated by a 50th percentile male dummy weighing 165 lbs. Table 1 shows the matrix of twenty-two tests conducted to date under these test conditions.

Side and top view high speed films were taken of each test at a nominal film speed of 1000 frames/sec. In addition, GSE seat belt load cells were used to measure tensions in belt webbings where applicable.

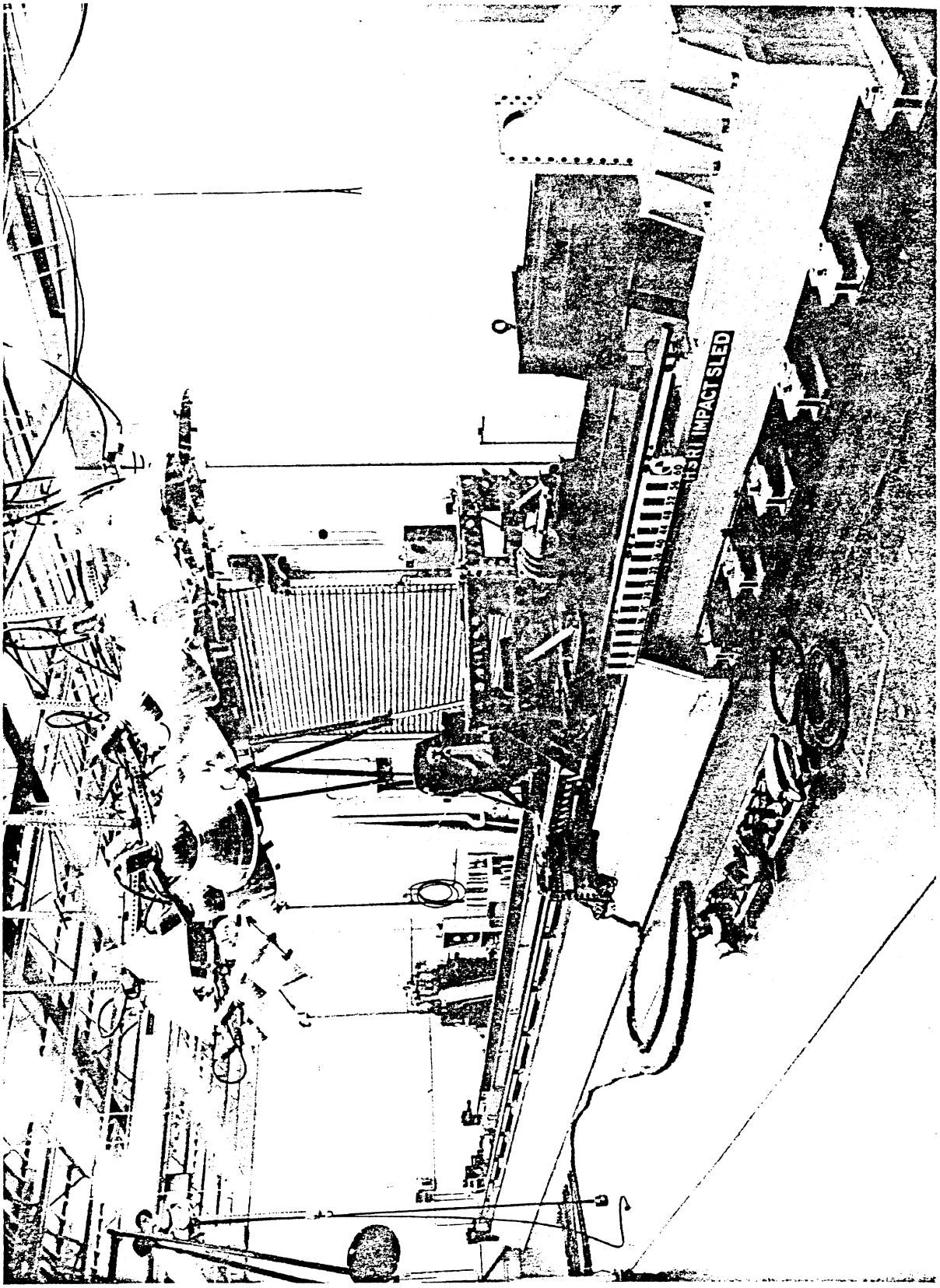

Figure 1. HSRI's Impact Sled Facility

TABLE 1

MATRIX OF TESTS

Test No.	Wheelchair Tie-Down	Occupant Restraint	Impact Direction	Page
80M001	Lap belt to floor via lift rings	Lap belt to floor plus velcro chest belt	frontal	4
80M002	Lap belt to floor via lift rings plus angle iron behind wheels	Lap belt to floor plus velcro chest belt	frontal	8
80M003	Bud adjustable T-bar to floor via lift rings	Velcro chest belt to chair back	frontal	12
80M004	Bud T-bar plus lap belt to floor via lift rings	Lap belt to floor plus velcro chest belt	frontal	16
80M005	Bud power pan and power lock-down	Lap belt to chair	frontal	21
80M006	Bud power pan and power lock-down	Bud passive belt (roof to floor) plus lap belt to chair	frontal	25
80M007	Bud power pan and power lock-down plus lap portion of Bud passive belt in front of chair arms	Bud passive belt (floor mount) plus lap belt to chair	frontal	29
80M008	Same as 80M007 except webbing of passive floor belt bolted at metal ring	Same as 80M007 except webbing of passive floor belt bolted at metal ring	frontal	33
80M009	4-point Aeroquip tied to sled	Bud passive belt plus lap belt to chair	frontal	37
80M010	Bud power pan and power lock-down plus bar wheel stop	Bud passive belt with webbing tied to metal ring plus lap belt to chair	frontal	41
80M011	Bud power pan and power lock-down plus lap portion of passive belt in front of chair arms (webbing tied at metal ring)	Bud passive belt plus lap belt to chair	frontal	45
80M012	Same as 80M011	Same as 80M011	45°	49
80M013	Bud T-bar (smaller adjustment holes) to floor via eye bolt	Lap belt to chair plus velcro chest belt	frontal	54
80M014	Bud fixed length T-bar plus lap belt to floor via eye bolt	Lap belt to floor plus velcro chest belt	frontal	59
80M015	Bud rim pin stanchion	Lap belt to stanchion	frontal	61
80M016	Two chairs in double rim pin stanchion	Lap belt to stanchion	side	65
80M017	CCI tie-down to sheet metal	Bud passive belt system plus lap belt to triangles	frontal	71
80M018	CCI tie-down to sheet metal	Falcon passive belt system plus lap belt to triangles	frontal	75
80M019	3-point Aeroquip straps to "G" track fastened to sheet metal	Bud passive belt system plus lap belt to chair	frontal	79
80M020	CCI tie-down to sheet metal	Falcon passive belt system (improved anchor welds) plus lap belt to chair	frontal	83
80M021	Target T-bar plus lap belt to floor via lift rings	Lap belt to floor	frontal	87
80M022	Target T-bar to floor via hook bolt welded closed on eye bolt	Lap belt to chair	frontal	91

All tests for 20 mph, 16 G impact.

III. RESULTS

The following pages describe and illustrate the test set-up and results observed from films for each of the twenty-two tests conducted to date. Also given are peak belt loads measured by GSE load cells. The sequence photograph shown on the last page for each test illustrates the general performance of the tie-down and restraint systems.

TEST NO.
80M001

Set-up

Both the dummy and wheelchair were restrained facing forward on the sled by a single lap belt secured to the floor (sled) by two lift ring assemblies. A belt with velcro fastening[1] across the chest of the dummy was attached at each end around the back wheelchair posts under the seat back upholstery. The wheelchair brakes were applied.

Results

Prior to impact the chair moved backward on the sled due to the sled acceleration (approx. .5 G) producing slack in the lap belt. The ring of the right lift ring assembly broke at the sharp bend on impact releasing the lap belt and allowing the wheelchair to move unrestrained into the padded front of the sled. The velcro fastening on the chest belt did not hold. The chair sustained little or no damage.

Peak Belt Loads (lbs.)

Left Lap	-	1050
Right Lap	-	1000
Chest	-	100

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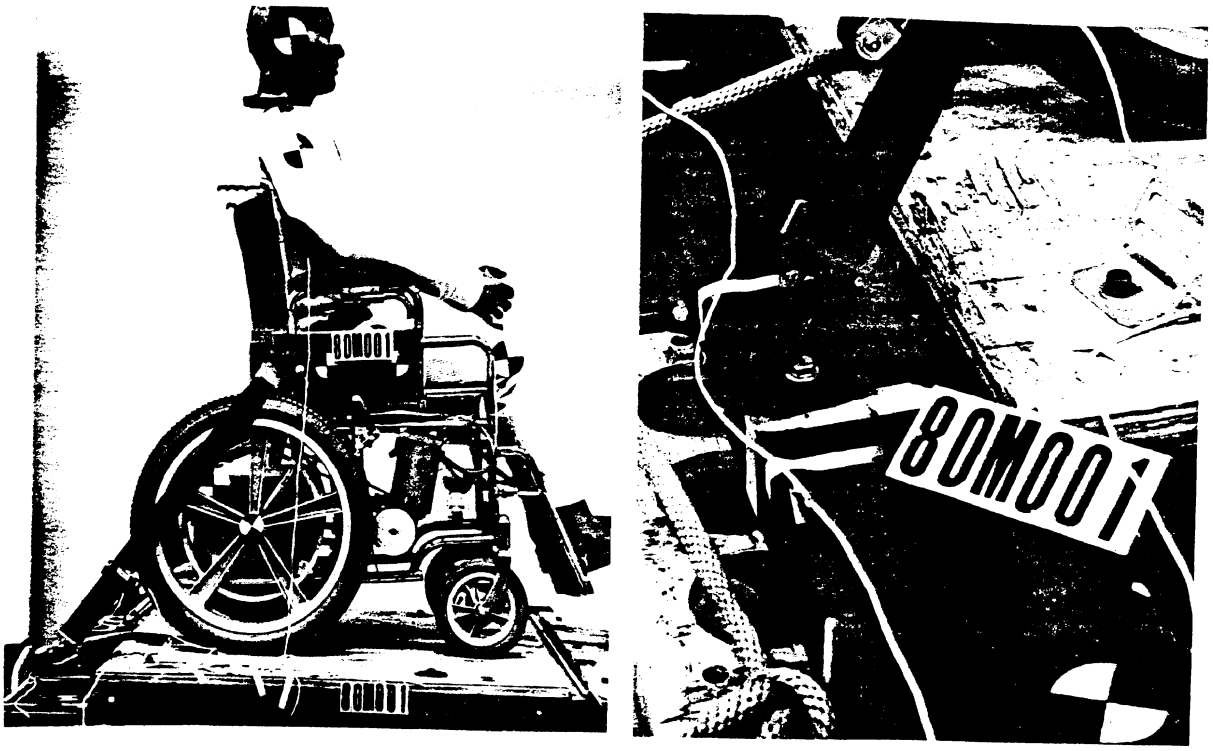
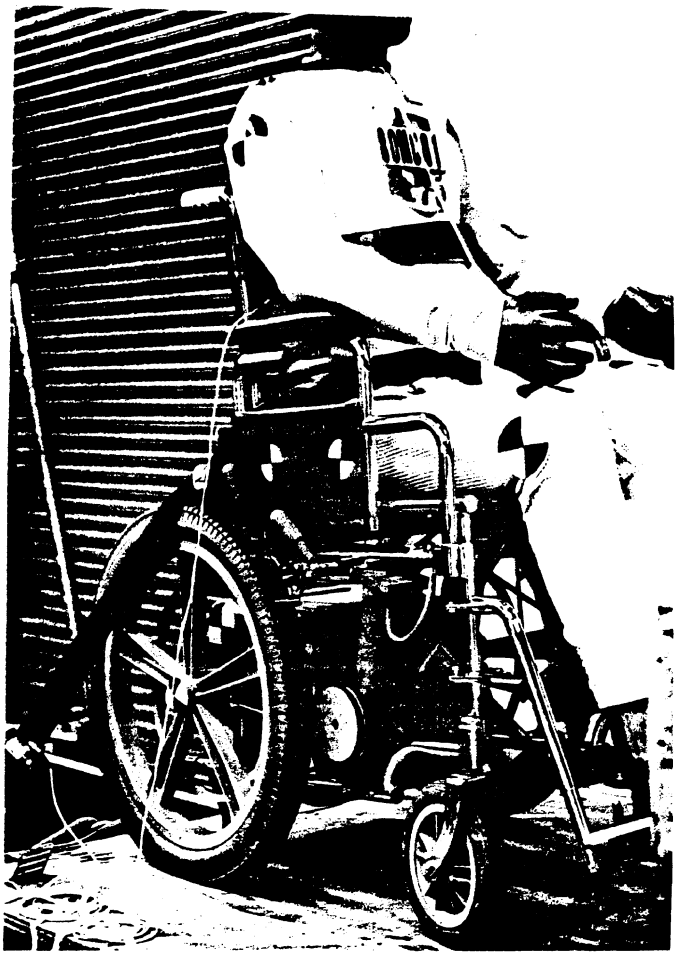
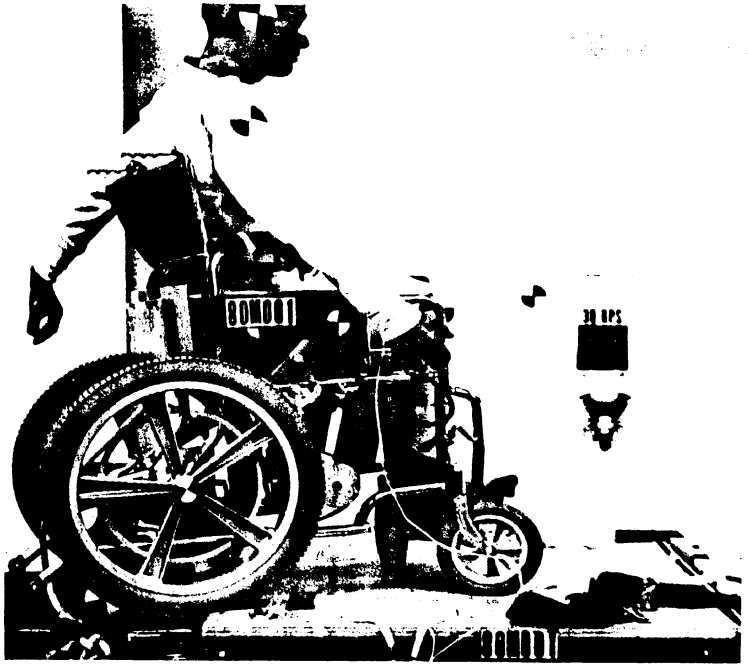
[1]Hereafter referred to as velcro chest belt.

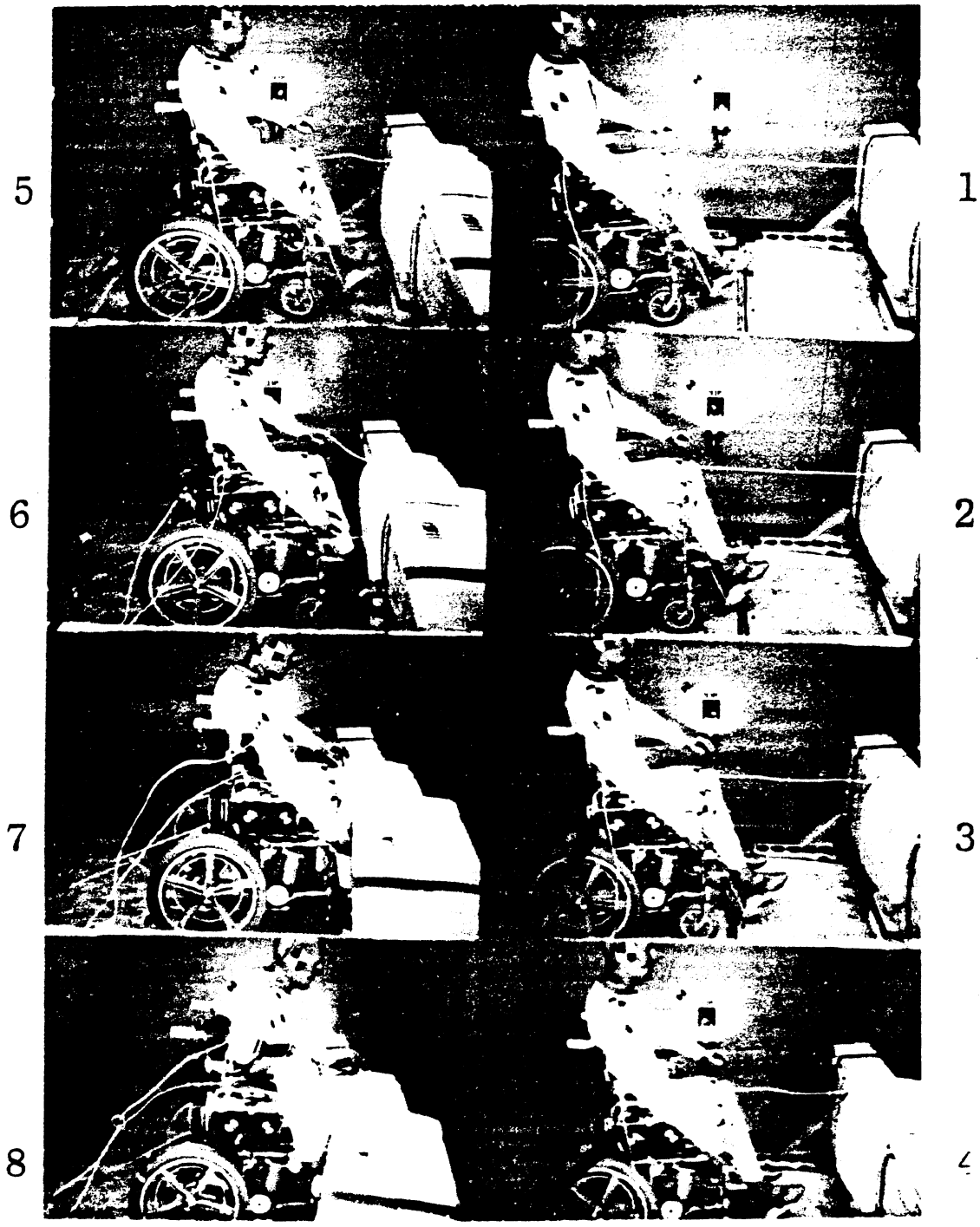




Set-up Photos for Test 80M001



Post-Impact Photos for Test 80M001



Time Sequence Photo for Test 80M001

TEST NO.
80M002

Set-Up

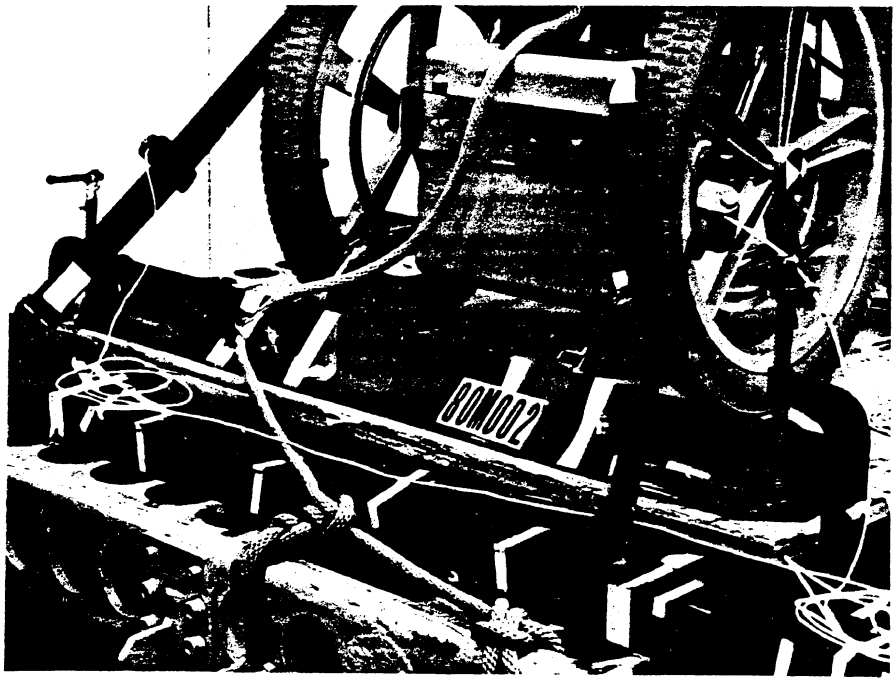
The wheelchair and dummy were secured facing forward on the sled in the same manner as test 80M001 by a lap belt around the dummy anchored to the sled by two lift ring assemblies. In addition, a steel angle was clamped to the floor behind the chair wheels to prevent backward movement of the chair during sled acceleration. A velcro chest belt secured to the wheelchair back posts was again placed around the dummy's chest. The wheelchair brakes were applied.

Results

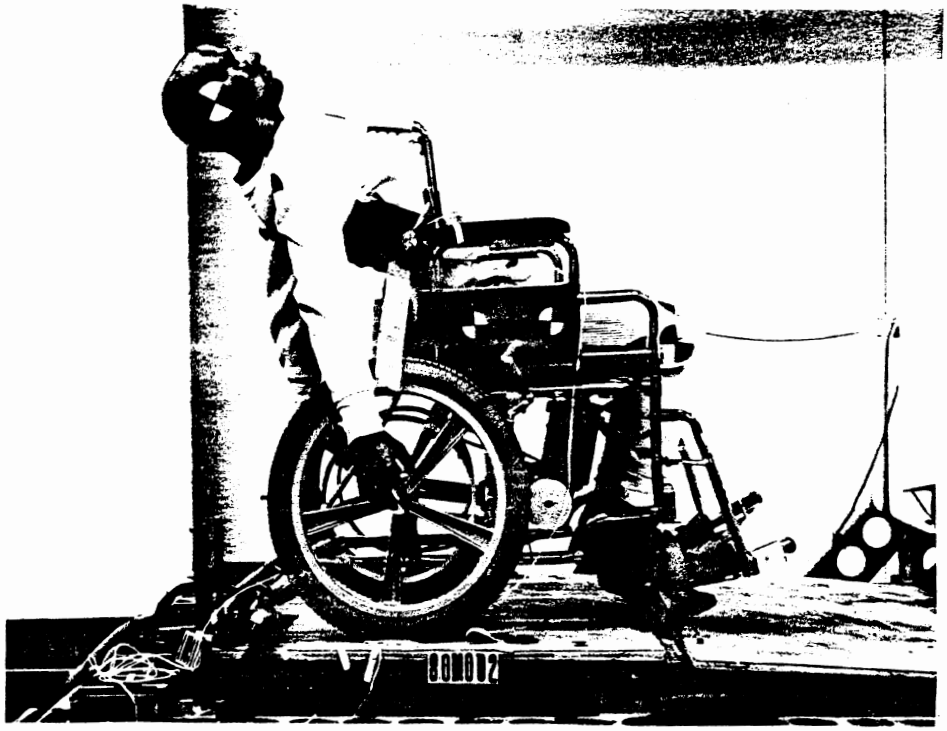
The chair did not move on sled acceleration and the lap belt remained taut until impact. Upon impact the ring of the left ring assembly broke at the sharp bend releasing the chair and dummy which moved forward and impacted with the padded front of the sled. The velcro belt released allowing the dummy's torso to flex forward. The chair back upolstery was torn loose on dummy rebound. The chair sustained little or no damage to the frame.

Peak Belt Loads (lbs.)

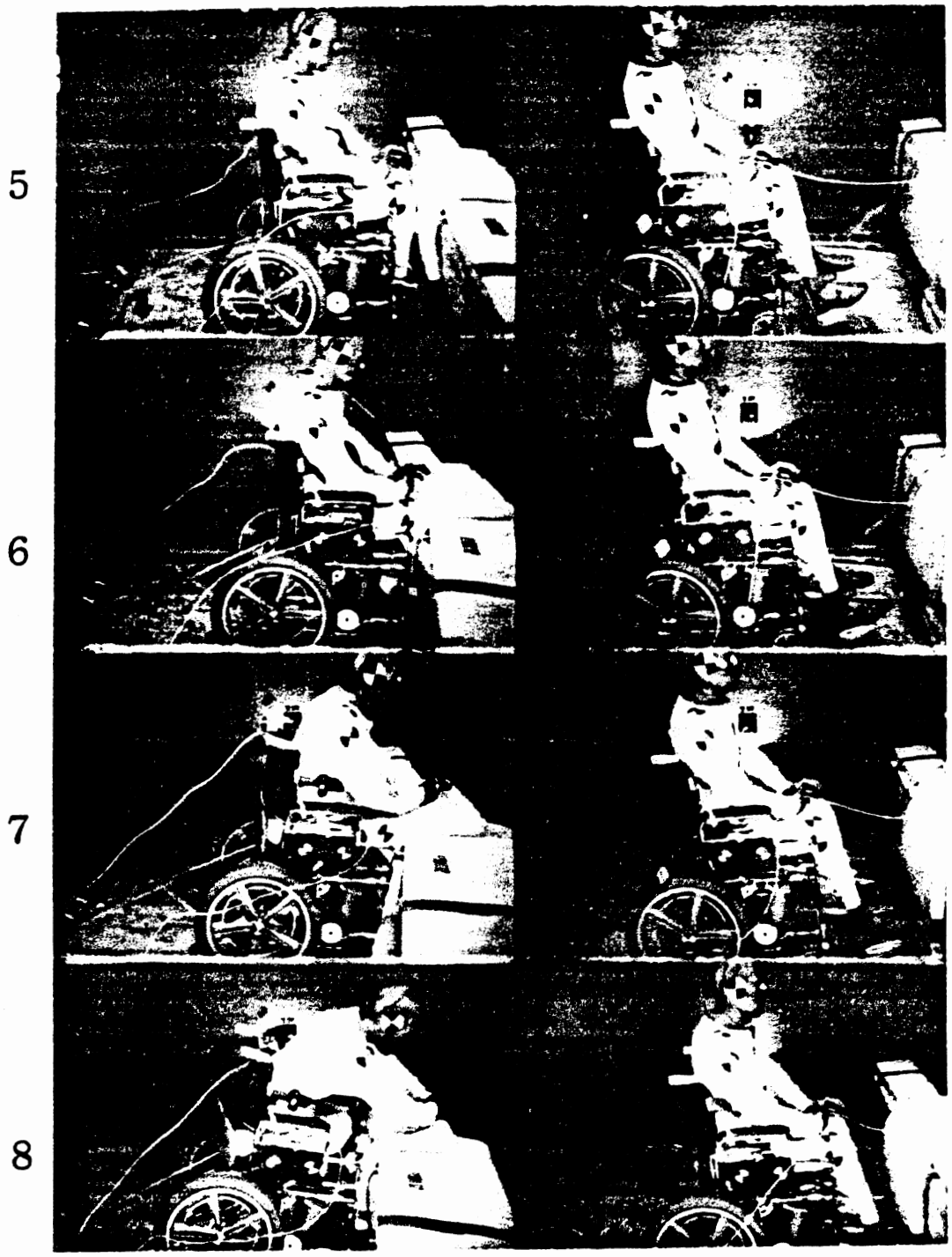
Left lap - 1050
Right lap - 900
Chest - 200



Set-Up Photo for Test 80M002



Post-Impact Photos for Test 80M002



Time Sequence Photos for Test 80M002

TEST NO.
80M003

Set-Up

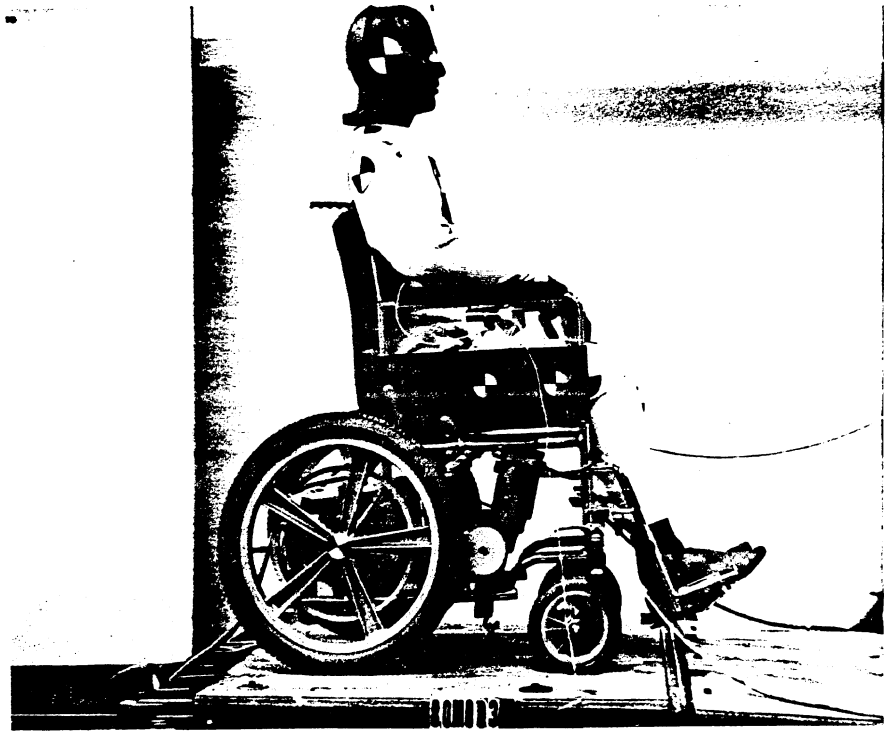
The wheelchair was secured facing forward on the sled by a Bud Industries adjustable T-bar placed across the lower horizontal frame members just behind the rising curved portion. A hook bolt through the center of the T-bar fastened to a lift ring assembly which was bolted to the sled. The T-bar was tightened down by turning a nut on the hook bolt until the front pneumatic castor tires showed significant compression. The dummy was secured to the chair only by a velcro chest belt attached to the back chair posts.

Results

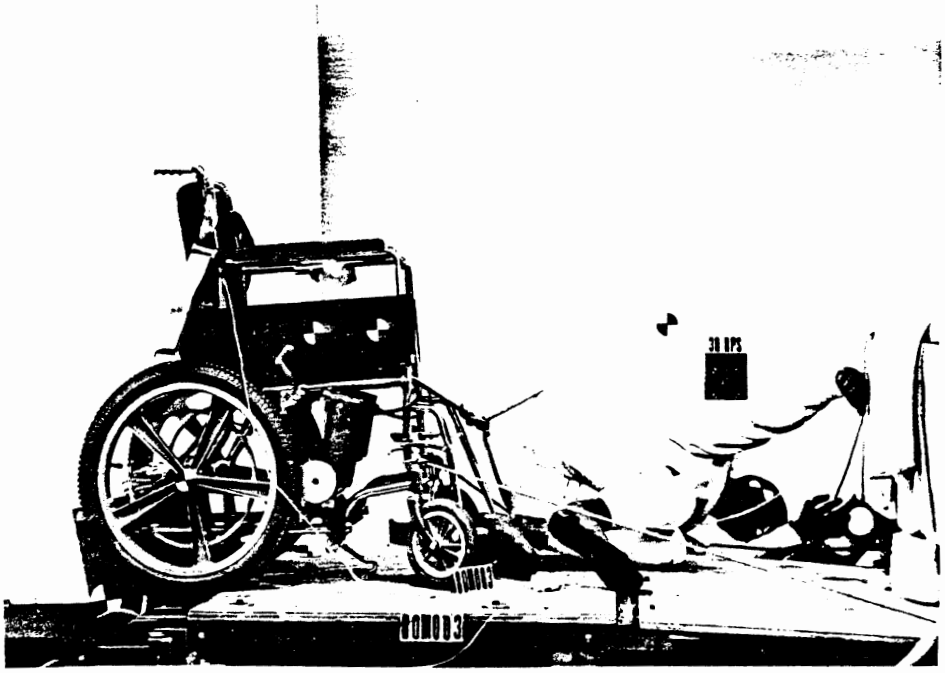
The ring of the lift ring assembly broke at the sharp bend releasing the wheelchair to move forward into the padded front of the sled. The T-bar and hook bolt bent significantly and the velcro belt came loose allowing the dummy to fall to the floor.

Peak Belt Loads (lbs.)

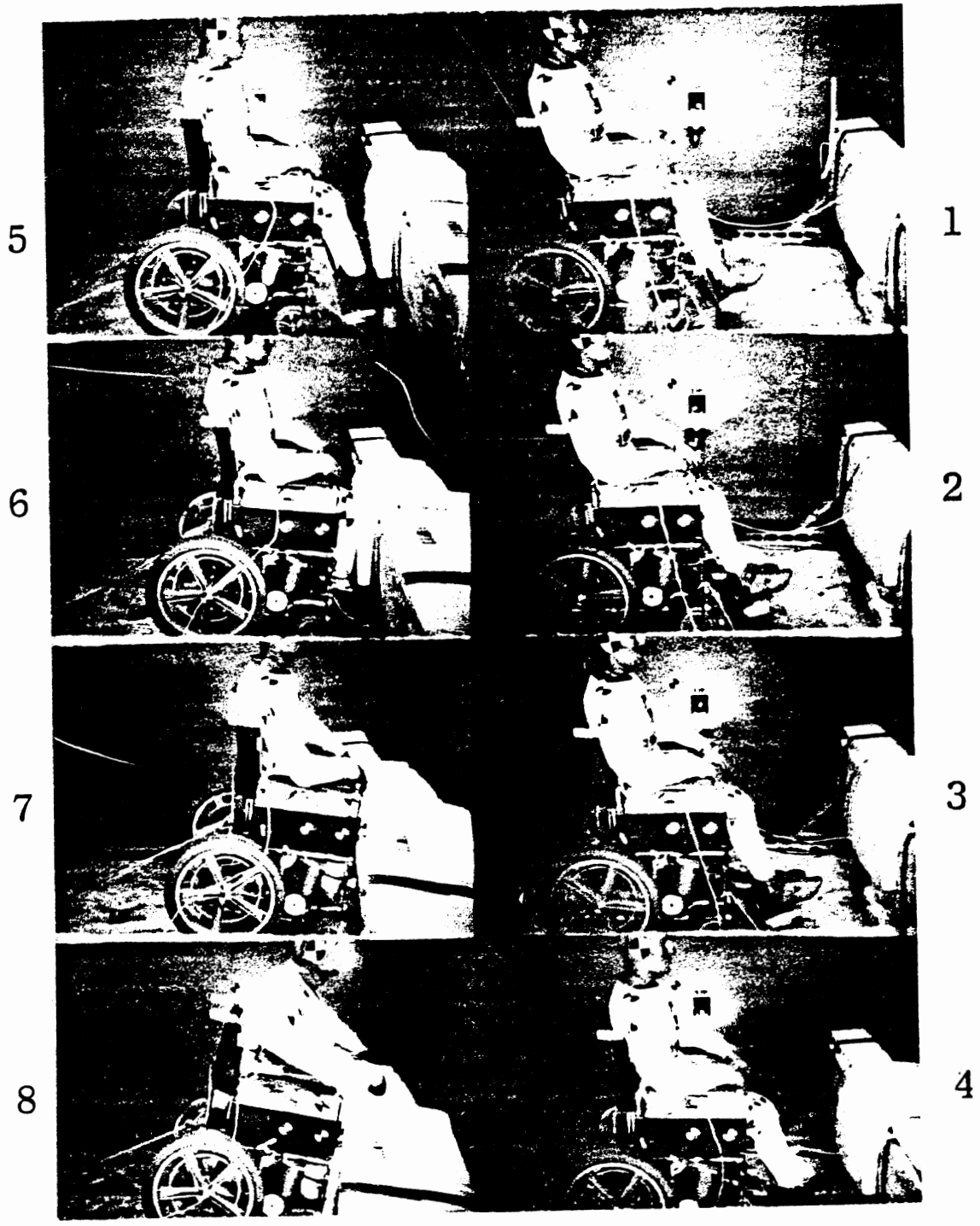
Velcro chest belt - 200



Set-Up Photos for Test 80M003



Post-Test Photos for Test 80M003



Time Sequence Photo for Test 80M003

TEST NO.
80M004

Set-Up

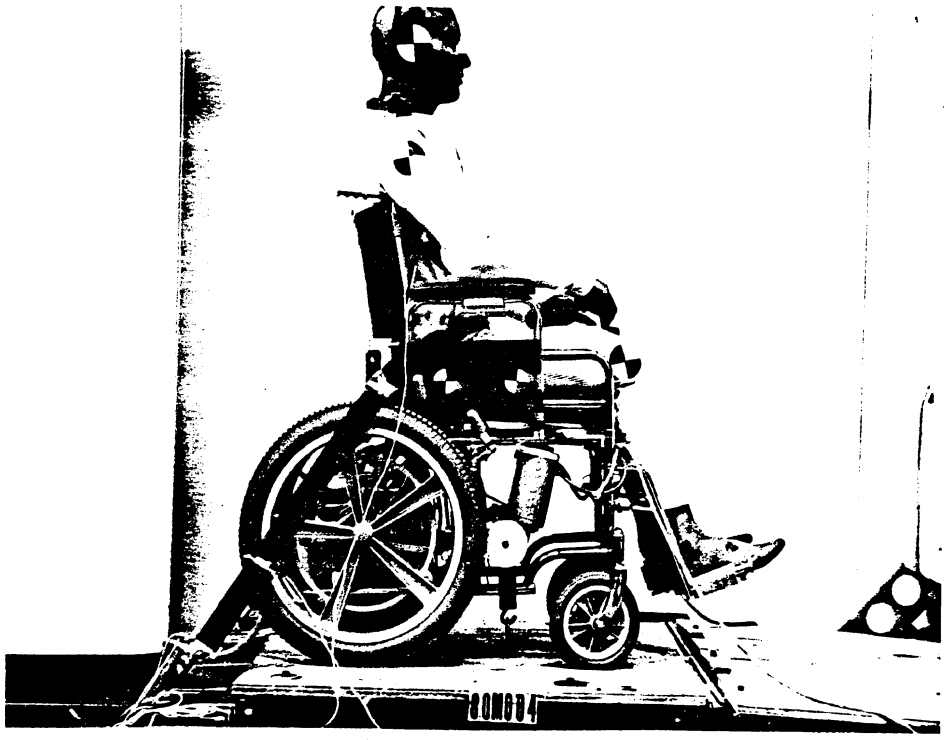
The adjustable T-bar described in test 80M003 and the lap belt to floor described in test 80M001 were used to secure the chair and dummy in a forward facing direction. All three anchor points used lift ring assemblies to fasten to the sled. The dummy was also restrained by a velcro chest belt looped around the chair back posts.

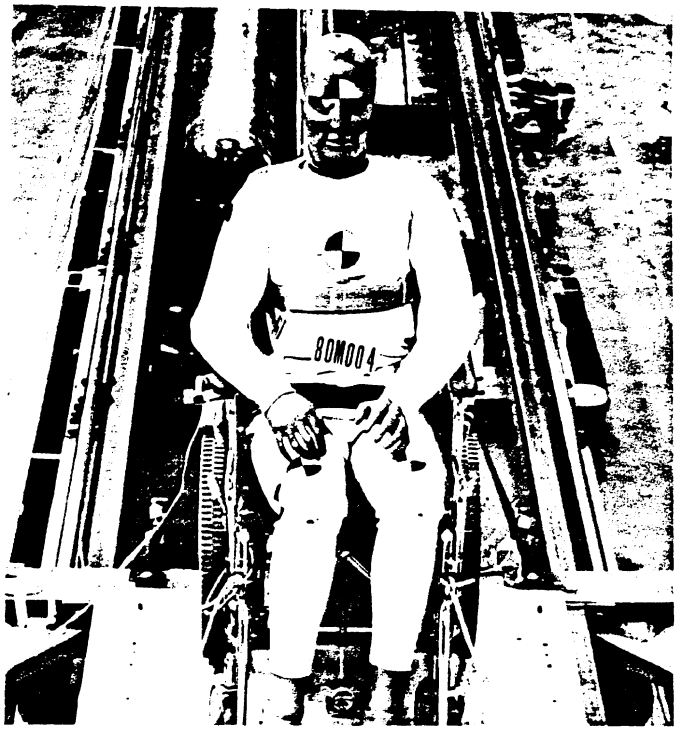
Results

The rings from the lift ring assemblies securing the T-bar and one side of the lap belt broke at the sharp bends allowing the wheelchair to move into the padded front of the sled. The T-bar itself bent and fractured, and the lap belt also unbuckled. Although the velcro on the chest belt held, the stitching tore out allowing the belt "D" ring to slide through the double webbing and result in significent belt slack.

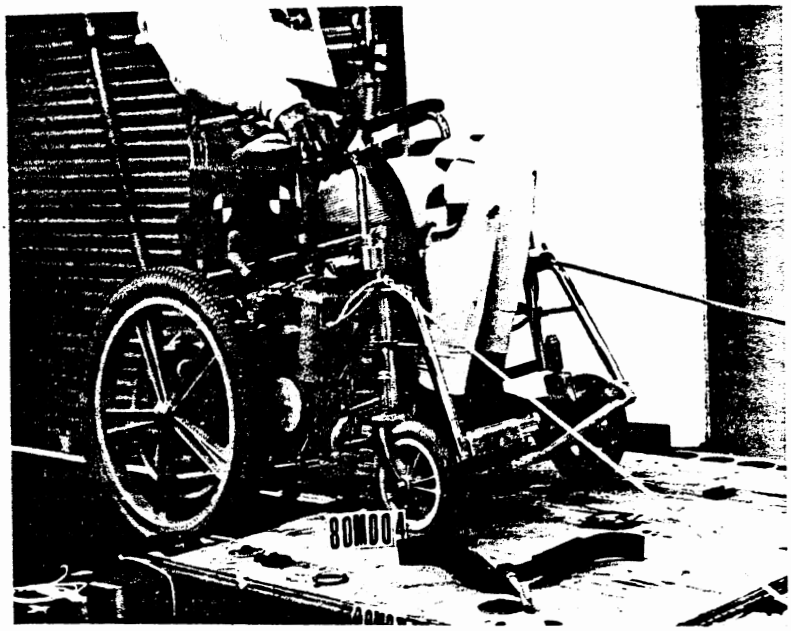
Peak Belt Loads (lbs.)

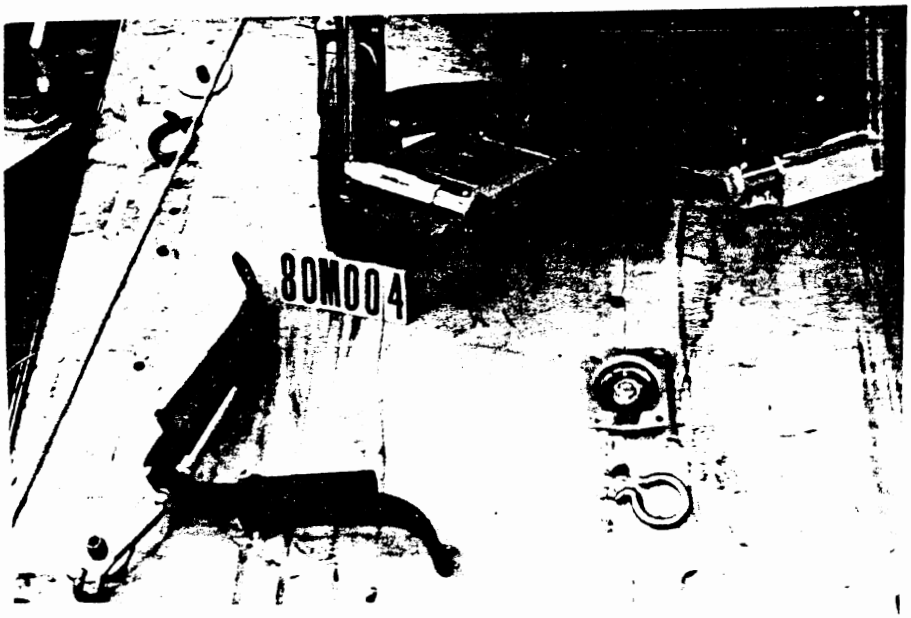
Left lap - 1150
Right lap - 1100





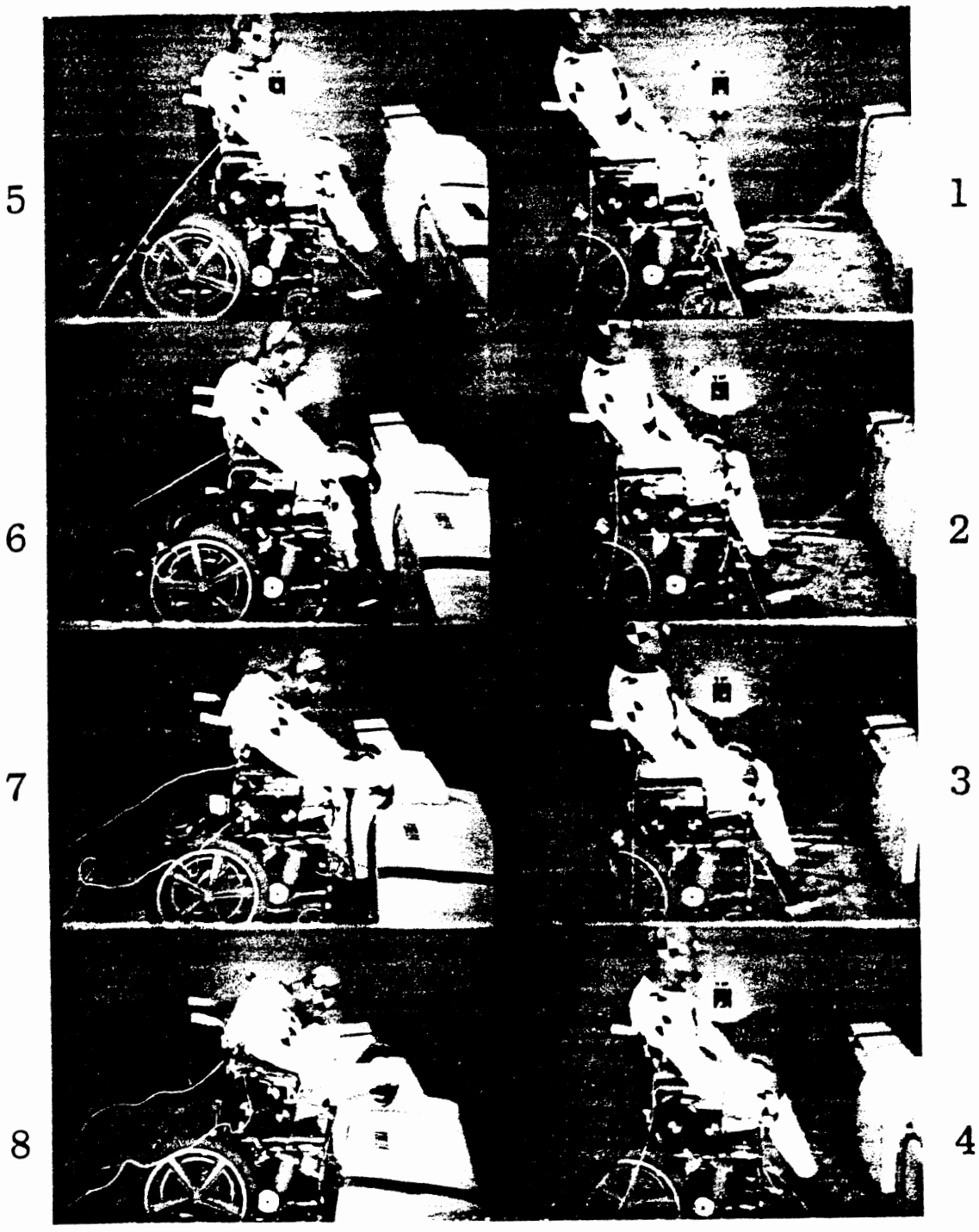
Set-Up Photos for Test 80M004





Post-Test Photos for Test 80M004

Post-Test Photo for Test 80M004



Time Sequence Photo for Test 80M004

TEST NO.
80M005

Set-Up

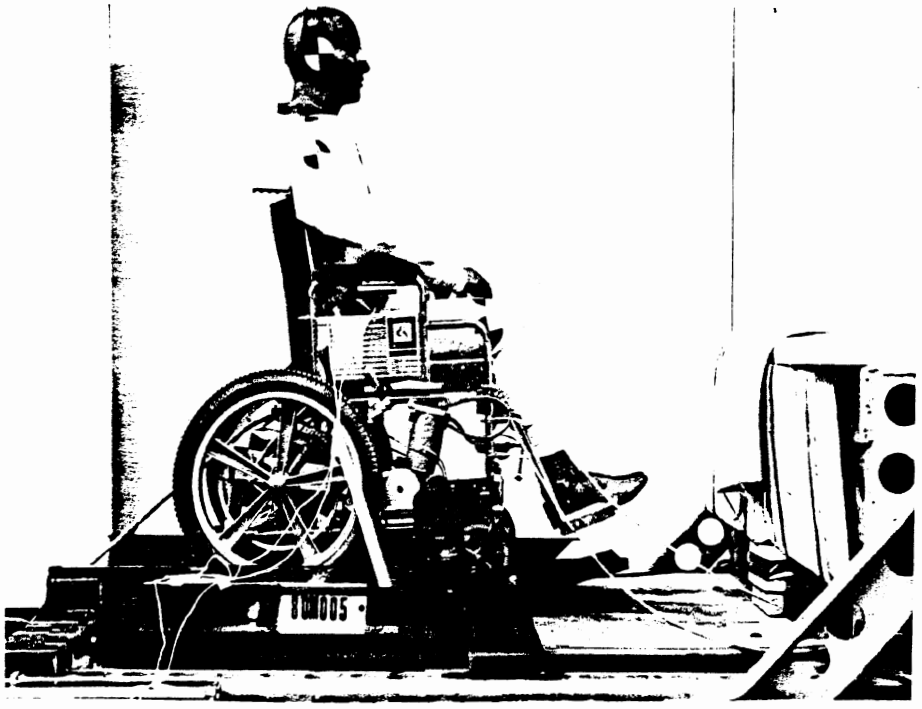
The wheelchair was secured in the Bud Industries power pan facing forward on the sled by the Bud power lock-down pressing on the raised portion of the right lower horizontal frame member. The power lock-down was bolted to the sled using two bolts and washers provided by Bud Industries and tightened until significant defomation in the washers occured. The dummy was secured in the chair by a lap belt anchored to the chair by wrapping the belt ends around the back posts under the power pack mounting brackets and chair upolstery.

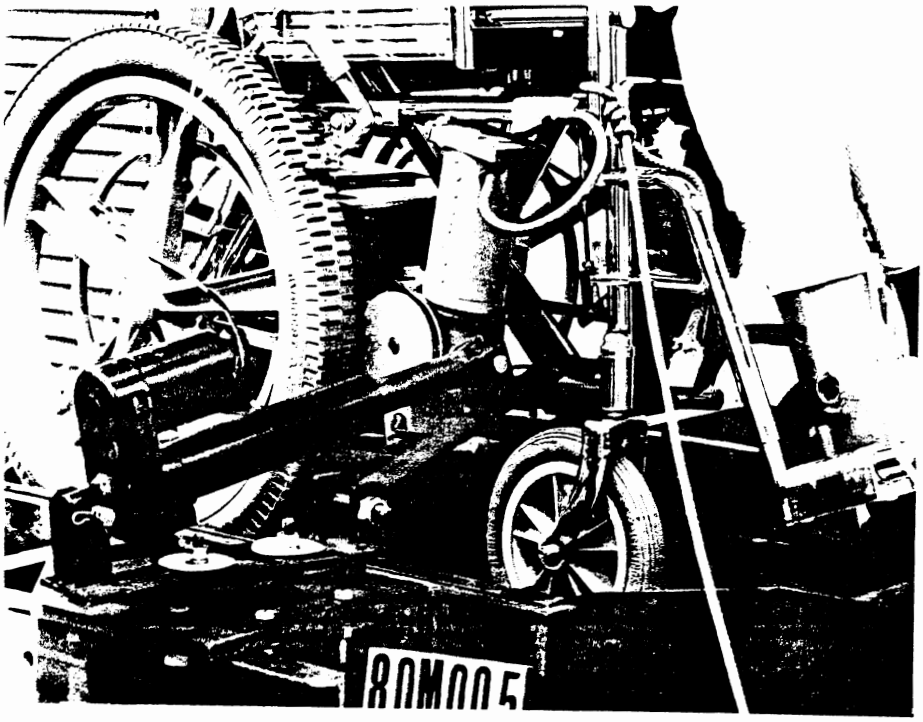
Results

There was no significant restraint of the chair by the power lock-down. The lock-down arm slid off the frame with little apparent effect on wheelchair movement. When the arm did interact with the chair frame at the cross-bars, the power lock-down rotated out of the way as the chair moved forward. The chair moved into the padded front of the sled with little or no turning so that the dummy's knees absorbed most of the energy. During the test the lap belt stayed secure and the dummy remained in the chair. The chair sustained little damage other than bending of the motor brackets.

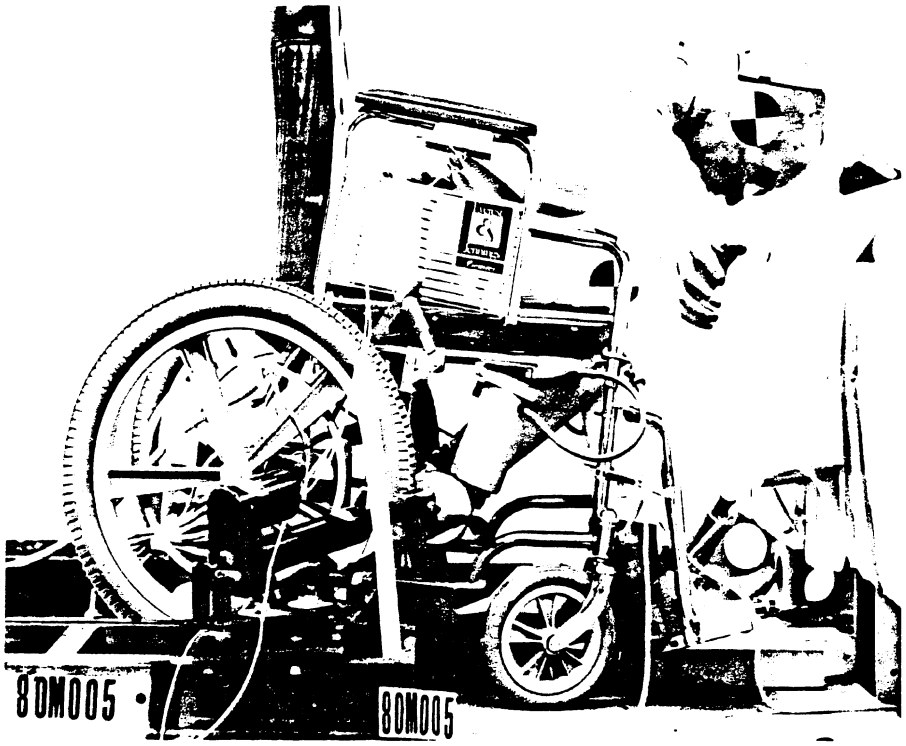
Peak Belt Loads (lbs)

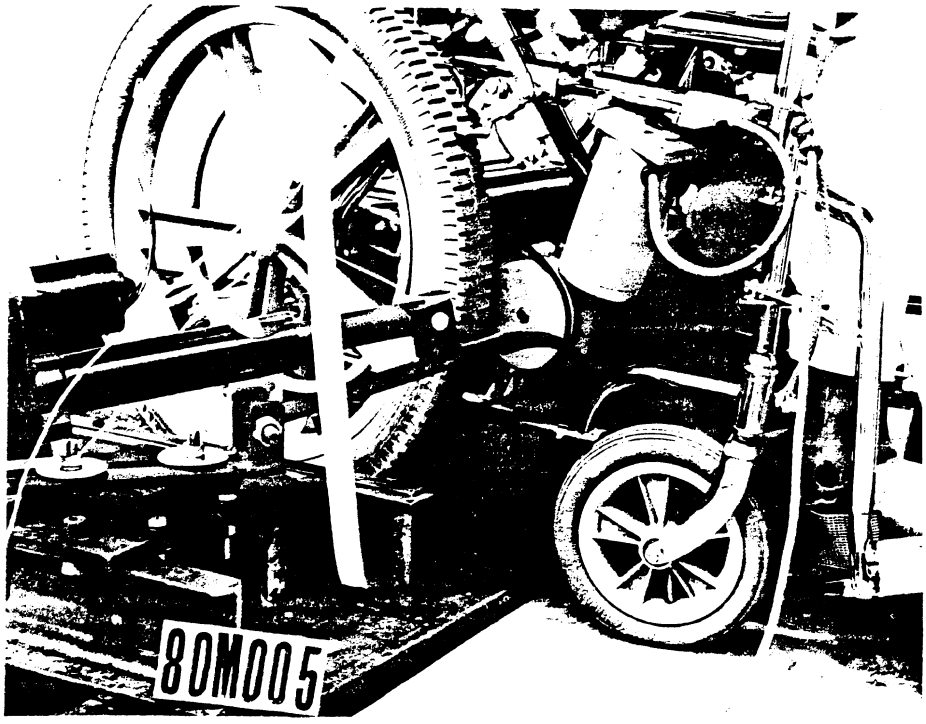
Left lap - 220
Right lap - 280



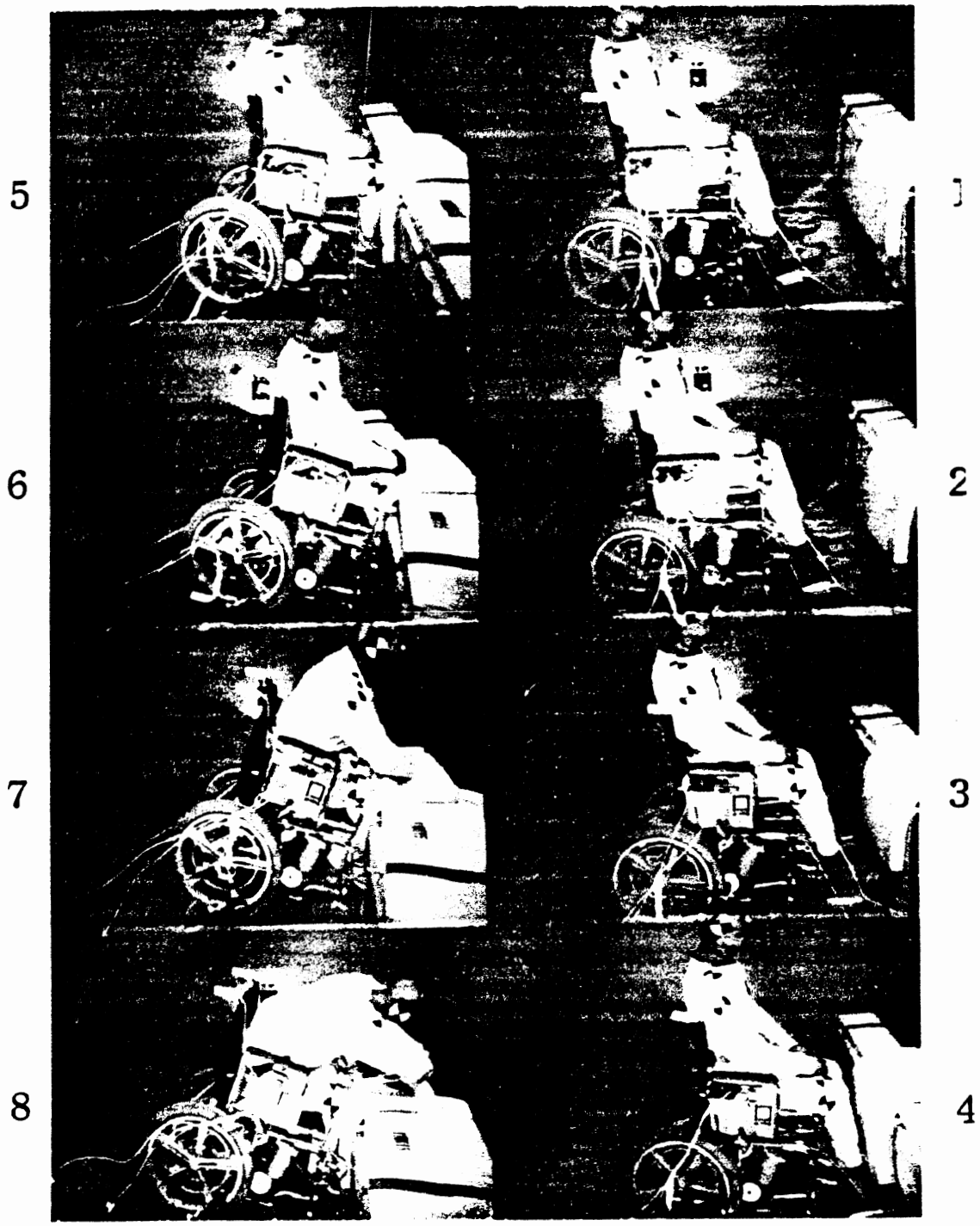


Set-Up Photos for Test 80M005





Post-Impact Photos for Test 80M005



Time Sequence Photo for Test 80M005

TEST NO.
80M006

Set-Up

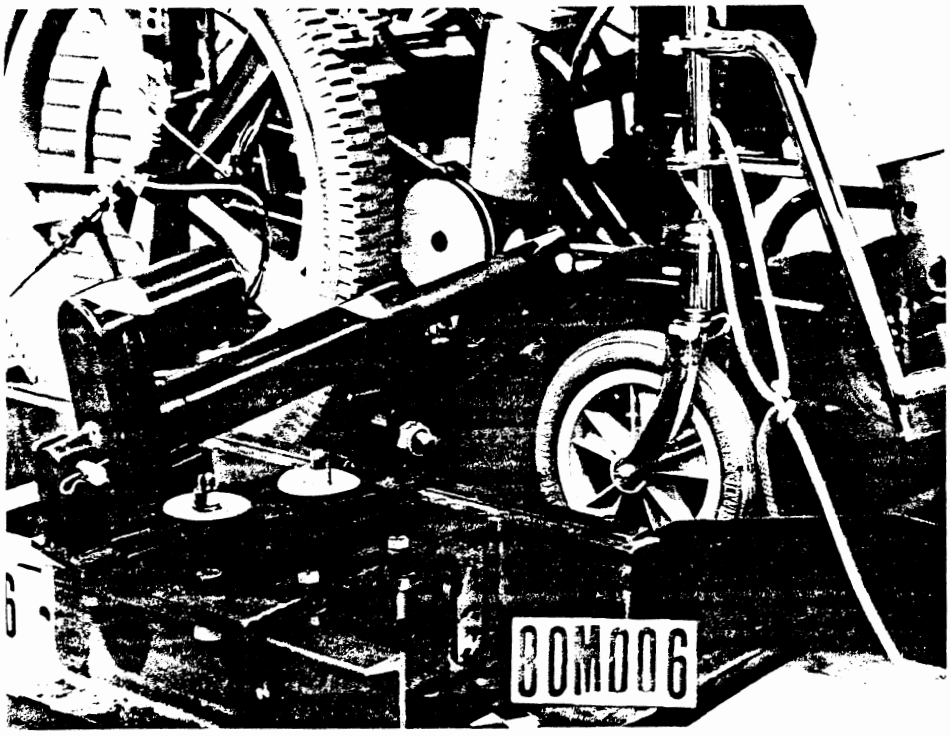
The wheelchair was secured to the sled in the forward facing direction using the Bud power lock-down and power pan system described in test 80M005. The dummy was restrained to the chair as in test 80M005 using a lap belt to the chair posts. In addition, a Bud passive belt restraint system (old style) was used to restrain the dummy. This system consists of a vehicle mounted shoulder and lap belt which is suspended in the vehicle by appropriate anchor points on the vehicle "B" pillar and by a loop in a roof to floor belt. The lap portion of the belt passes over the chair armrests. Heavy duty eye bolts and other hardware provided by Bud Industries were used to anchor the belts to the simulated vehicle structure.

Results

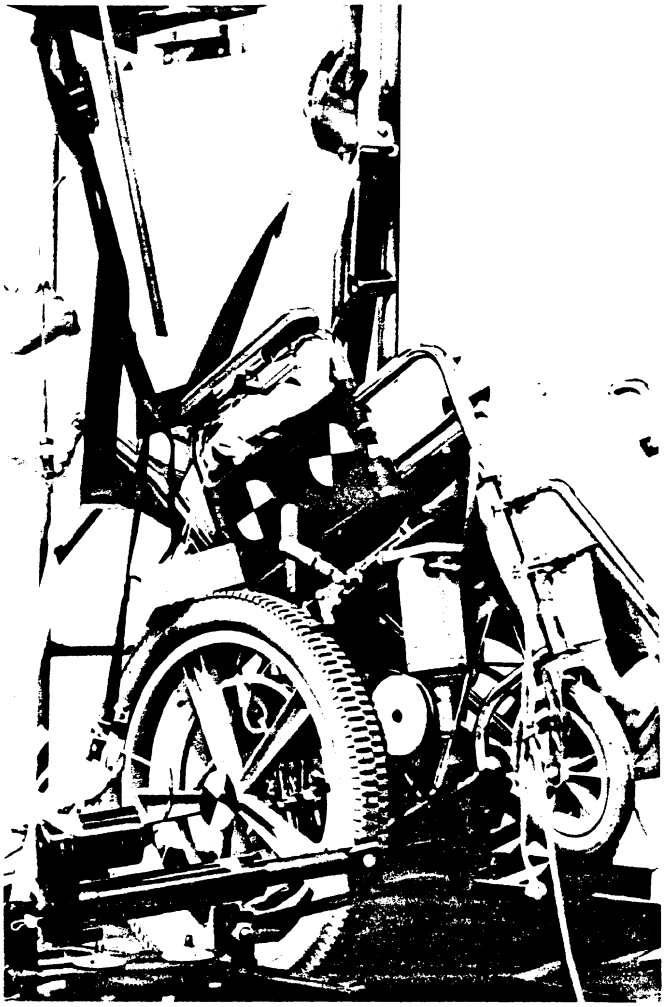
The power lock-down did not secure the chair which became restrained by the passive belt system through loading on the dummy. The lower part of the chair, being unrestrained, moved forward, causing the dummy and chair to tilt backwards. A tether rope caught on a sled bolt preventing the chair from flipping to the floor. The lap belt stayed secure. High forces in the floor to roof belt caused the steel structure used to simulate the vehicle roof anchor point to collapse.

Peak Belt Loads (lbs)

Retractor belt	- 520
Passive chest	- 1700
Passive lap	- 1200
Right chair lap	- 230
Upper roof to floor	- 1950
Lower roof to floor	- 2500



Set-Up Photos for Test 80M006



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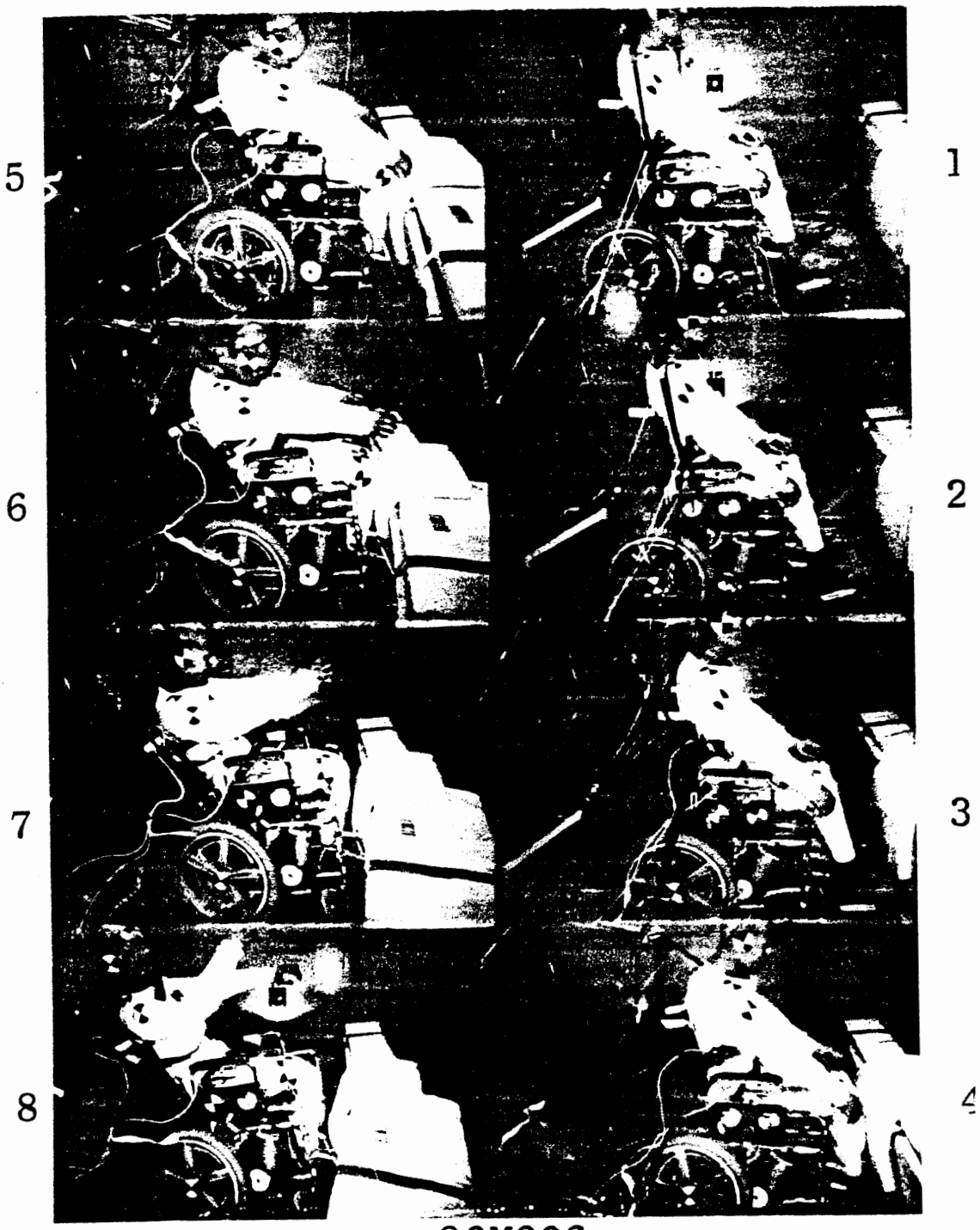


Time Sequence Photo for Test 80M006

TEST NO.
80M007

Set-Up

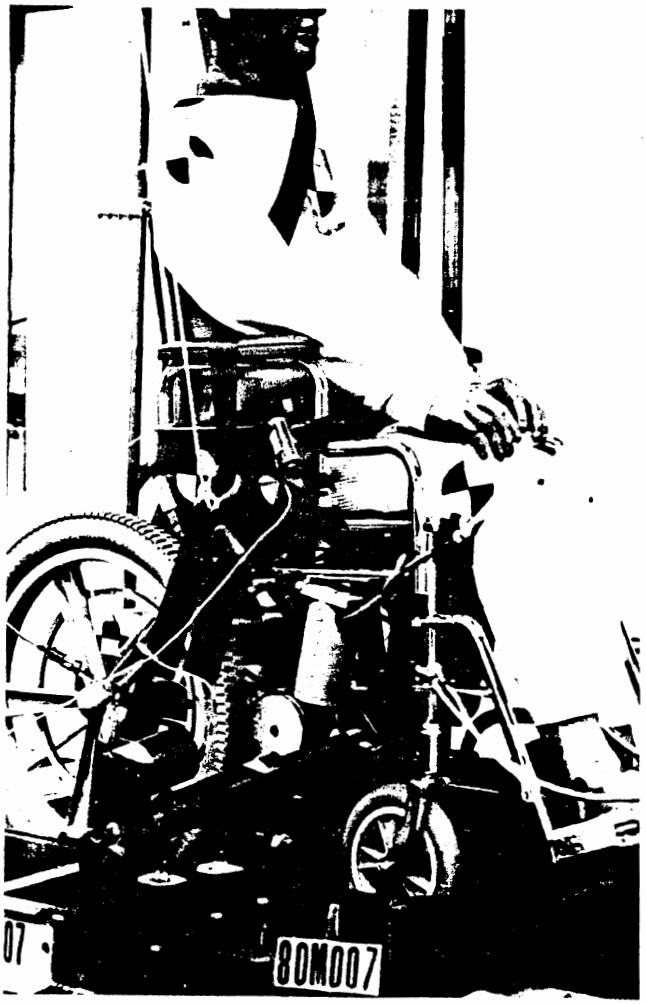
The wheelchair was secured to the sled in the forward facing direction using the Bud power lock-down and power pan system described in test 80M005. The dummy was restrained to the chair as in test 80M005 using a lap belt to the chair posts. In addition, a Bud passive belt restraint (new style) was used to provide additional dummy restraint. This belt system is similar to the system used in test 80M006 except that the floor to roof belt is replaced by a floor mounted belt with a metal ring through which the chest/lap belt is placed. The belt system is held in place by an elastic cord from the metal ring to the vehicle roof. In this test, the lap portion of the passive belt was placed in front of the wheelchair arms (desk type) with the hope of providing improved chair restraint without loading through the occupant. Heavy duty eye bolts and other hardware provided by Bud Industries were used to anchor the belts to the simulated vehicle structure.

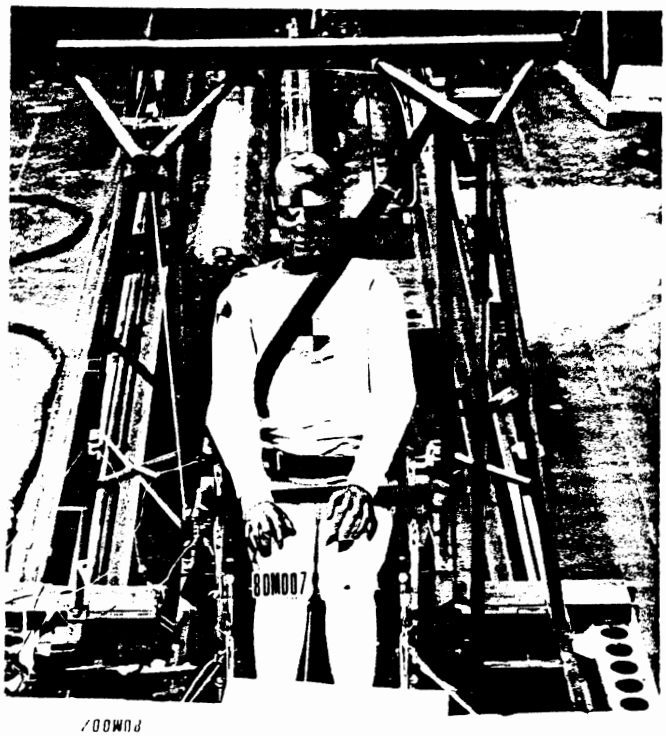
Results

The power lock-down did not restrain the chair. The chair and dummy moved forward into the passive belt system causing the stitching around the metal ring in the floor mounted belt to break releasing the chair to move out of the power pan and into the front of the sled. The chair sustained little damage.

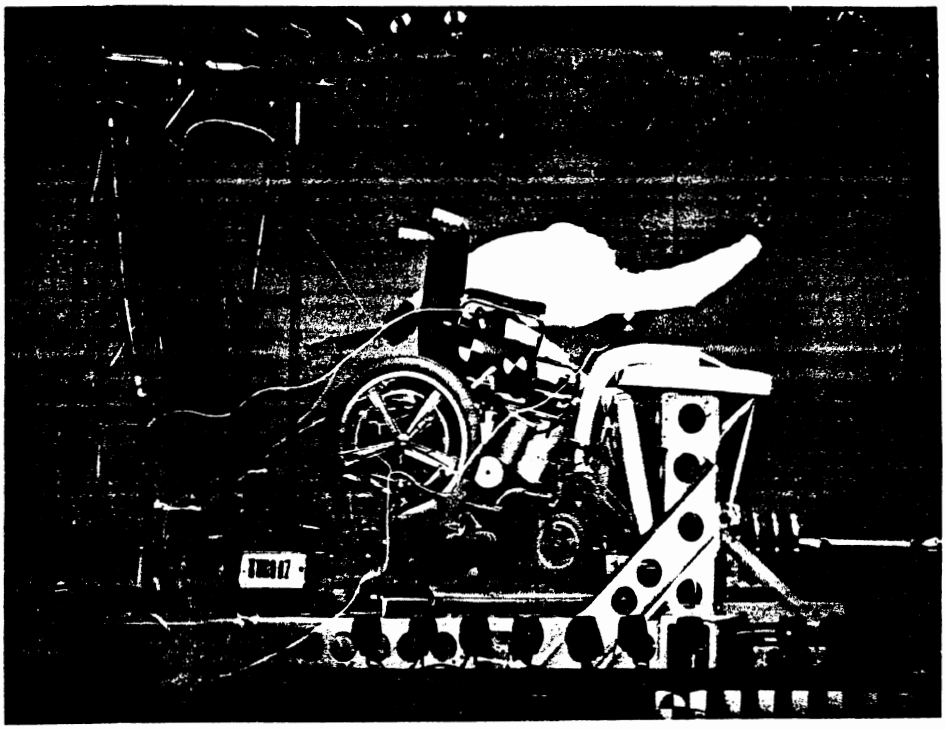
Peak Belt Loads (lbs)

Shoulder	- 680
Right chair lap	- 440
Lap passive belt (left)	- 880
Lap passive belt (right)	- 780
Right floor belt	- 1300

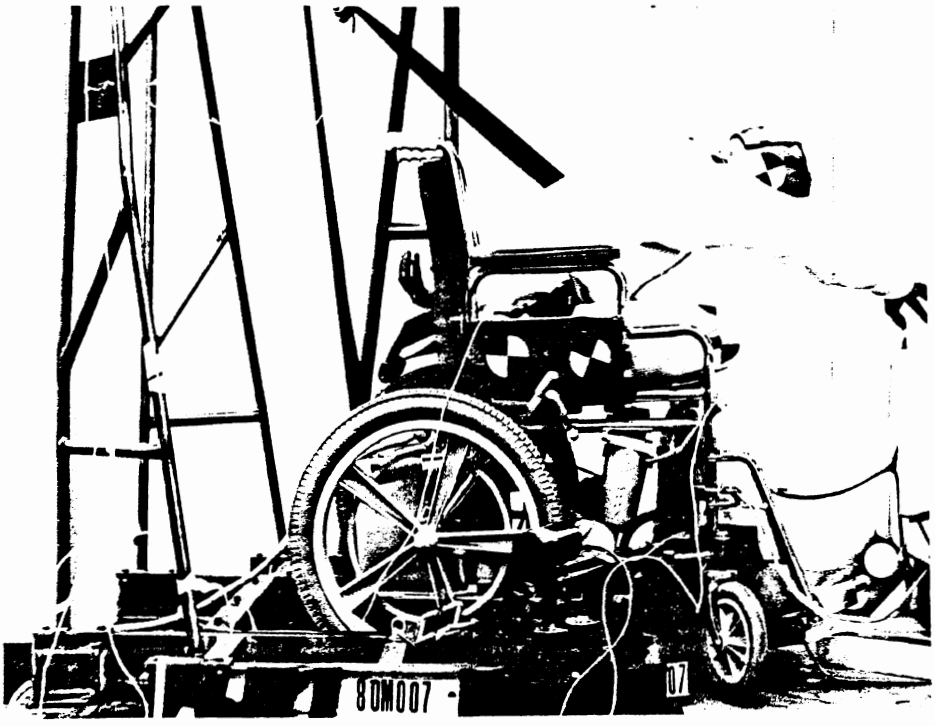




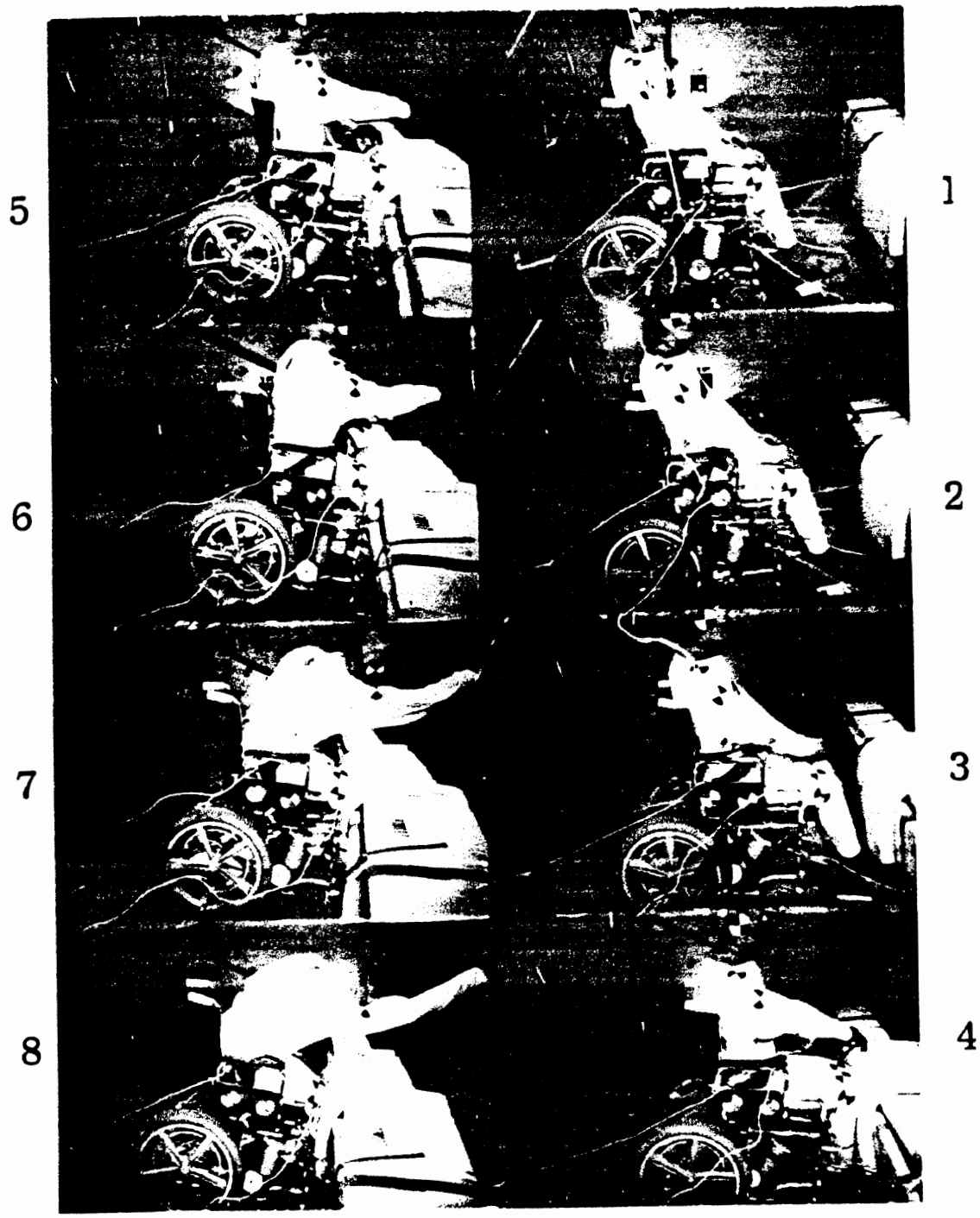
Set-Up Photos for Test 80M007



Stop Action During Impact Test 80M007



Post-Test Photo for Test 80M007



80M007

Time Sequence Photo for Test 80M007

TEST NO.
80M008

Set-Up

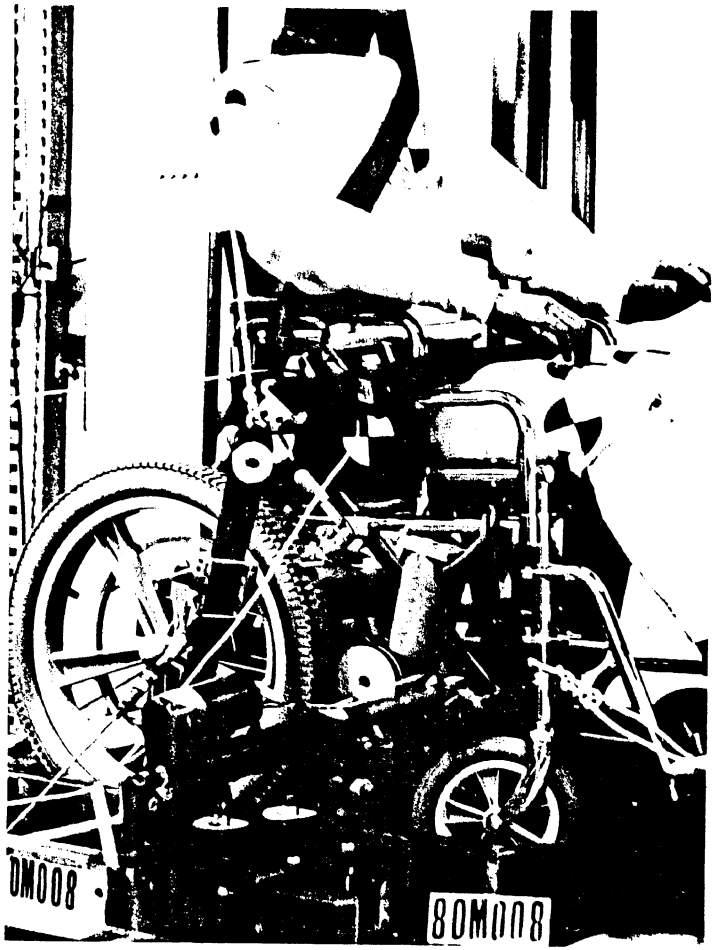
The wheelchair and dummy were restrained facing forward on the sled as in test 80M007 except that the belt webbing of the floor mounted portion of the passive belt system was bolted together with large washers at the metal ring in an attempt to prevent the system from breaking loose at this point.

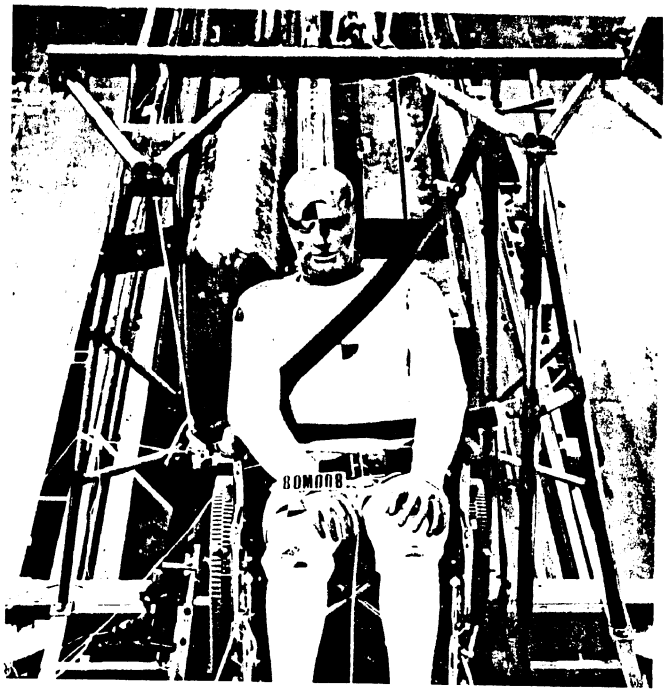
Results

The results were the same as test 80M007 except that higher belt loadings were achieved before the belt webbing ripped through the bolts at the metal ring releasing the chair and dummy. The chair arms and frame were bent during impact.

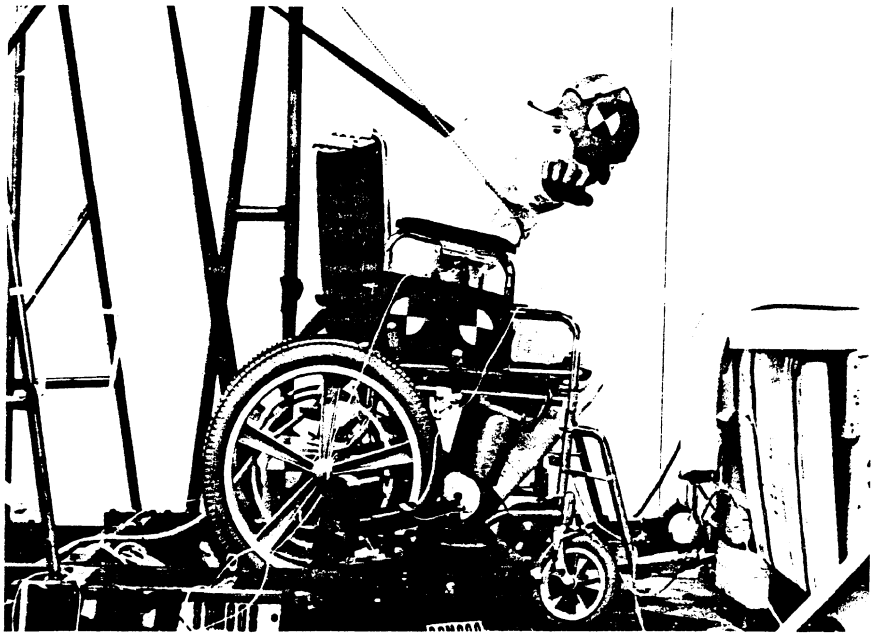
Peak Belt Loads (lbs)

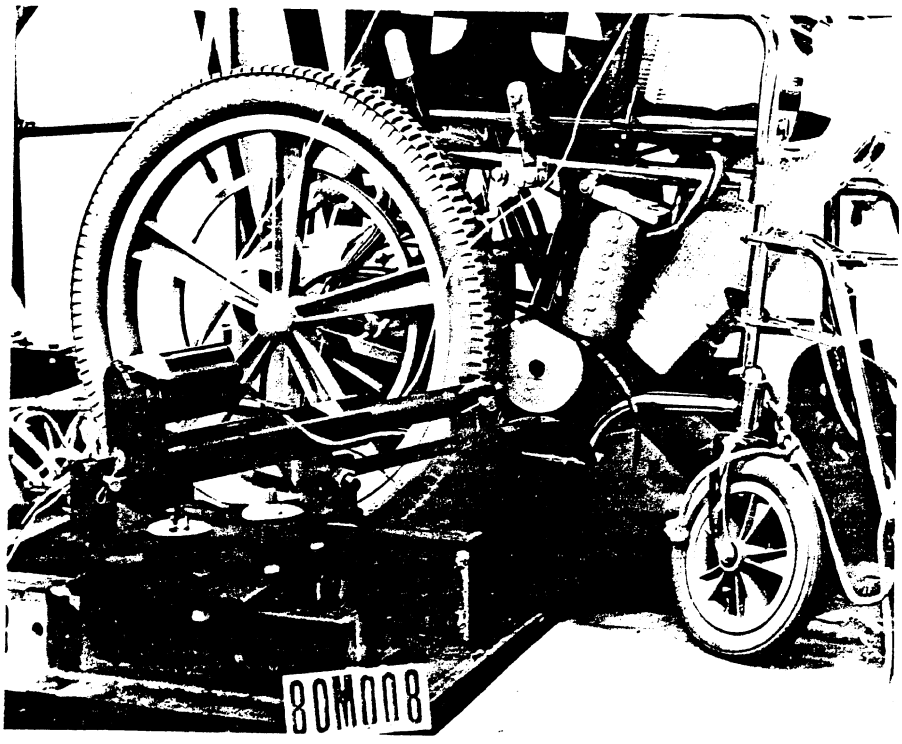
Shoulder	- 1200
Right lap	- 220
Passive belt (left)	- 1150
Passive belt (right)	- 1050
Right floor belt	- 1950



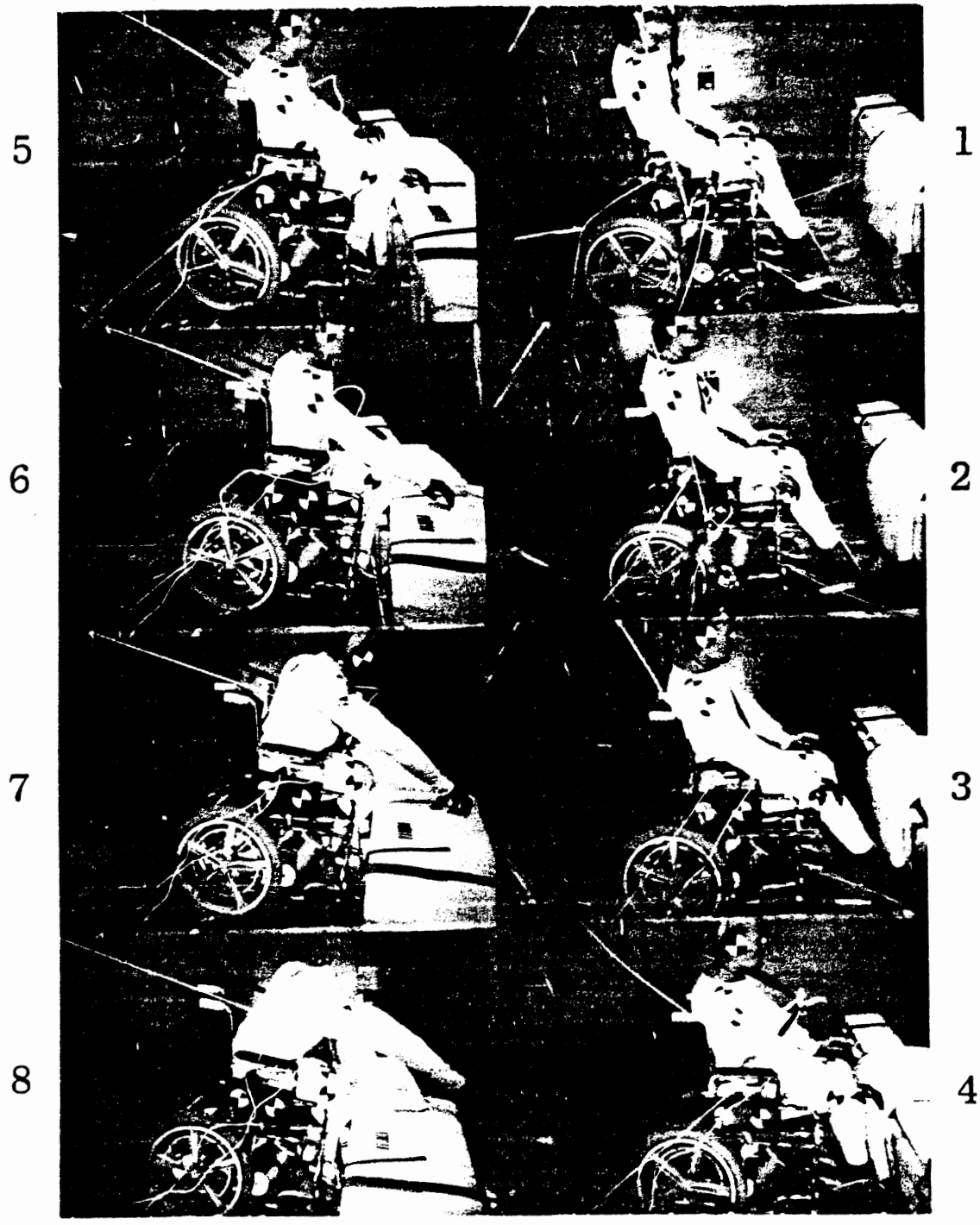


Set-Up Photos for Test 80M008





Post-Test Photos for Test 80M008



Time Sequence Photo for Test 80M008

TEST NO.
80M009

Set-Up

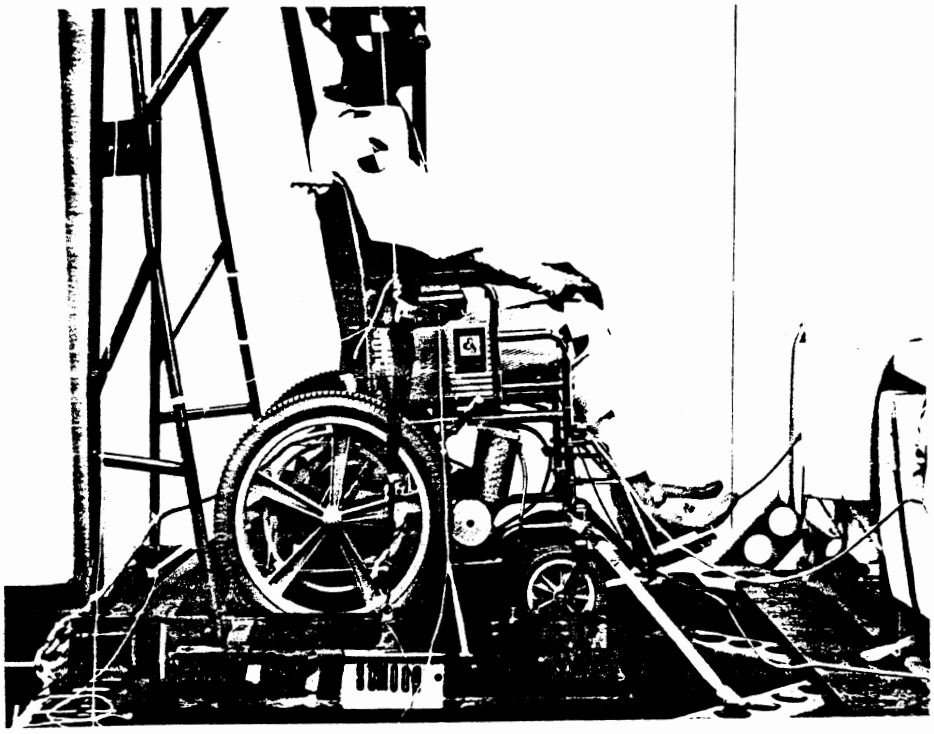
The wheelchair was secured to the sled in the forward facing position using four Aeroquip tie-down straps. Two straps wrapped around the front chair frame members just above the castors and angled forward and outward, being tied to the sled structure itself. Two other straps wrapped around the rear frame posts just above the intersection with the seat frame tubing and were tied straight back to the sled structures. The dummy was secured to the chair by a lap belt anchored to the rear chair posts. Additional dummy restraint was provided by the Bud passive belt system described in test 80M007 except that the lap portion of this belt was placed directly on the dummy over the chair arms and the floor belt webbing was tied to the metal ring.

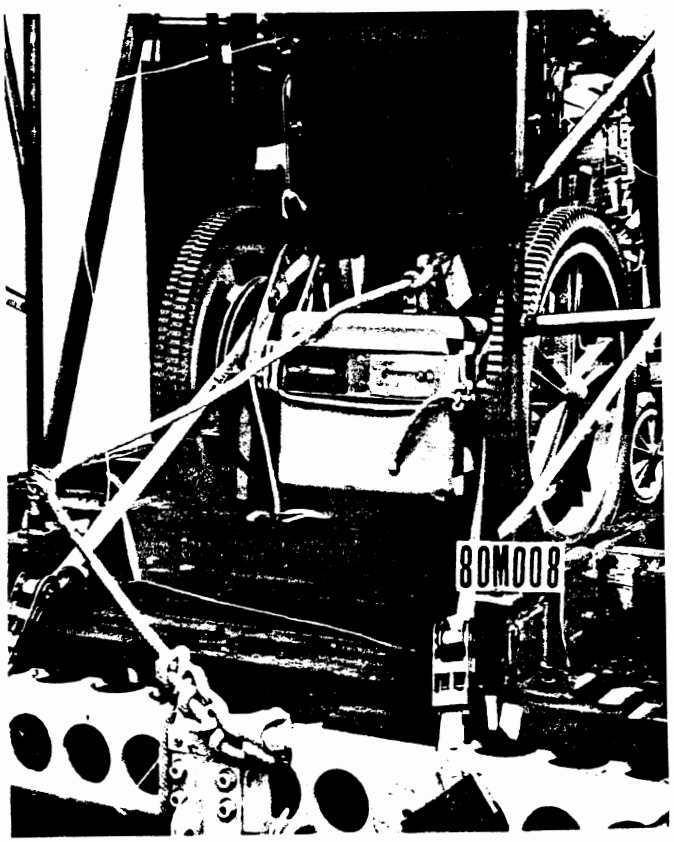
Results

The Aeroquip straps provided good restraint of the wheelchair and the chair moved only a couple of inches due to stretching of the straps. There was no apparent damage to the chair frame and the passive belt system with lap belt to chair provided good upper and lower torso restraint for the dummy.

Peak Belt Loads (lbs)

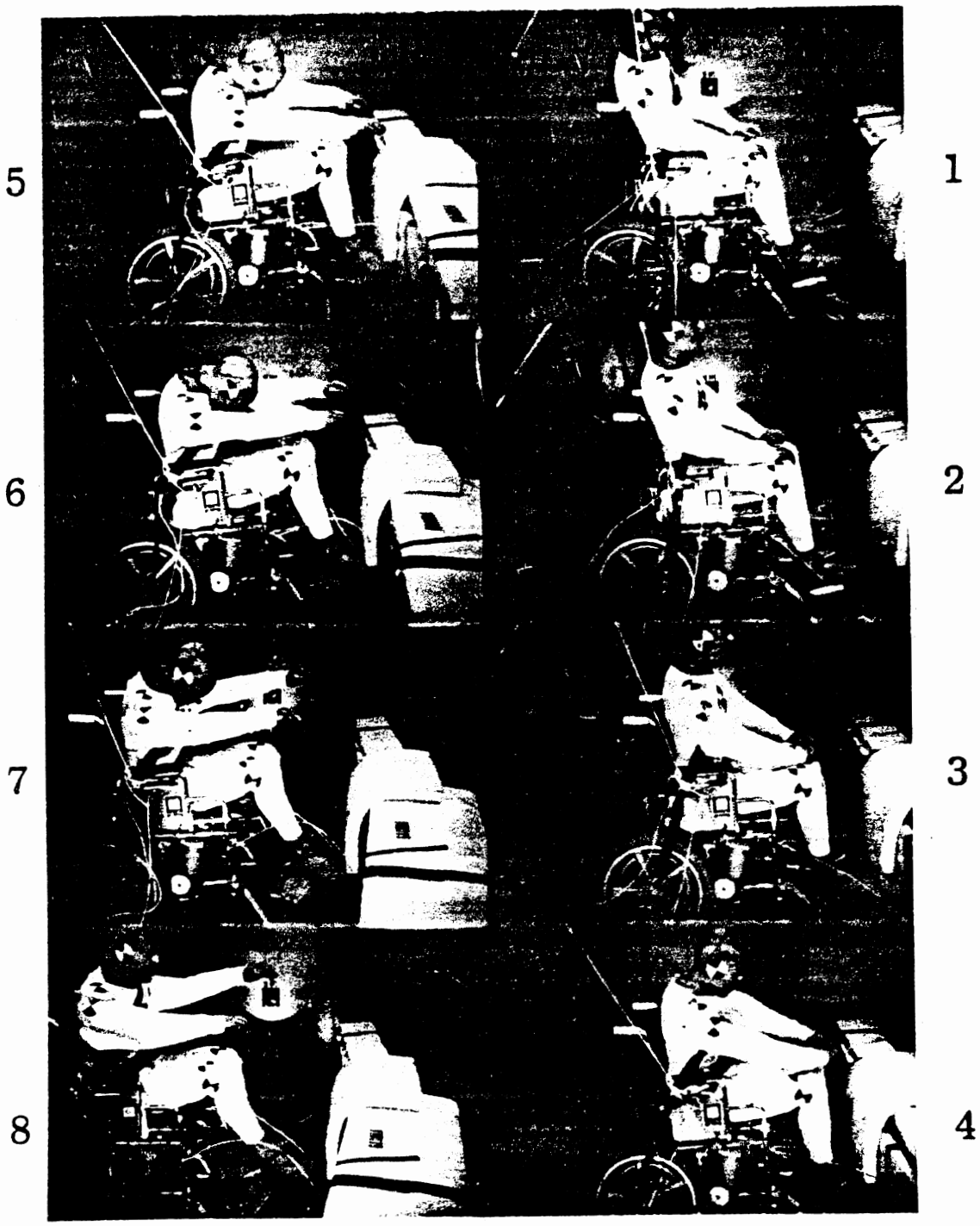
Shoulder belt	- 1250
Right lap belt	- 760
Passive lap belt (left)	- 660
Passive lap belt (right)	- 440
Right floor belt	- 1550





Set-Up Photos for Test 80M009

Post-Impact Photo for Test 80M009



Time Sequence Photo for Test 80M009

TEST NO.
80M010

Set-Up

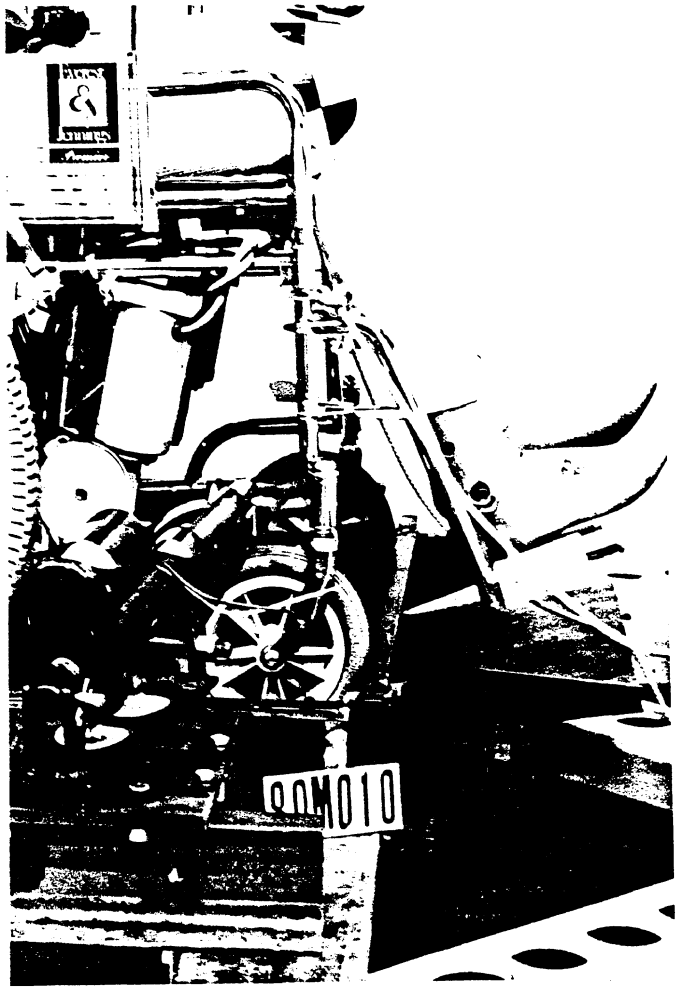
The wheelchair and dummy were restrained facing forward on the sled with the Bud power pan and power lock-down as in test 80M007 except that: 1) The lap portion of the passive belt system was passed over the wheelchair arms, 2) a steel bar was welded in place across the top edge of the power pan to provide a wheel stop for forward chair motion, and 3) the belt webbing of the floor mount belt was tied to the metal ring.

Results

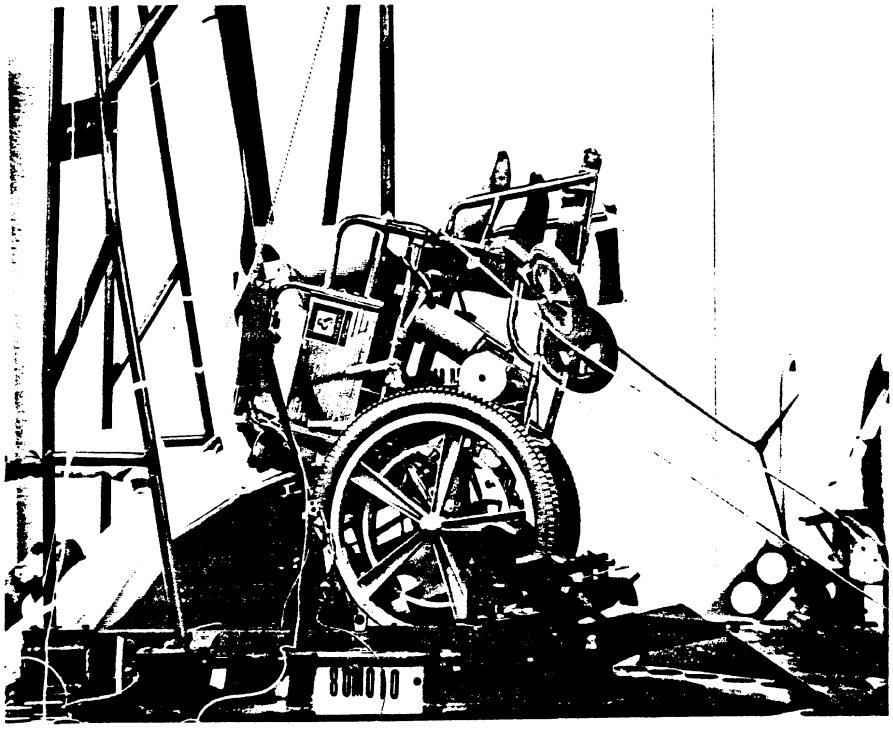
The wheelchair jumped the wheel stop bar almost as if it were not there and the dummy's knees impacted with the front of the sled. The dummy was restrained at the upper torso by the passive belt system causing the chair to flip over backwards so that the back of the dummy's head impacted the sled floor. The rear posts of the chair were bent backward during the impact.

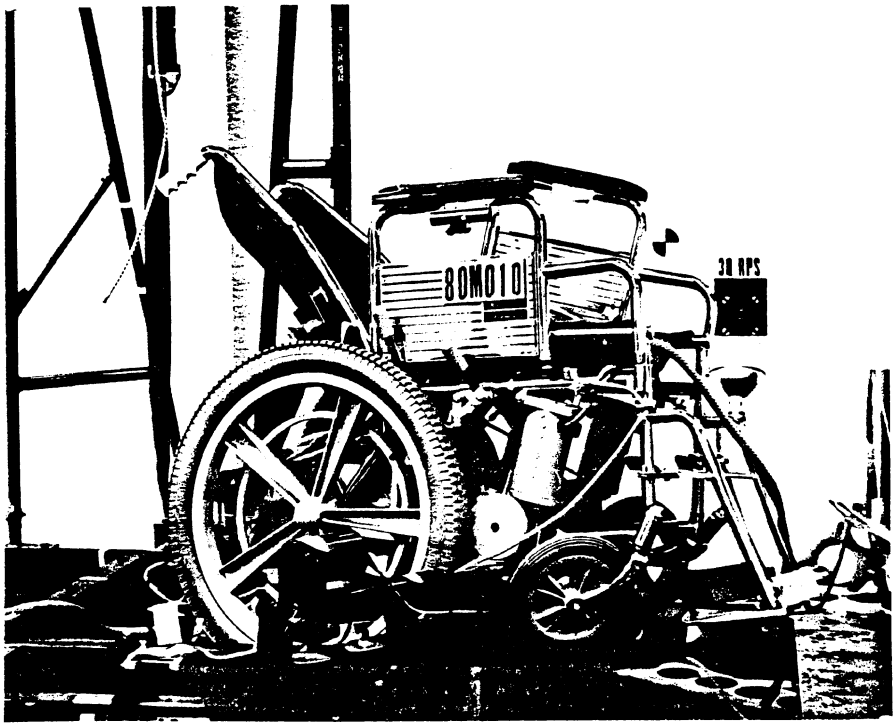
Peak Belt Loads (lbs)

Shoulder	- 1600
Right lap belt	- 260
Passive lap (left)	- 1400
Passive lap (right)	- 1050
Right floor	- 2150

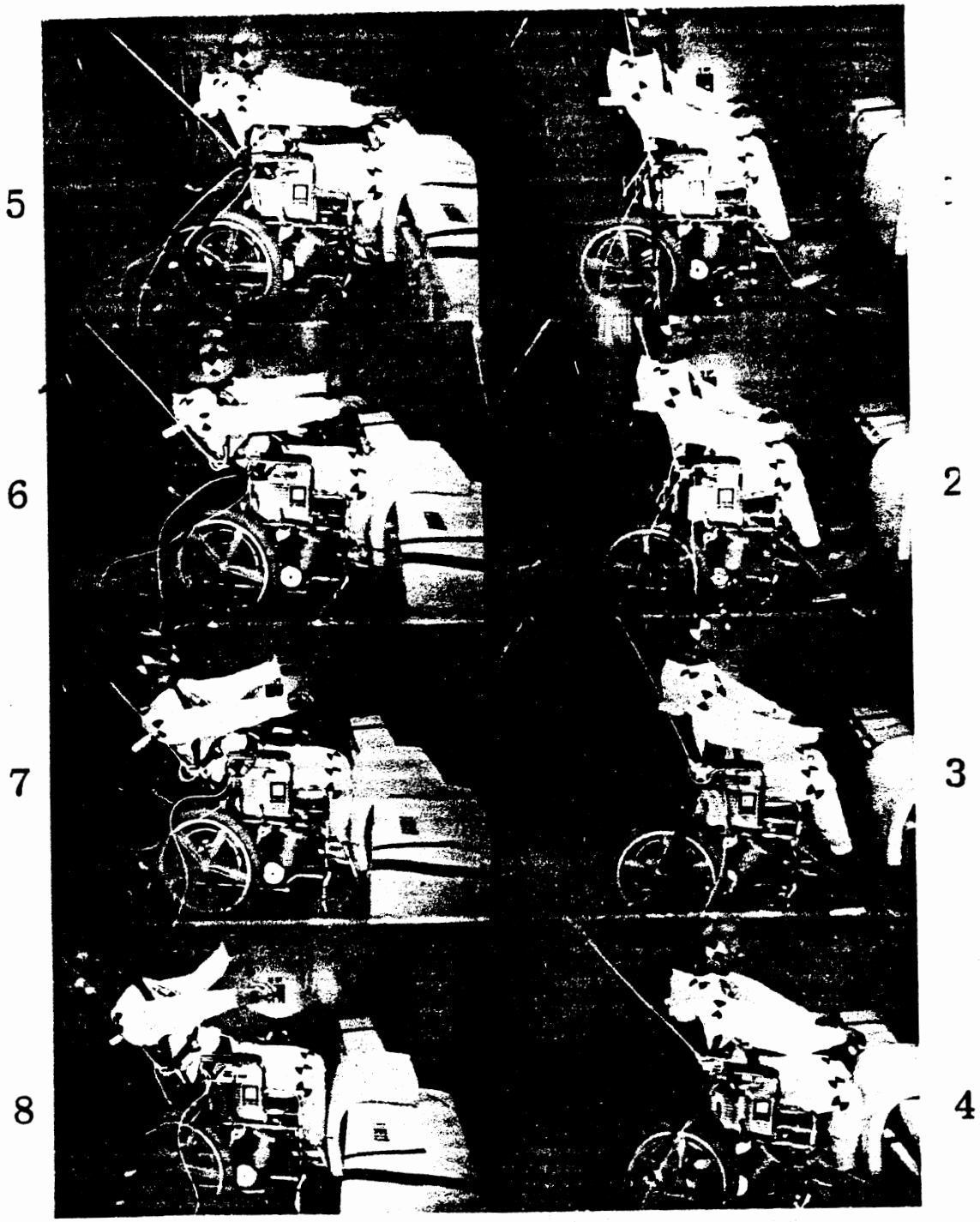


Set-Up Photo for Test 80M010





Post-Impact Photos for Test 80M010



Time Sequence Photo for Test 80M010

TEST NO.
80M011

Set-Up

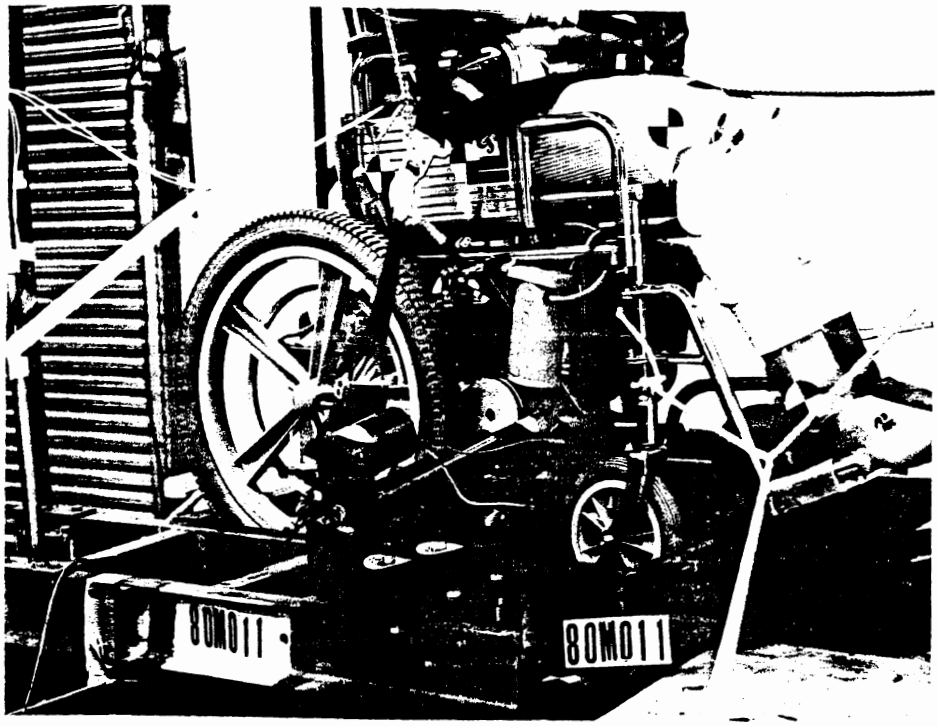
The wheelchair and dummy were restrained facing forward on the sled with the Bud power pan and power lock-down as in test 80M010 except that the lap portion of the Bud passive restraint webbing was placed in front of the wheelchair arms as in test 80M007. As in test 80M010, the floor belt webbing was tied to the metal ring and a wheel stop bar was in place in front of the wheelchair castor wheels. A lap belt to the back chair posts secured the dummy's pelvis in the chair.

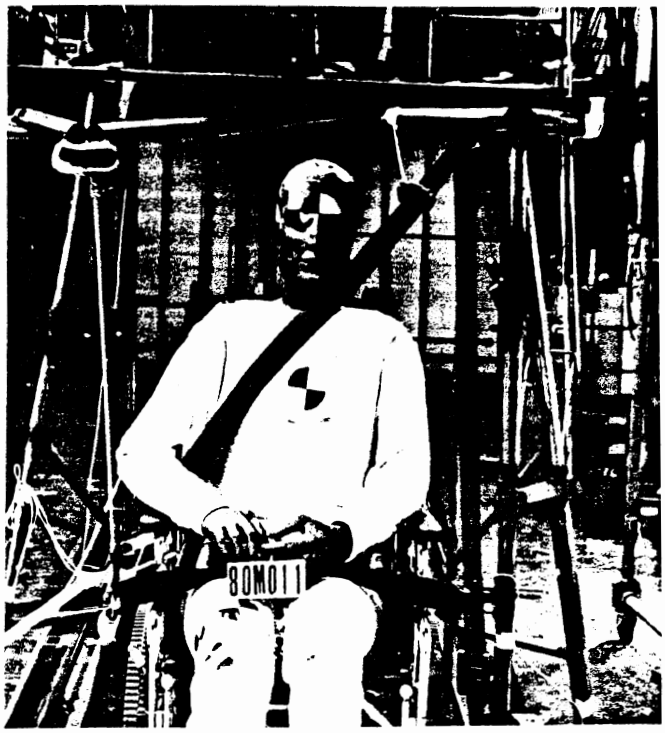
Results

This system provided fairly good restraint of the chair and occupant in the forward direction but both the chair and occupant were restrained by the passive belt system as indicated by the high belt loads. After impact the chair flipped backward to the sled floor. The chair arms sustained considerable inward bending.

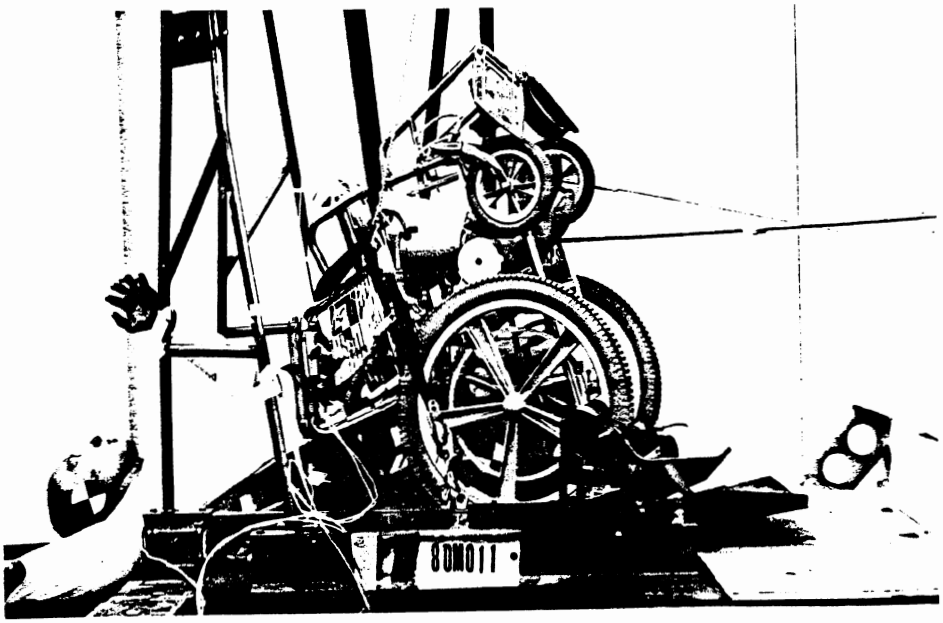
Peak Belt Loads (lbs)

Shoulder	- 1800
Left lap	- 340
Passive lap	- 1450
Right floor anchor	- 2200
Left floor anchor	- 1500





Set-Up Photos for Test 80M011



Post-Impact Photos for Test 80M011

Time Sequence Photo for Test 80M011

TEST NO.
80M012

Set-Up

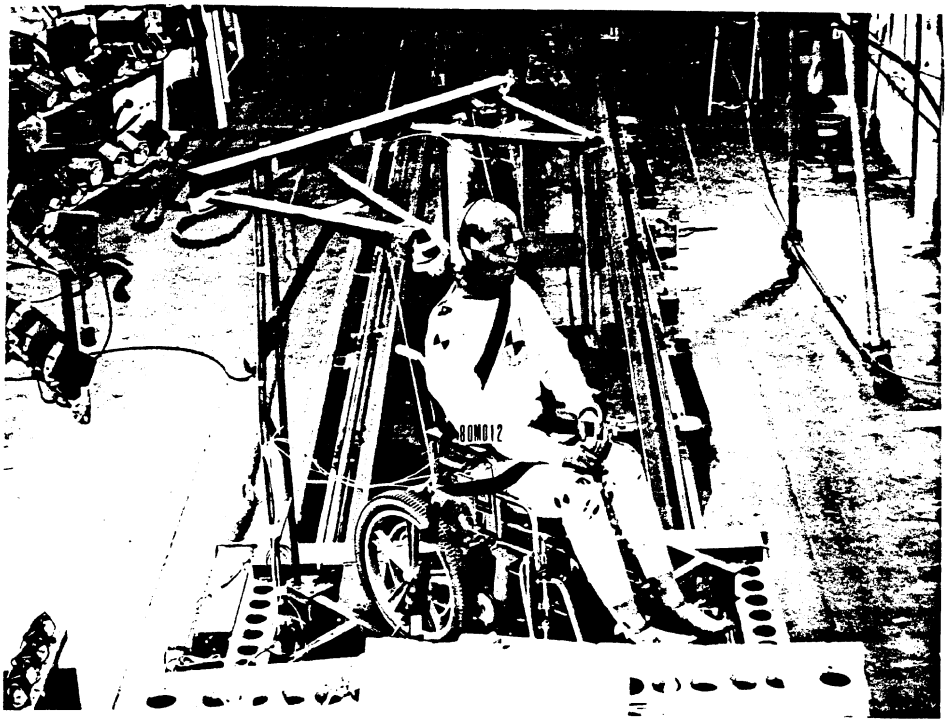
The wheelchair and dummy were restrained to the sled identically to test 80M011 but were orientated at 45 degrees to the sled track with the dummy's right shoulder toward the impact direction.

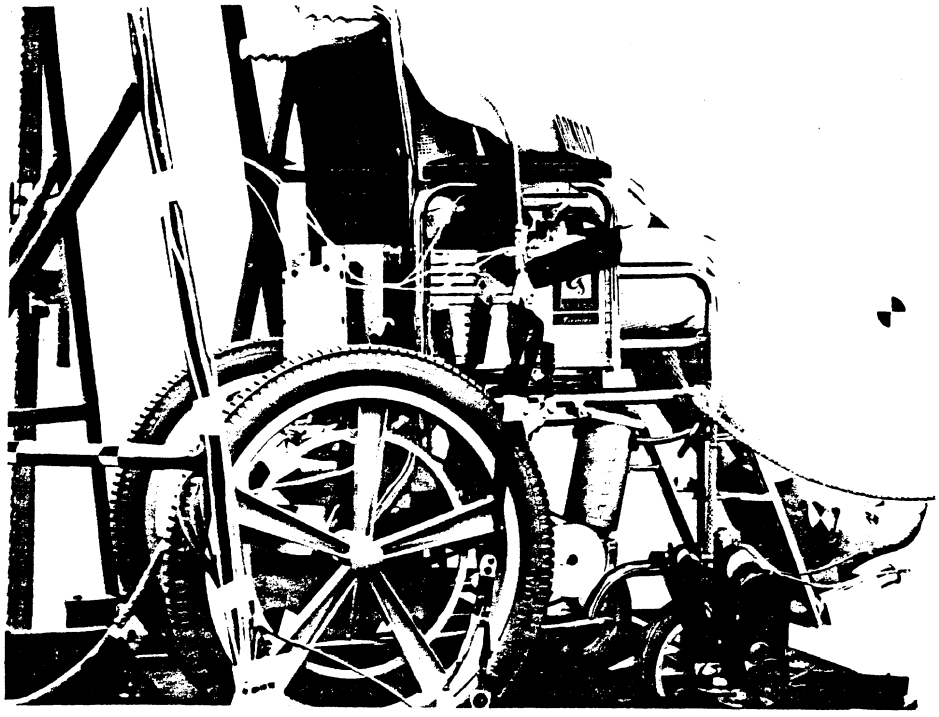
Results

As with test 80M011, the chair was restrained from forward motion by the passive belt system. Because the loading was mainly on the right side of the chair, the tubing of the right arm was bent significantly into the abdominal region of the dummy. The upper torso and head of the dummy showed greater excursions than in test 80M011 since the dummy slid sideways through the torso belt.

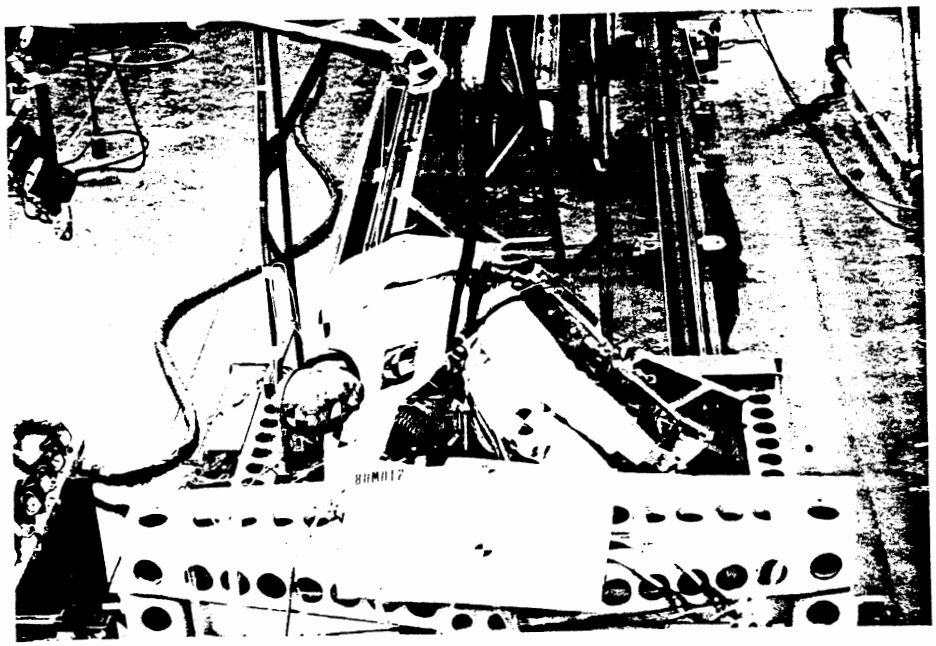
Peak Belt Loads (lbs)

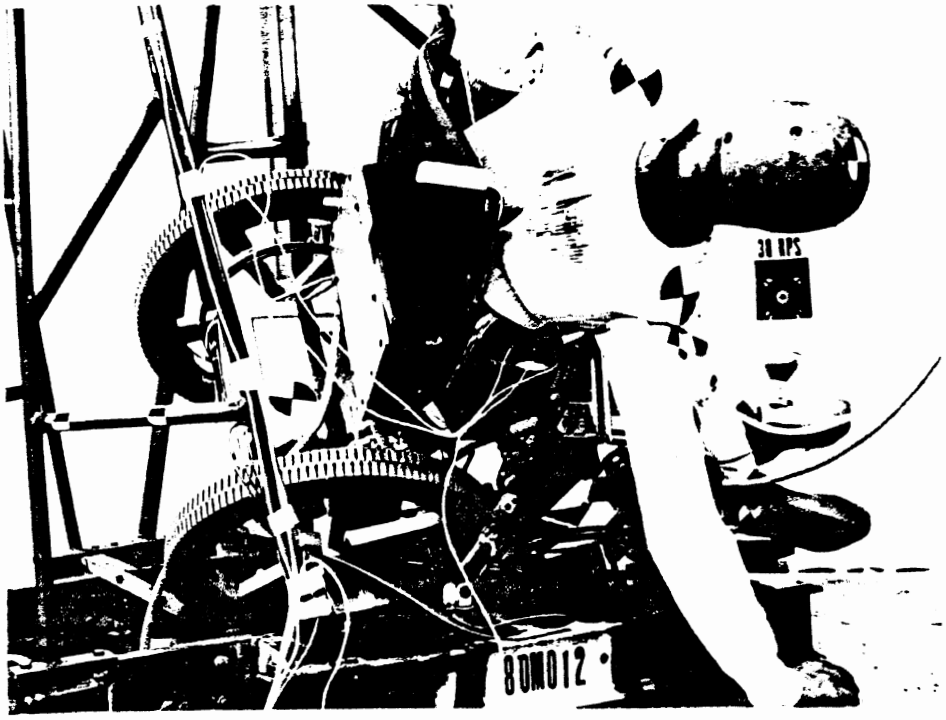
Shoulder	- 1700
Right lap	- 80
Left lap	- 280
Passive lap	- 1500



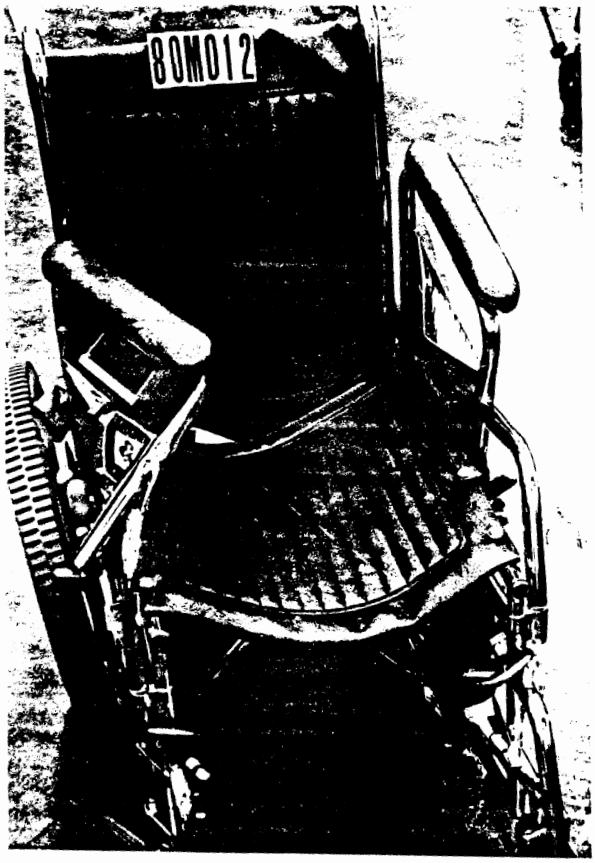


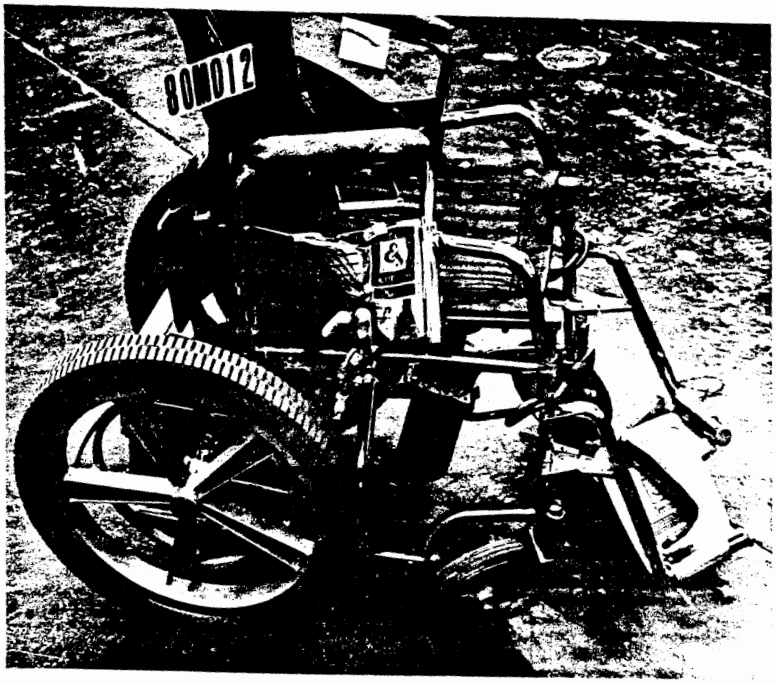
Set-Up Photos for Test 80M012



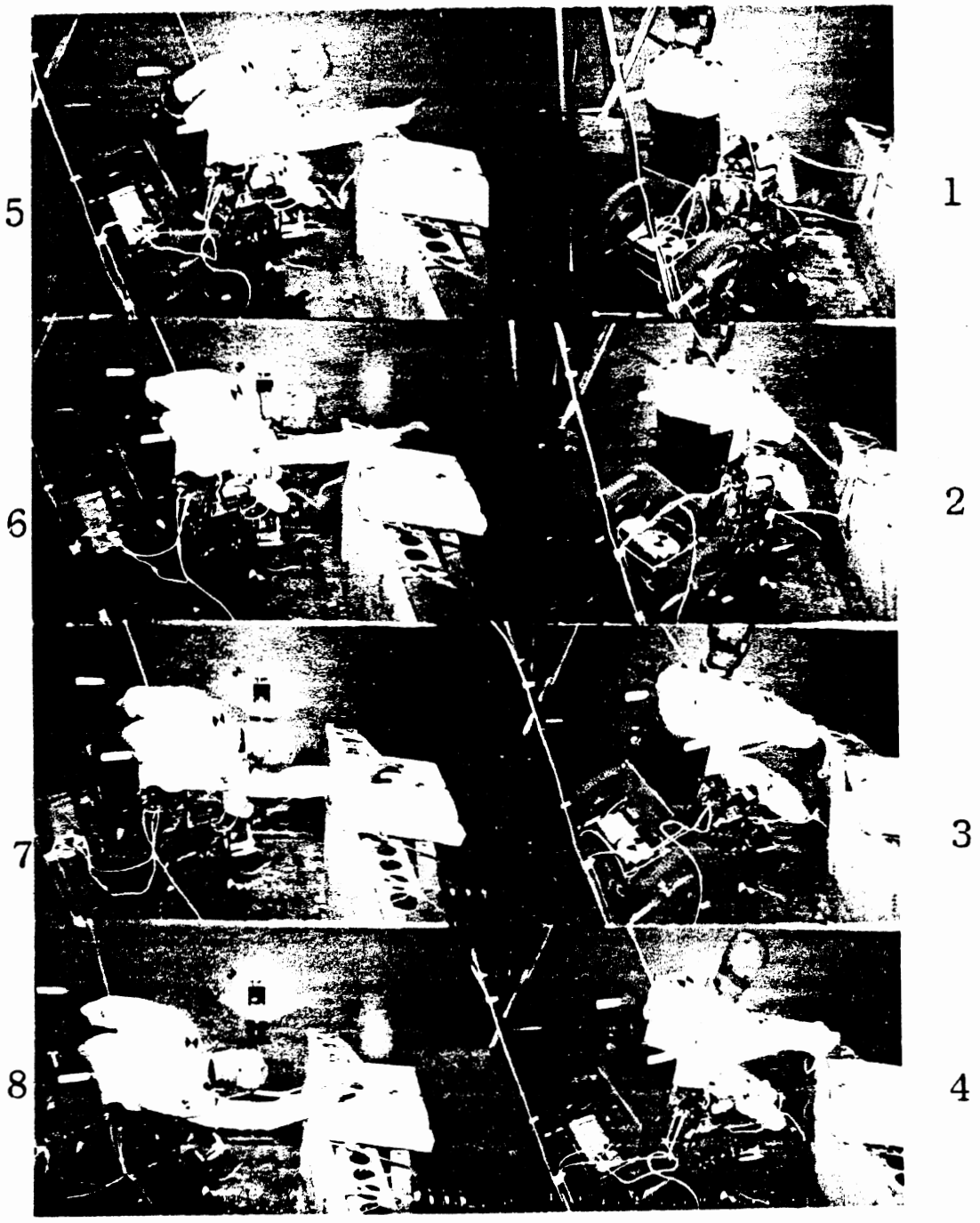


Post-Impact Photos for Test 80M012





Post-Impact Photos for Test 80M012



Time Sequence Photo for Test 80M012

TEST NO.
80M013

Set-Up

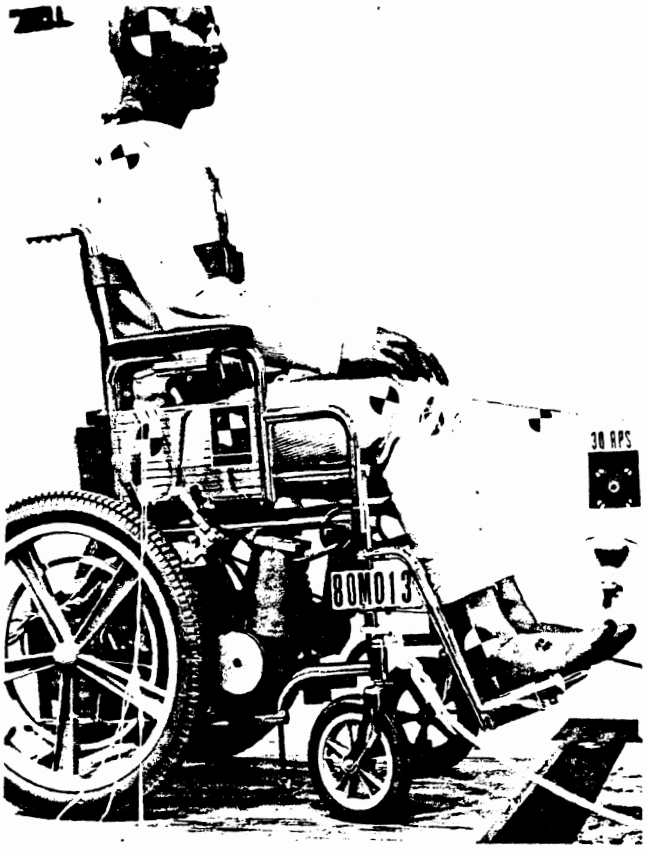
The wheelchair was restrained facing forward on the sled by a Bud Industries T-bar similar to that used in test 80M003. The adjustment holes in the T-bar were reduced to about 1/8" diameter for increased strength and a heavy duty eye bolt was used in place of a lift ring for attachment to the floor. The dummy was restrained to the chair by a lap belt and a velcro chest belt to the chair back posts.

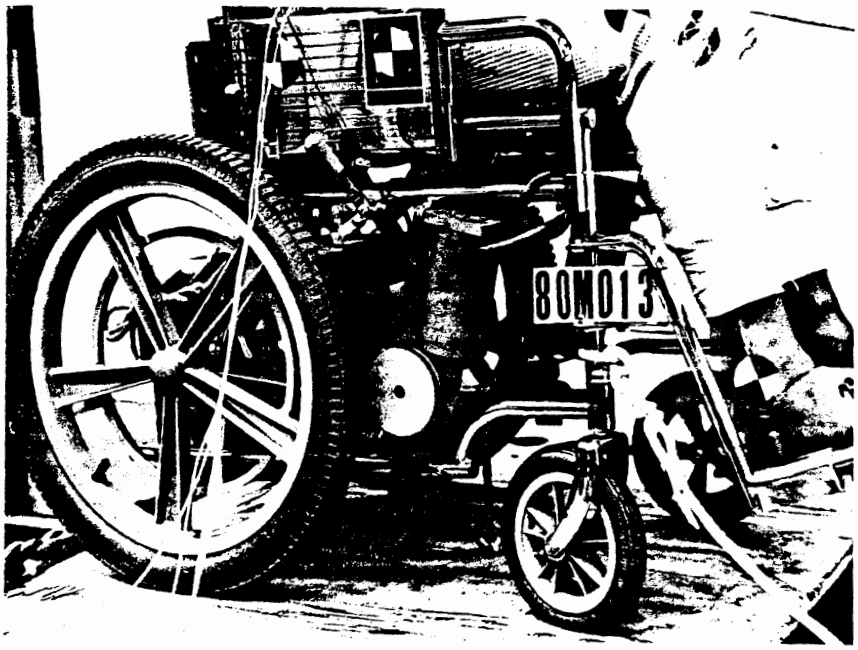
Results

The T-bar broke in half at the center hook bolt hole and the chair moved unrestrained into the padded front of the sled. The lap belt came unlatched at the buckle during the test but the velcro fastening on the chest belt held and the dummy stayed in the chair. After impact the chair flipped over backwards.

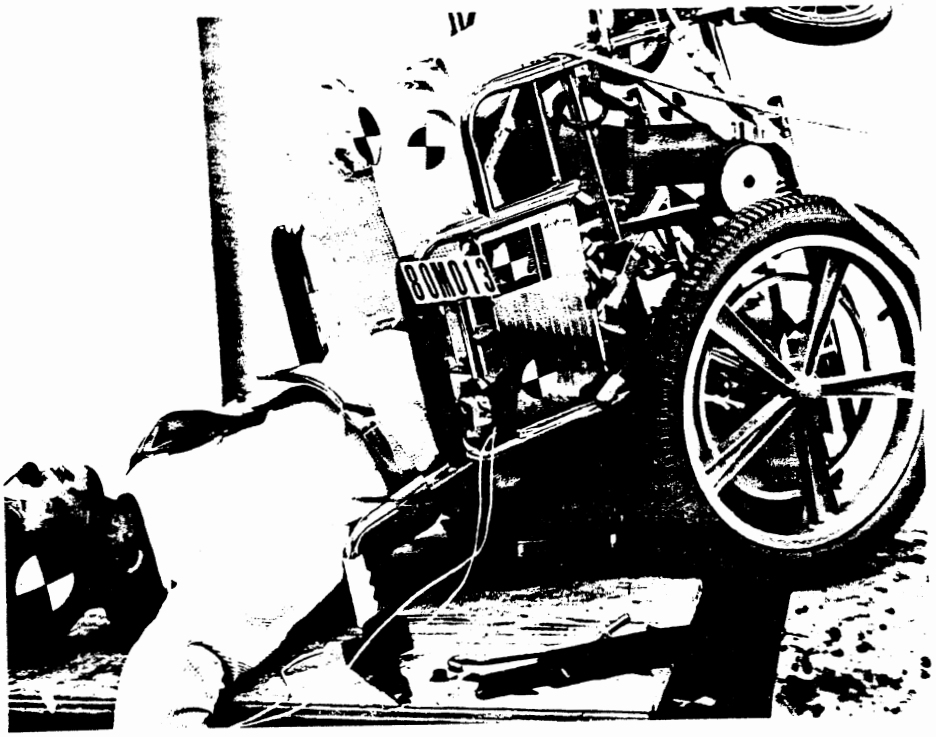
Peak Belt Loads (lbs)

Left lap - 200
Right lap - 150

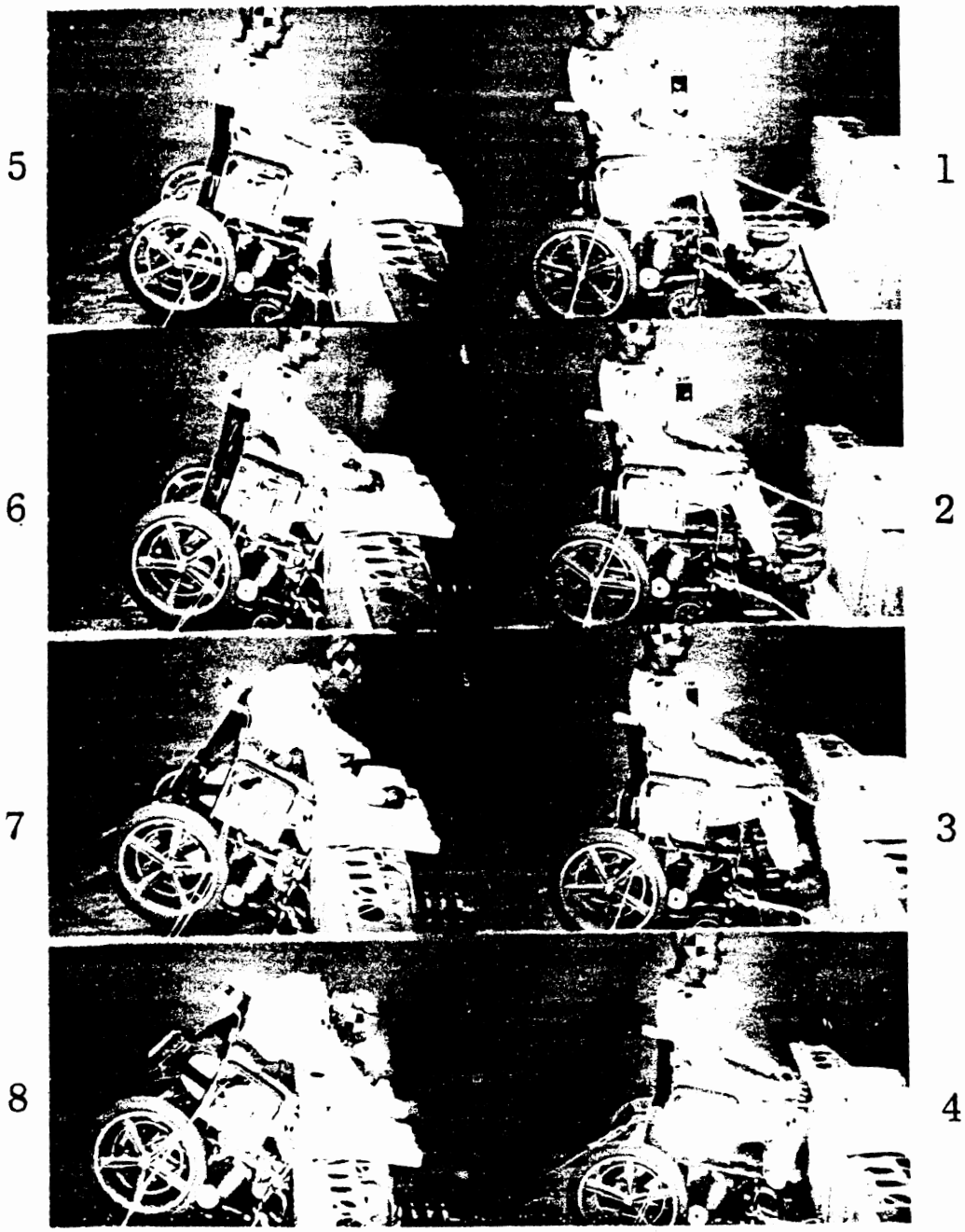




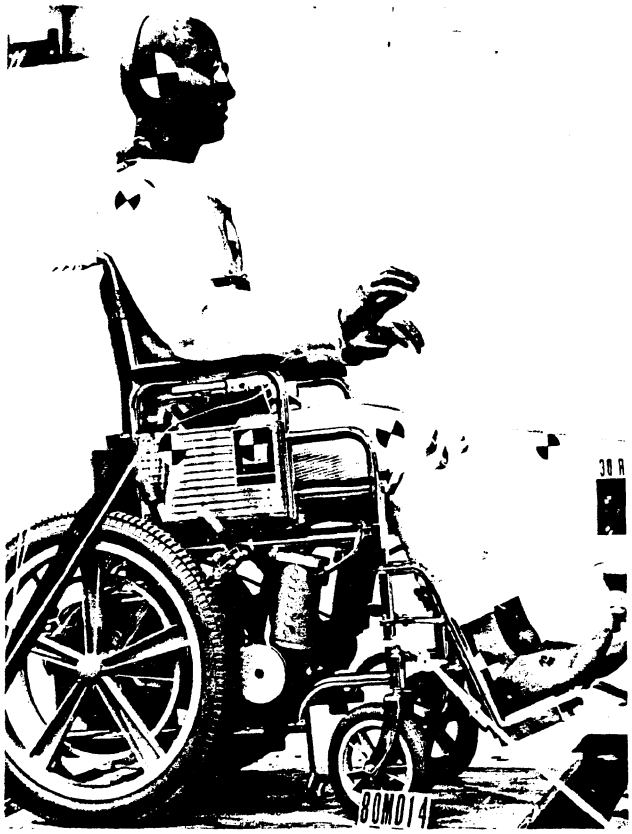
Set-Up Photos for Test 80M013



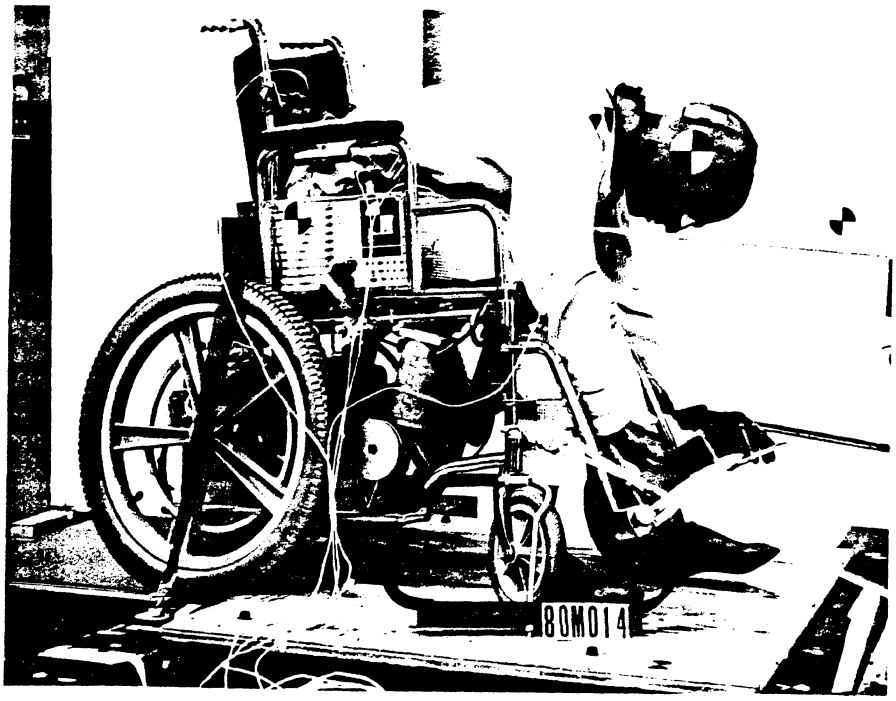
Post-Impact Photo for Test 80M013



Time Sequence Photo for Test 80M013



Set-Up Photo for Test 80M014



Post-Impact Photo for Test 80M014

TEST NO.
80M014

Set-Up

The wheelchair was restrained facing forward on the sled by a Bud Industries fixed length T-bar made of a piece of 1" square steel extrusion and a lap belt to the floor. The T-bar attached to the floor by a hook bolt through a center hole to a heavy duty eye bolt. The lap belt anchor points were also heavy duty eye bolts. A velcro chest belt to the chair back posts was also used.

Results

The hook portion of the T-bar hook bolt straightened out releasing the chair from the T-bar tie-down. The lap belt restrained the chair and dummy from any significant forward motion but the chair was only restrained from falling off the back of the sled by tether ropes. The velcro fastenings on the chest belt held but a D-ring opened allowing the dummy to jackknife forward. The chair sustained significant bending of the main axles due to forces from the floor lap belt.

Peak Belt Loads (lbs)

Left floor lap	- 1850
Right floor lap	- 1500
Left chest	- 290
Right chest	- 390

Time Sequence Photo for Test 80M014

TEST NO.
80M015

Set-Up

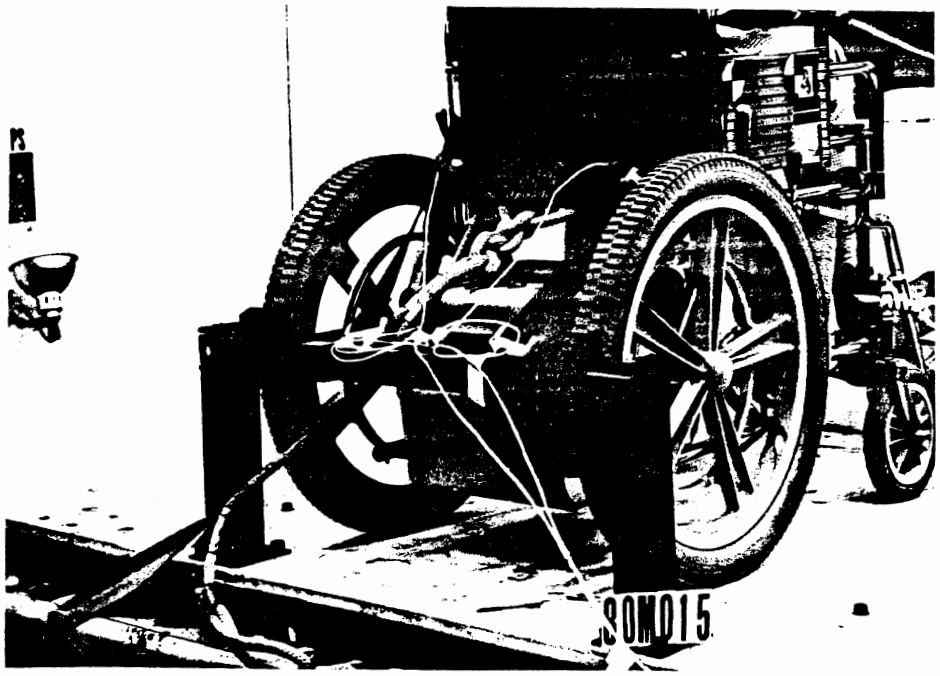
The wheelchair was restrained facing forward on the sled by a Bud Industries single chair rim pin stanchion. The dummy was restrained by a lap belt anchored to holes in the rim pin brackets.

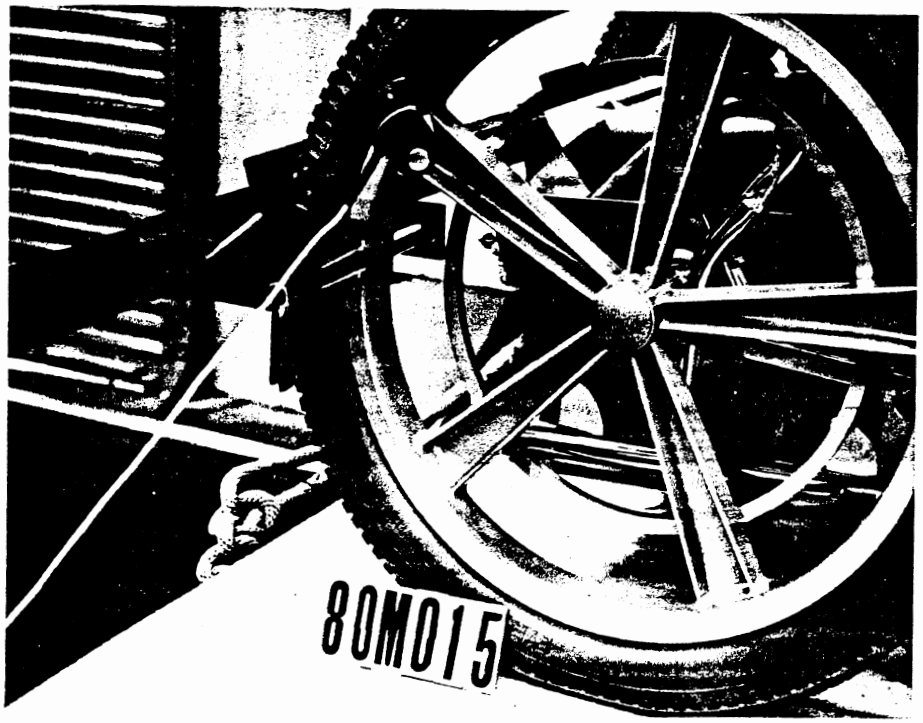
Results

This system offered good wheelchair and dummy restraint. The absence of an upper torso belt, however, allowed a large head excursion due to jackknifing.

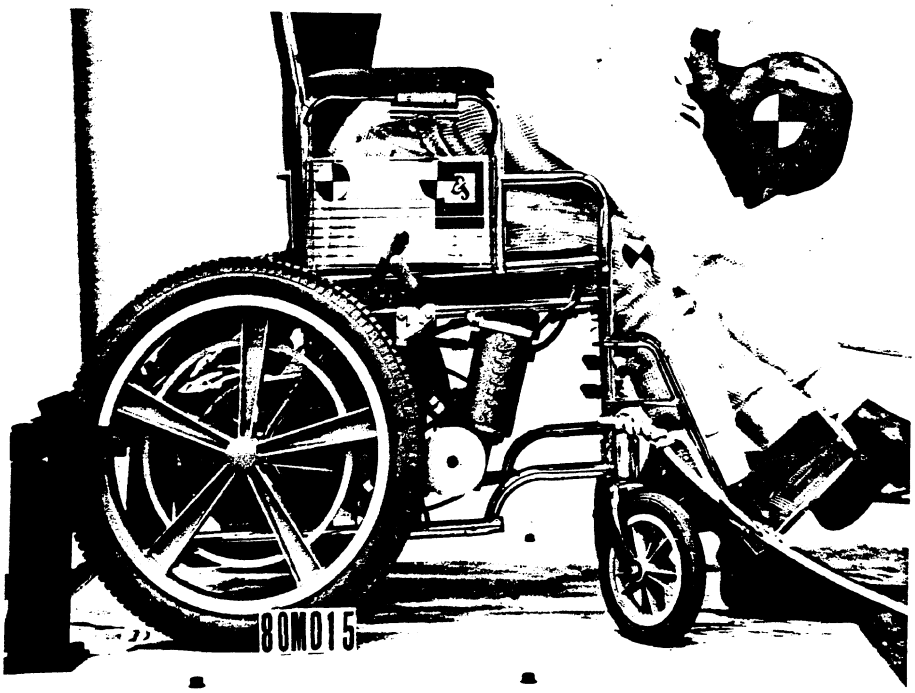
Peak Belt Loads (lbs)

Left lap - 1350
Right lap - 1100

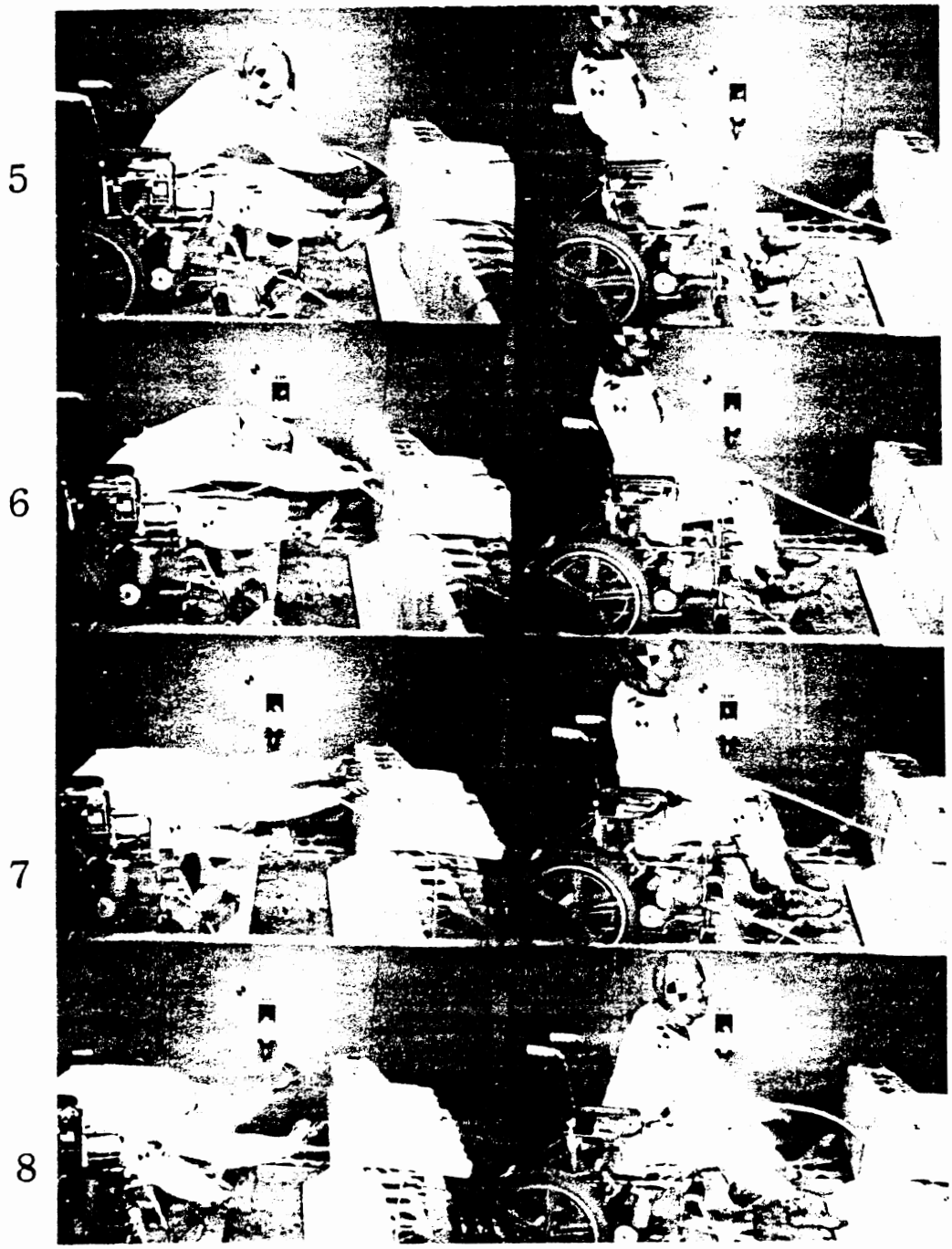




Set-Up Photos for Test 80M015



Post-Impact Photo for Test 80M015



Time Sequence Photo for Test 80M015

TEST NO.
80M016

Set-Up

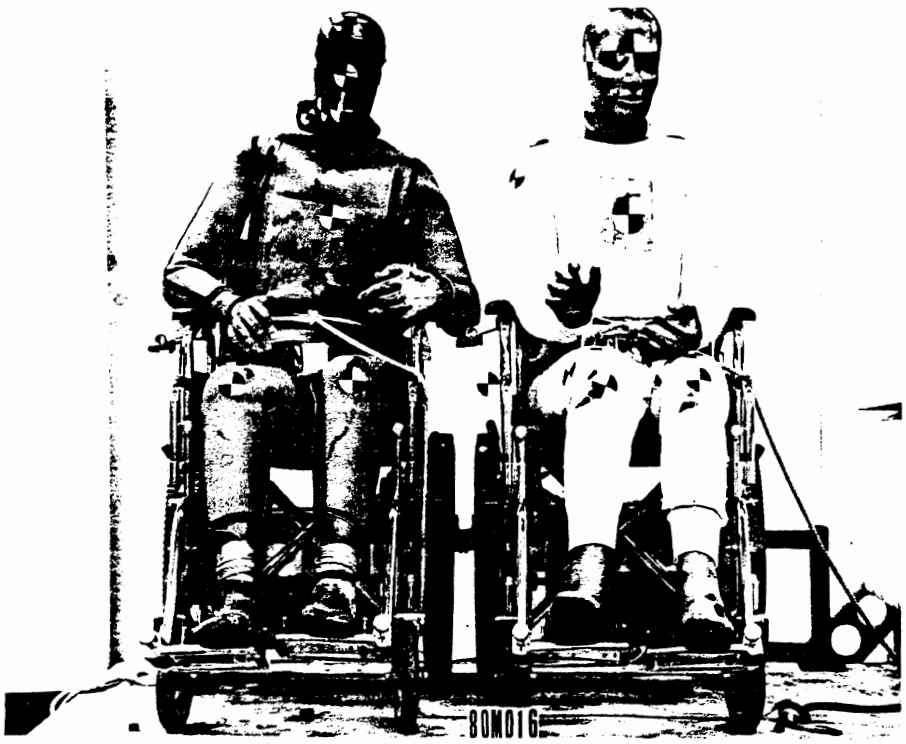
Two wheelchairs were restrained facing sideways on the sled by a Bud Industries double chair rim pin stanchion. Two 50th percentile male dummies were restrained by lap belts anchored to the rim pin brackets on the stanchion. The chairs were positioned as far to the rear of the sled as possible and the thumb screws which secure the sliding rim pin brackets were tightened with pliers.

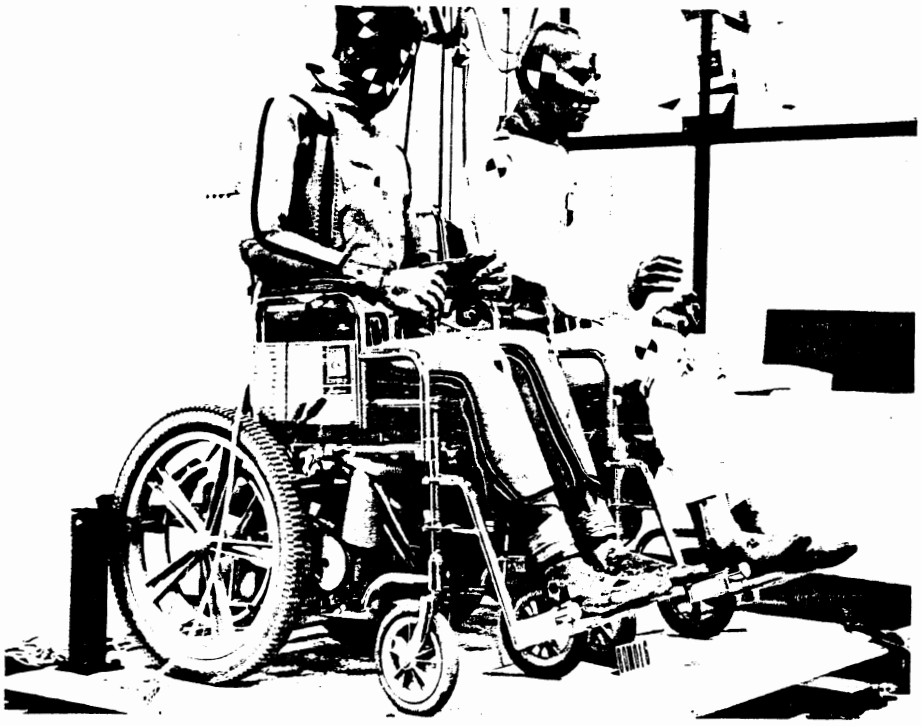
Results

The rim pin fixtures of the stanchion slid along the bar to the front of the stanchion bar. The front chair impacted into the padded front of the sled fracturing the left magnesium wheel rim and badly bending the chair. The rear chair impacted into the front chair and then flipped backward over the stanchion with the dummy ending upside down and hanging off the side of the sled. Both lap belts held the dummy's in the chairs.

Peak Belt Loads (lbs)

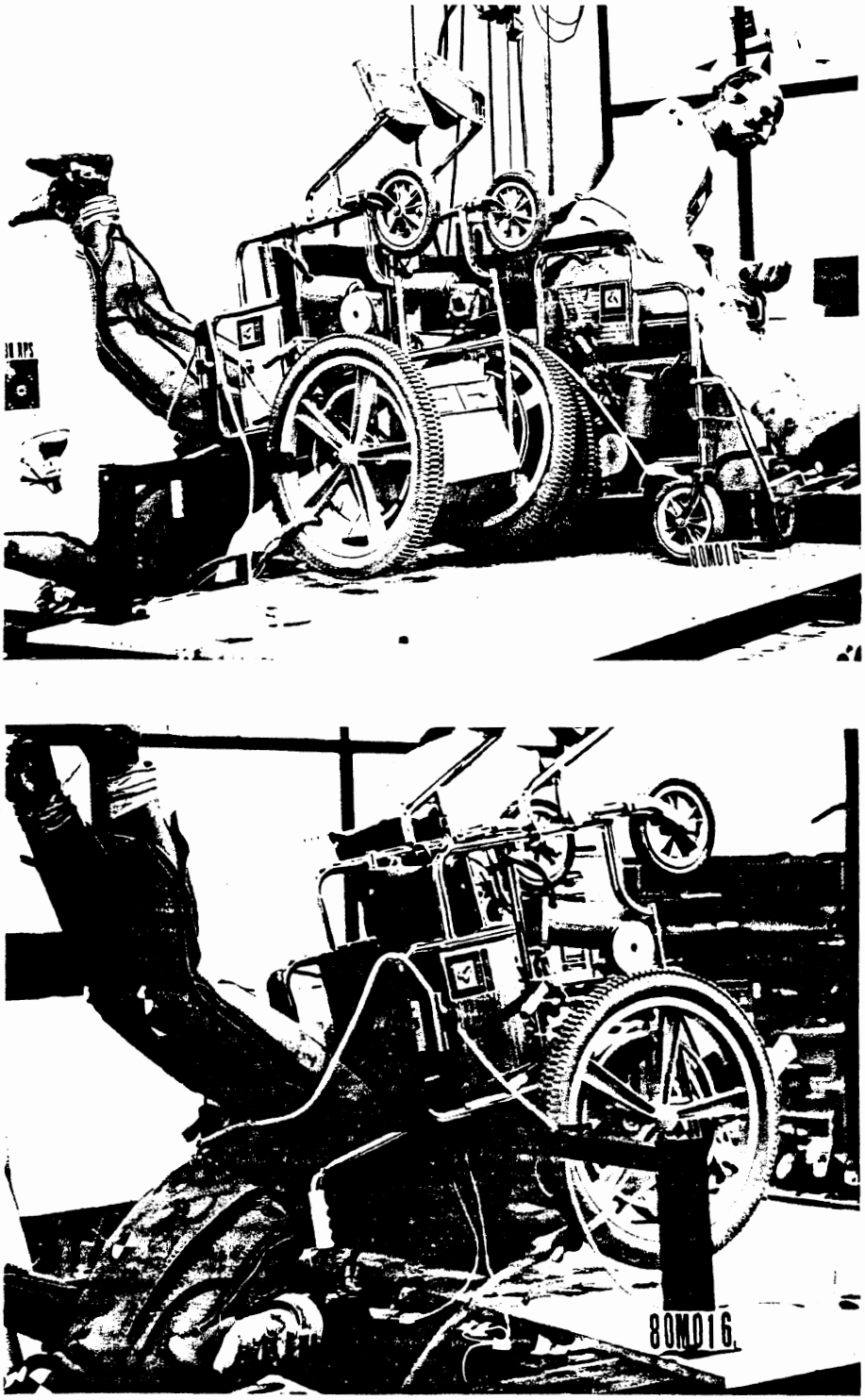
Left lap (front)	- 600
Right lap (front)	- 470
Left lap (rear)	- 350
Right lap (rear)	- 720



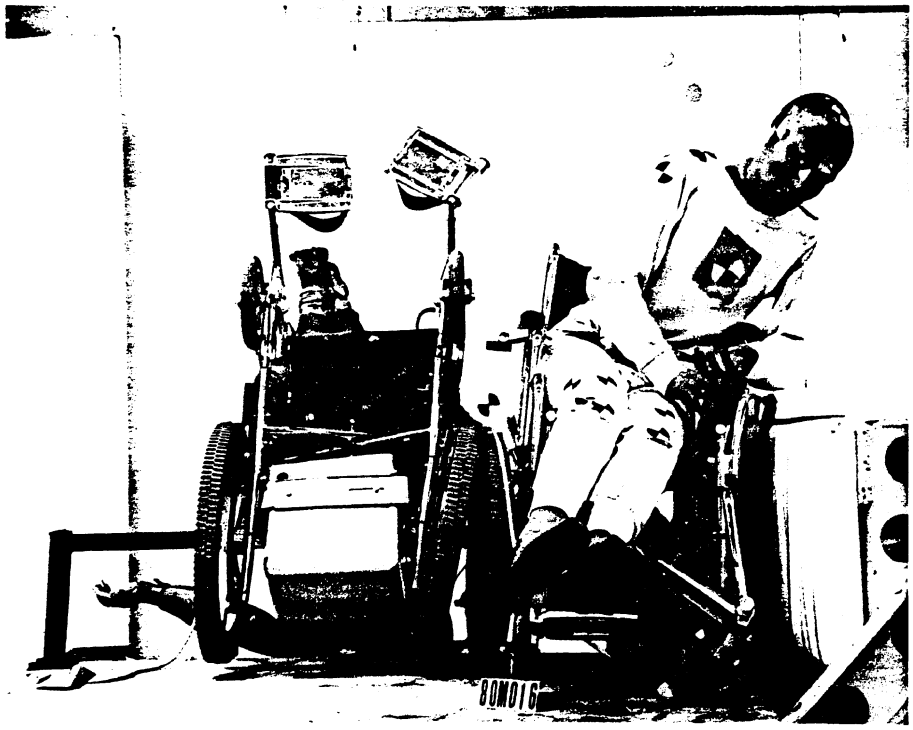


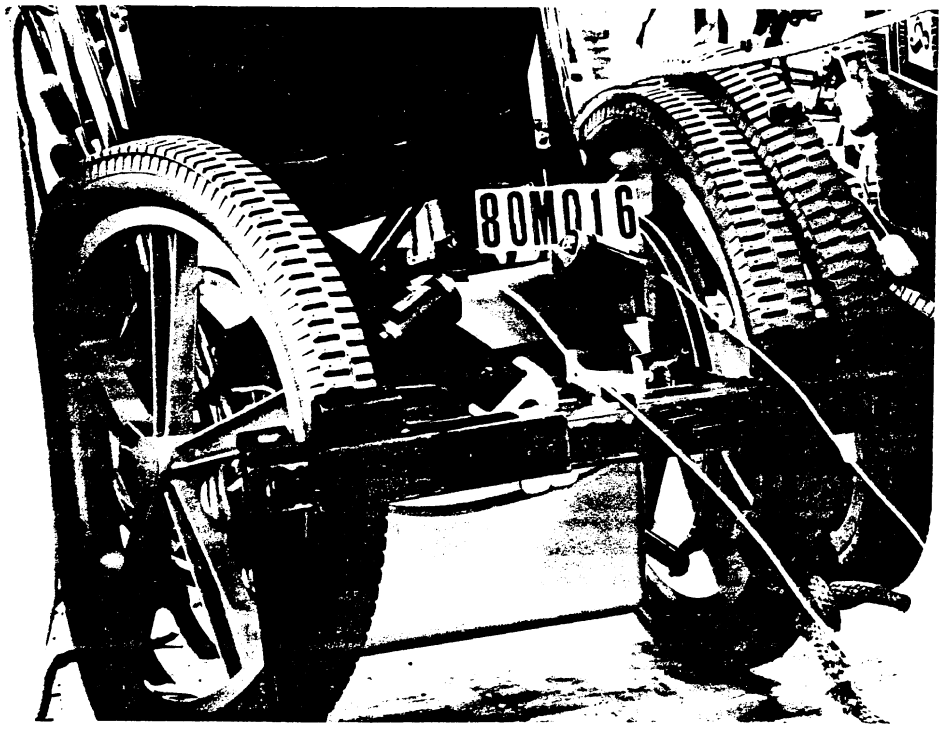
Set-Up Photos for Test 80M016

Set-Up Photo for Test 80M016

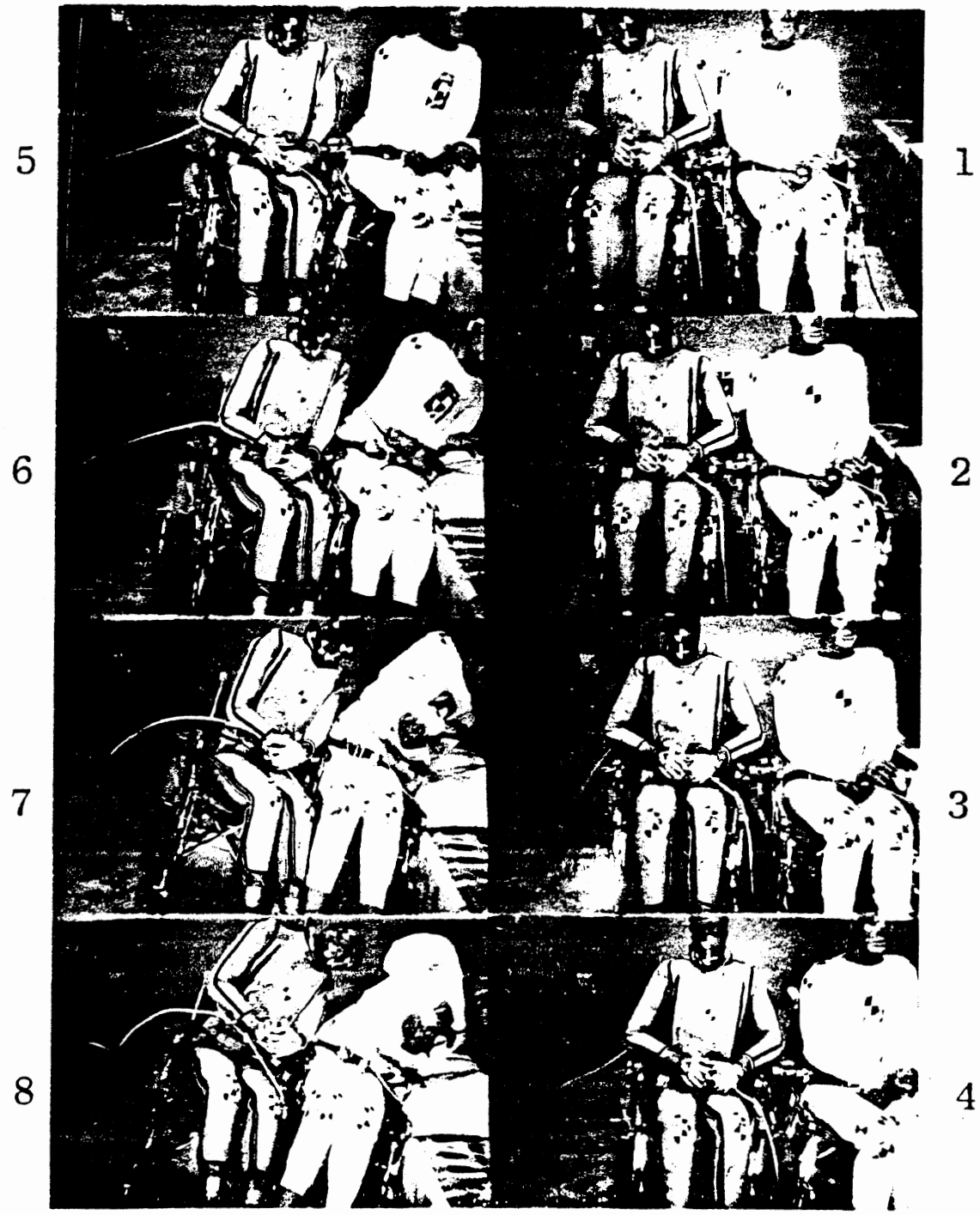


Post-Impact Photos for Test 80M016





Post Impact Photos for Test 80M016



Time Sequence Photo for Test 80M016

TEST NO.
80M017

Set-Up

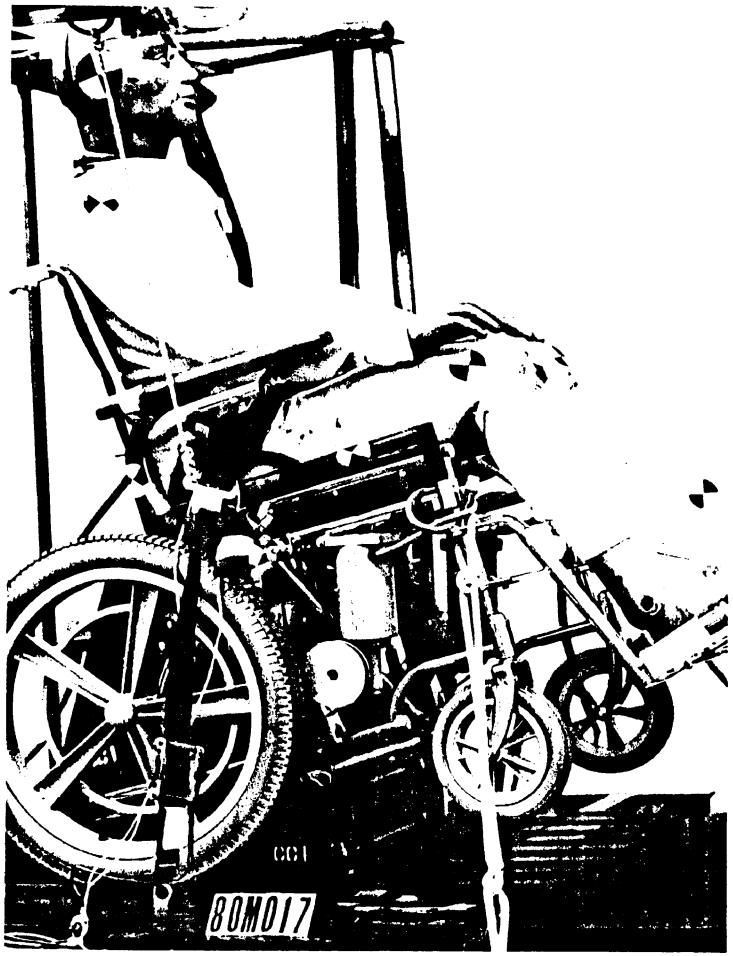
The wheelchair was restrained facing forward on the sled by a Creative Controls, Inc. (CCI) tie-down system consisting of a restraint platform bolted to the sled and triangular steel plates and bars attached to the wheelchair itself. A van sheet metal floor was bolted to the sled and the CCI platform was bolted to the sheet metal using four 1/2" bolts and two steel plates under the sheet metal to distribute the loads. The dummy was secured to the chair by a lap belt anchored to the CCI triangles. The Bud Industries passive belt system was used in conjunction with Bud Industries cantilevered chair arms to provide complete torso restraint.

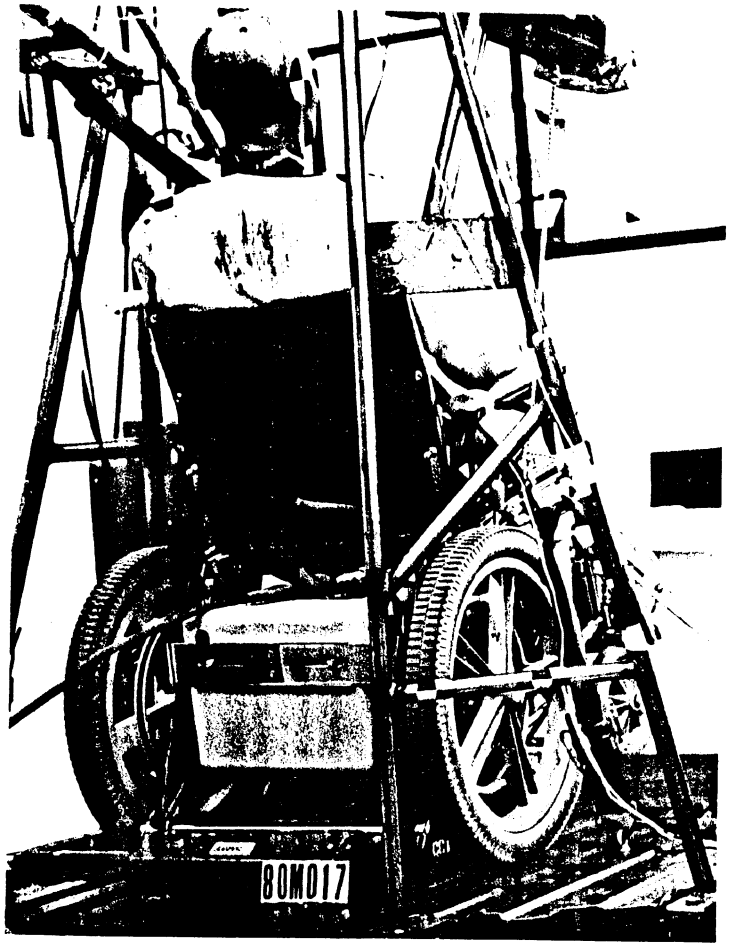
Results

This system provided excellent wheelchair and occupant restraint. The sheet metal deformed slightly and the rear CCI retaining bar bent slightly at both ends.

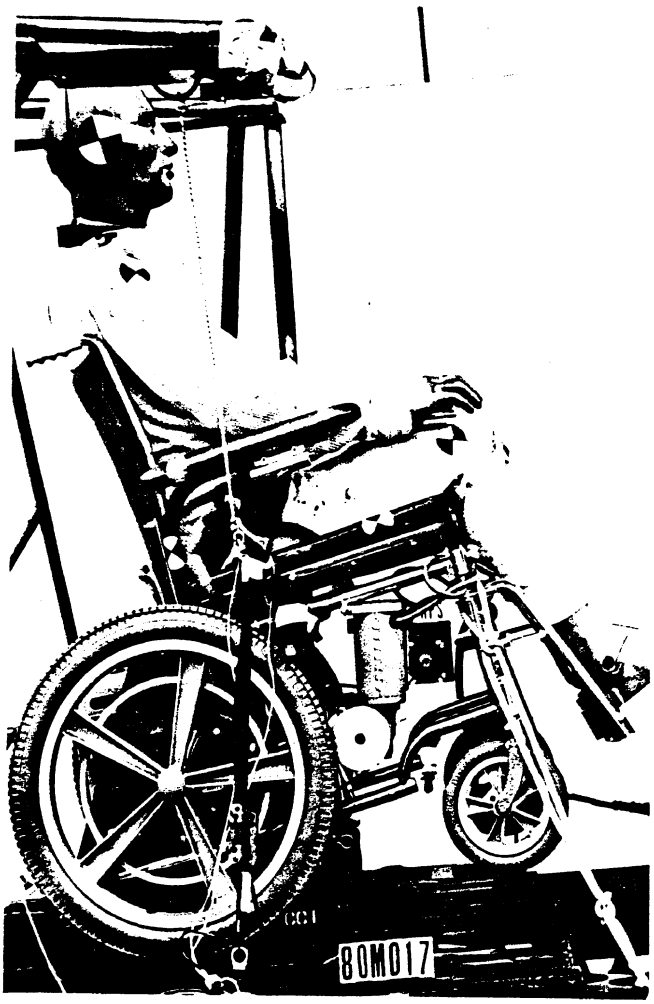
Peak Belt Loads (lbs)

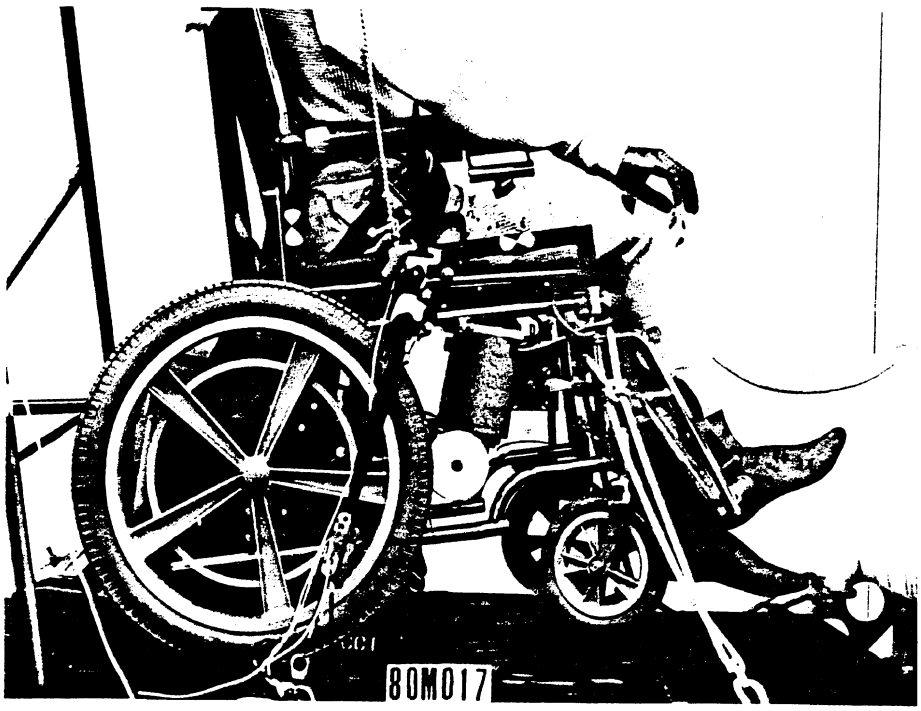
Shoulder - 1300
Right lap - 1000
Left lap - 1050



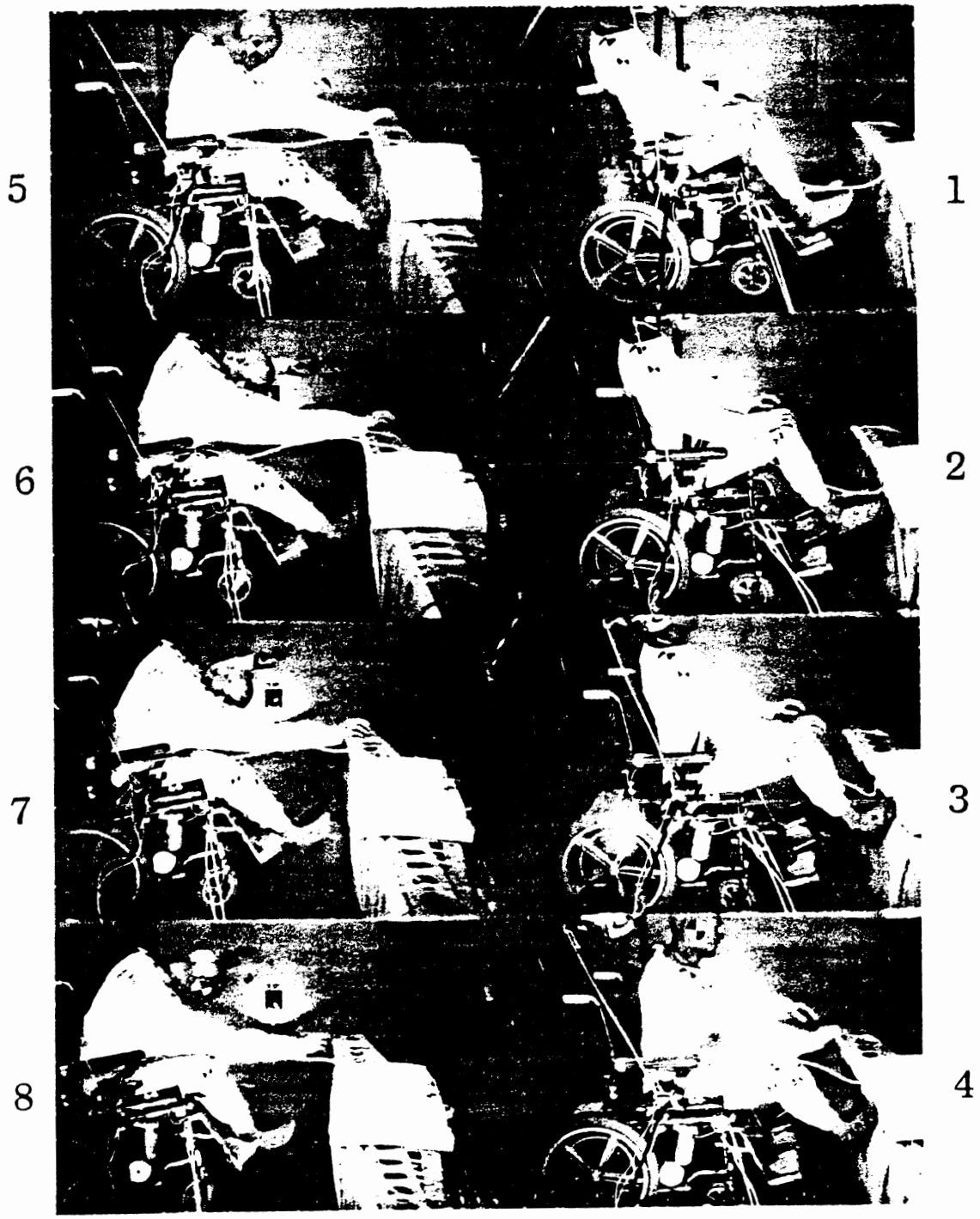


Set-Up Photos for Test 80M017





Post-Impact Photos for Test 80M017



80M017

Time Sequence Photo for Test 80M017

TEST NO.
80M018

Set-Up

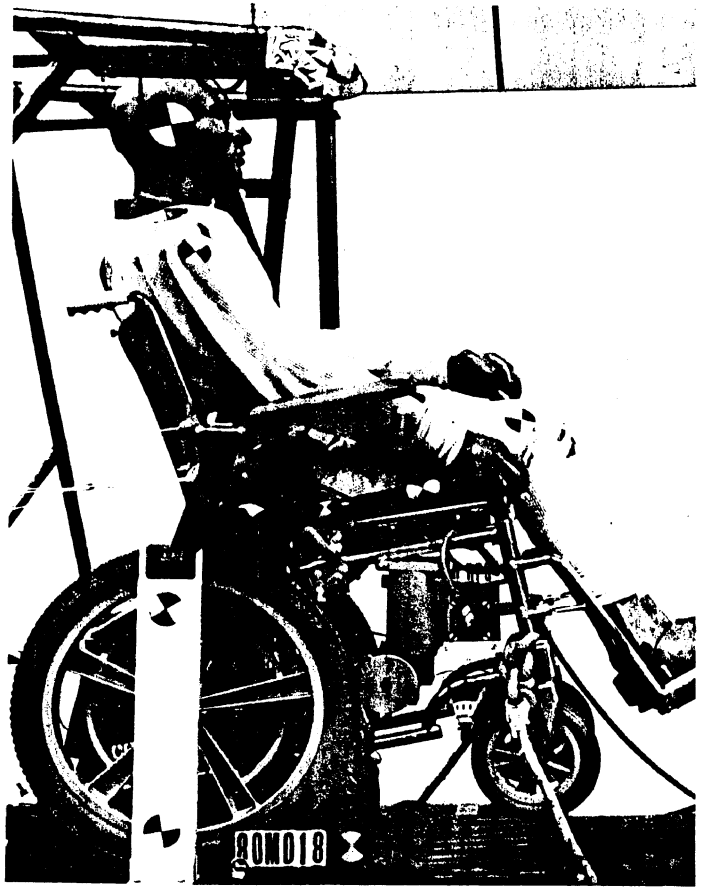
The wheelchair was restrained facing forward on the sled using the CCI tie-down system as in test 80M017. The dummy was secured to the chair by a lap belt anchored to the CCI triangles. A passive belt system by Falcon, Inc. was used with the Bud Industries wheelchair arms to provide upper torso restraint for the dummy. This Falcon system uses a post bolted to the floor to position the passive belt appropriately.

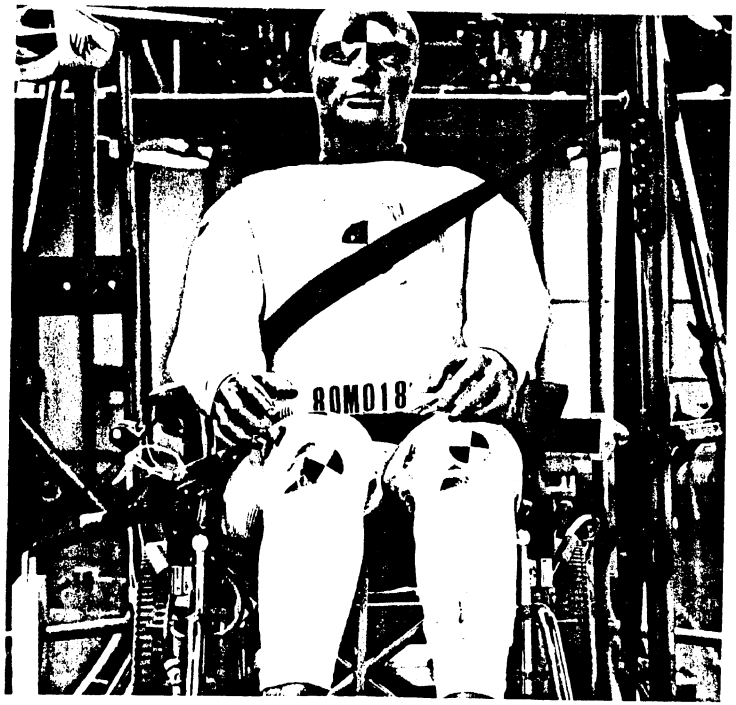
Results

The CCI system provided excellent wheelchair restraint. A bad weld at the left shoulder anchor point resulted in incomplete torso restraint for the dummy. The Falcon post tilted forward by bending the sheet metal and this added to the belt ineffectiveness and dummy excursions.

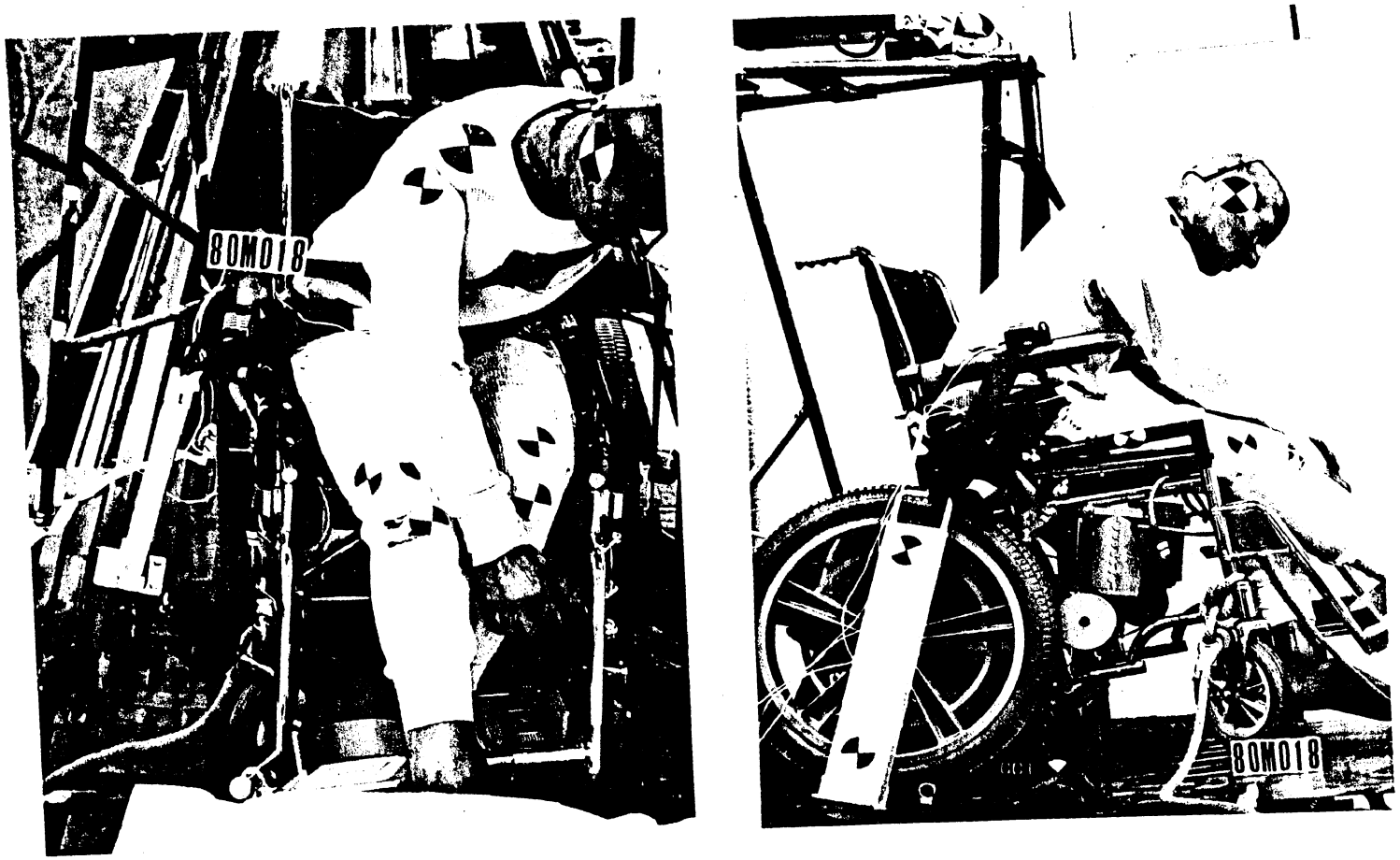
Peak Belt Loads (lbs)

Shoulder	- 660
Left chair lap	- 1400
Passive lap	- 390

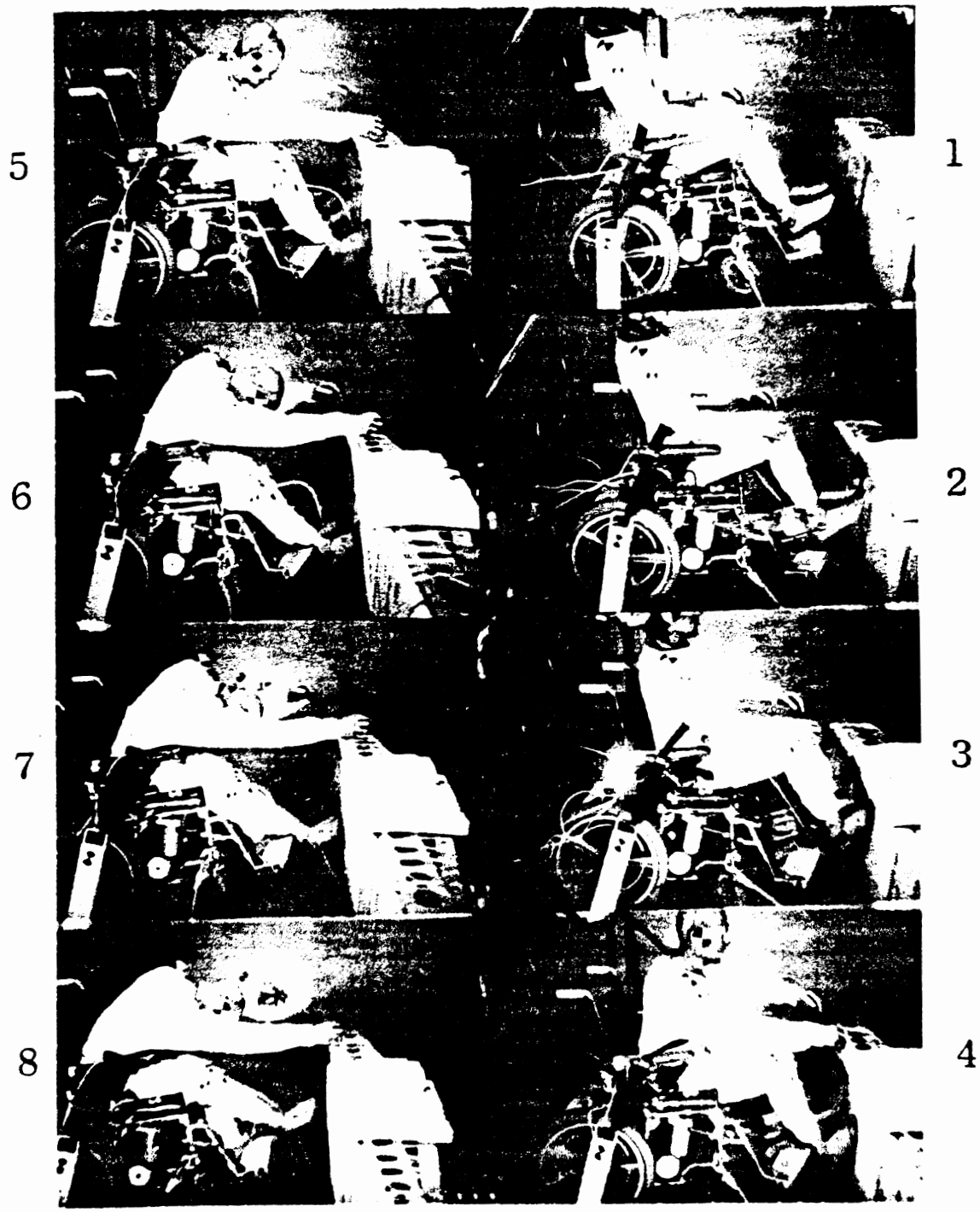




Set-Up Photos for Test 80M018



Post-Impact Photos for Test 80M018



80M018

Time Sequence Photo for Test 80M018

TEST NO.
80M019

Set-Up

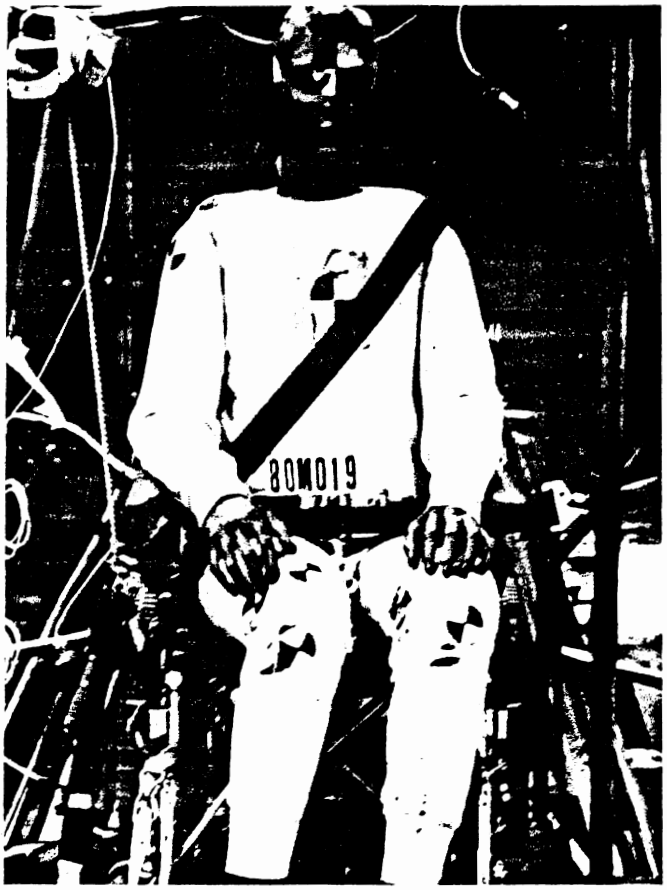
The wheelchair was restrained facing forward on the sled using three Aeroquip straps anchored to Aeroquip "G" tracks which were bolted to the van sheet metal with hardened 1/4" flathead screws at 1-1/2" intervals. Two 1/8" thick by 2" wide steel plates running the length of the "G" tracks were placed under the sheet metal to distribute loads. Two straps secured the chair from the rear by attaching to the rear frame posts just above the seat upholstery frame members and one strap attached to the right front frame post above the footrest fixture. The dummy was restrained by a lap belt to the chair back posts and a Bud passive restraint system used in conjunction with the Bud wheelchair arms.

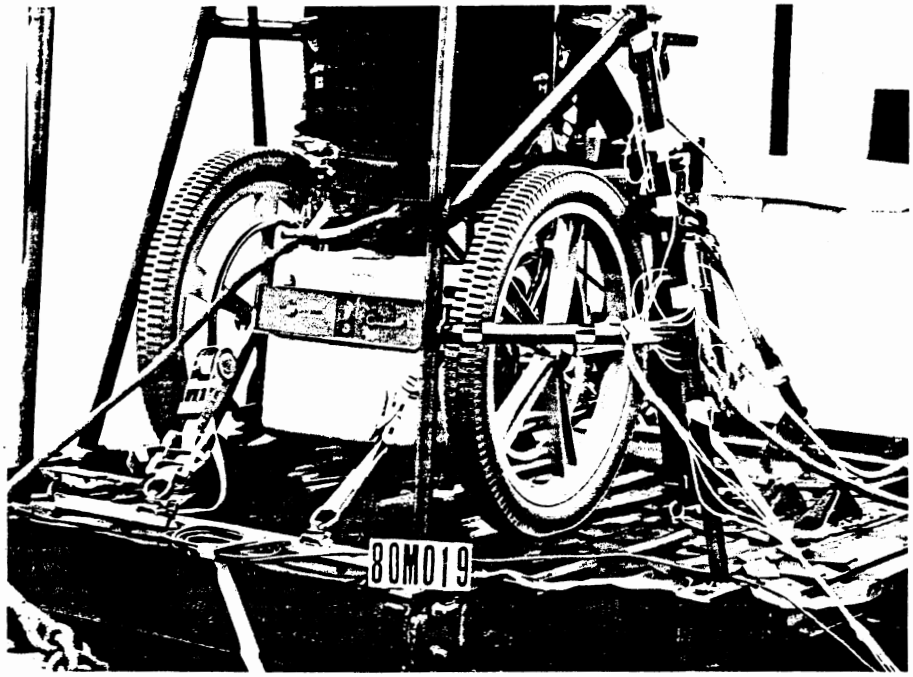
Results

Both rear Aeroquip plugs pulled out of the "G" track simultaneously due to fracturing of metal collars on the plugs. The Bud passive belt system provided good occupant restraint taking an extra load after the Aeroquip plugs released.

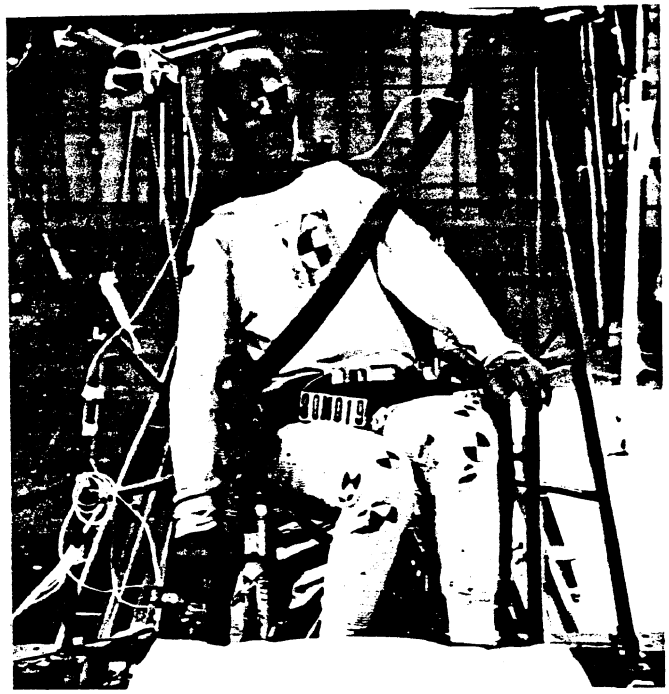
Peak Belt Loads (lbs)

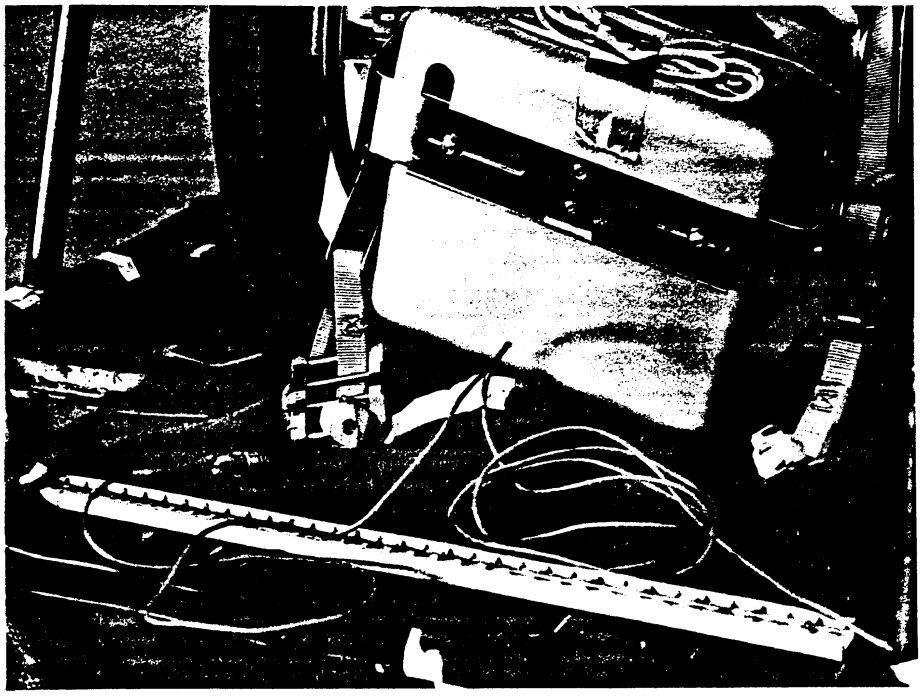
Passive shoulder	- 1750
Passive lap	- 640
Rt. floor passive belt	- 1750
Left rear aeroquip	- 3462



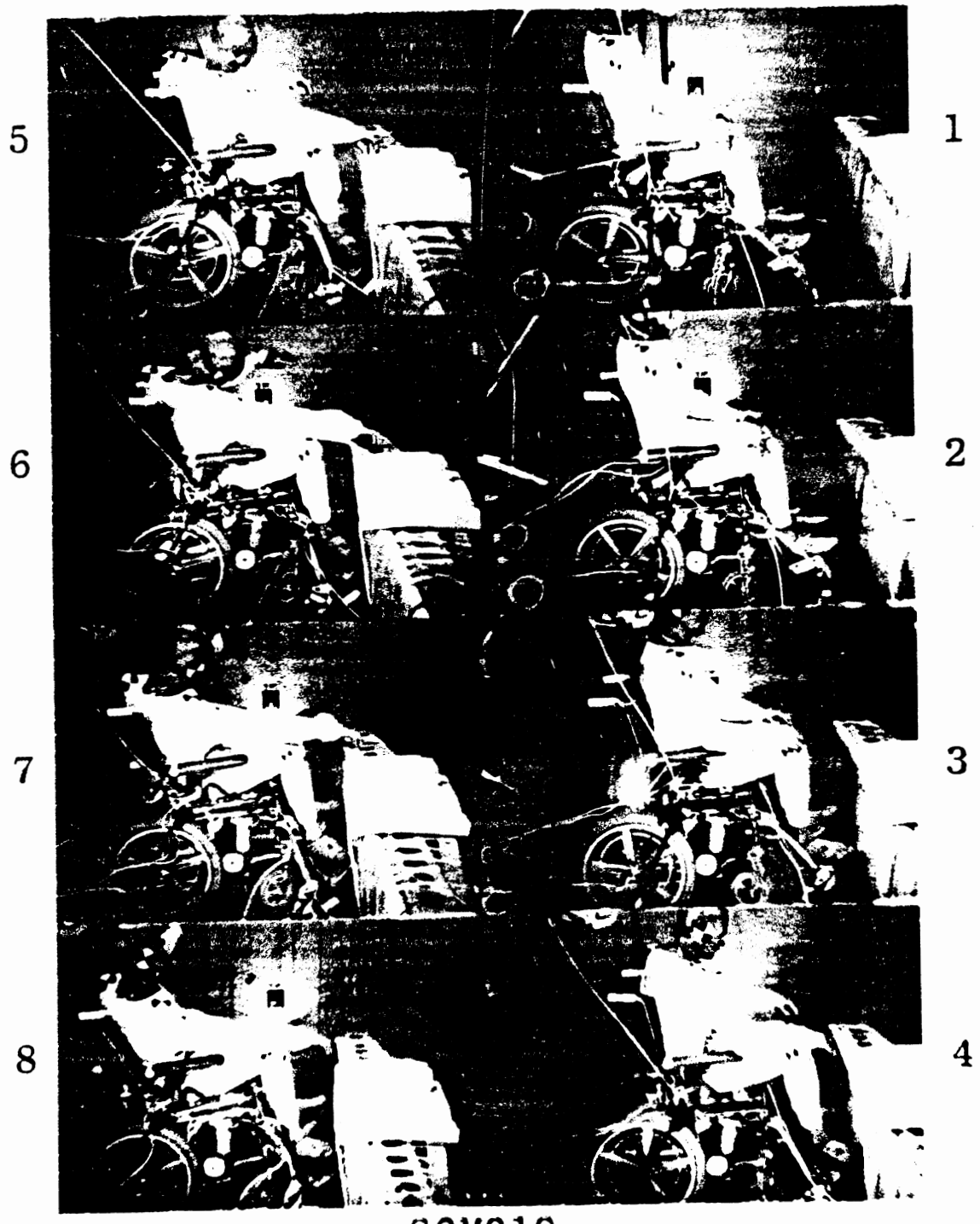


Set-Up Photos for Test 80M019





Post-Impact Photos for Test 80M019



Time Sequence Photo for Test 80M019

TEST NO.
80M020

Set-Up

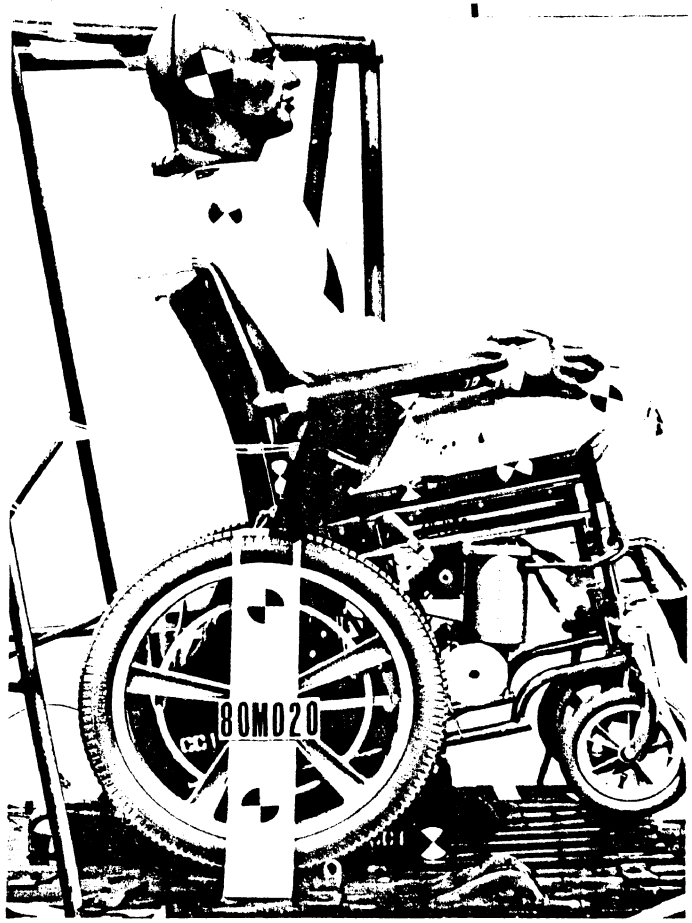
The wheelchair and dummy were restrained facing forward on the sled by the same tie-downs (CCI) and belt system (Falcon and lap) as used in test 80M018. The sheet metal was bolted to the sled more securely around the Falcon post and an angle bracket was used to replace the left shoulder anchor fixture and was welded securely to the simulated vehicle structure.

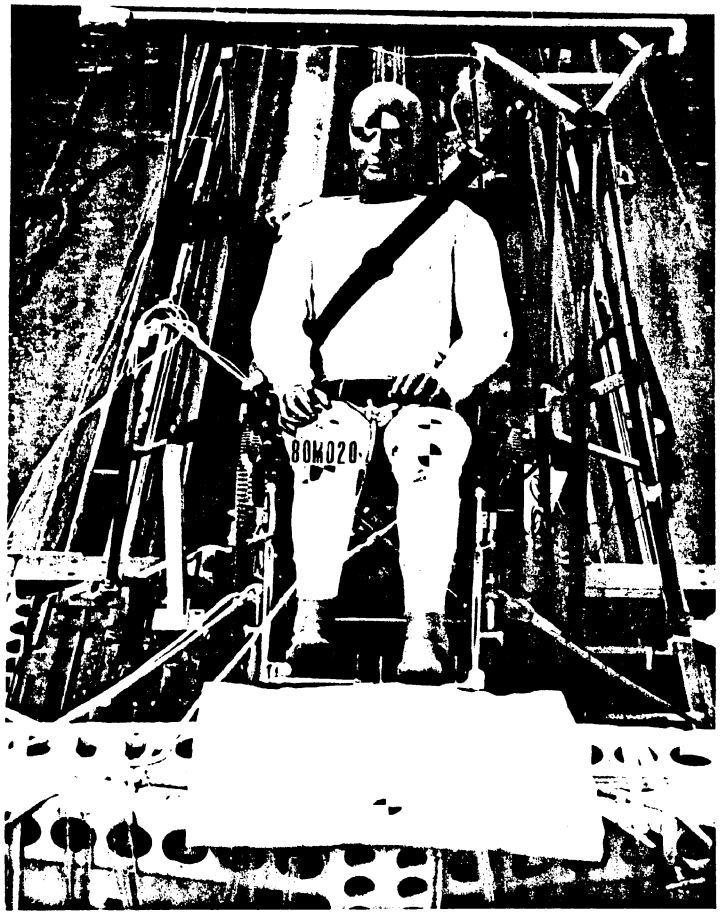
Results

This system provided excellent wheelchair and dummy restraint. The post leaned over slightly due to deformation of the sheet metal, but the upper torso restraint was still quite effective.

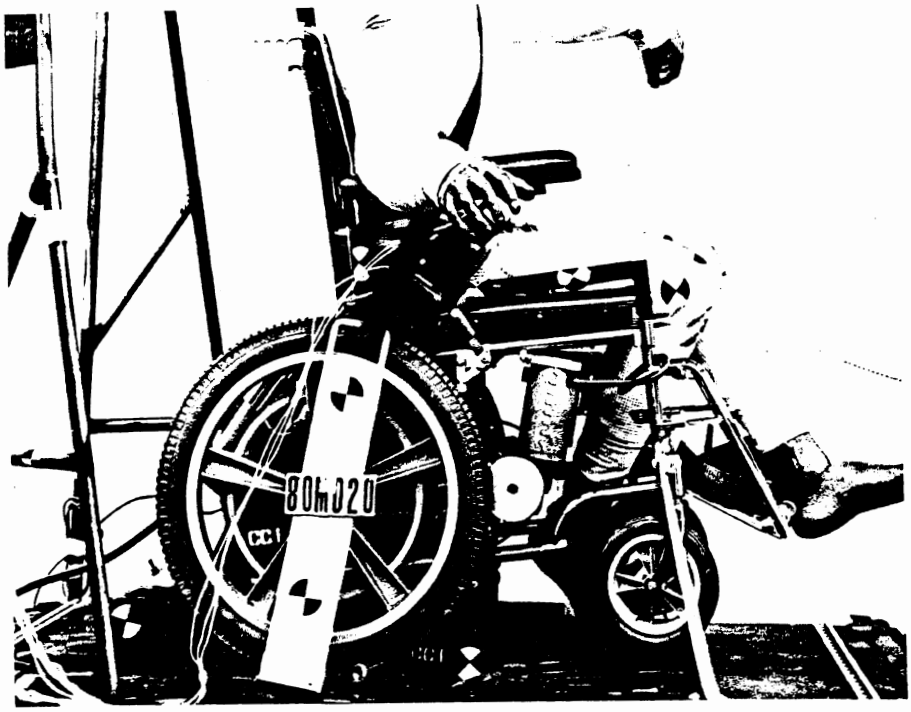
Peak Belt Loads (lbs)

Shoulder	- 1600
Right lap	- 900
Left lap	- 1300
Passive lap	- 640

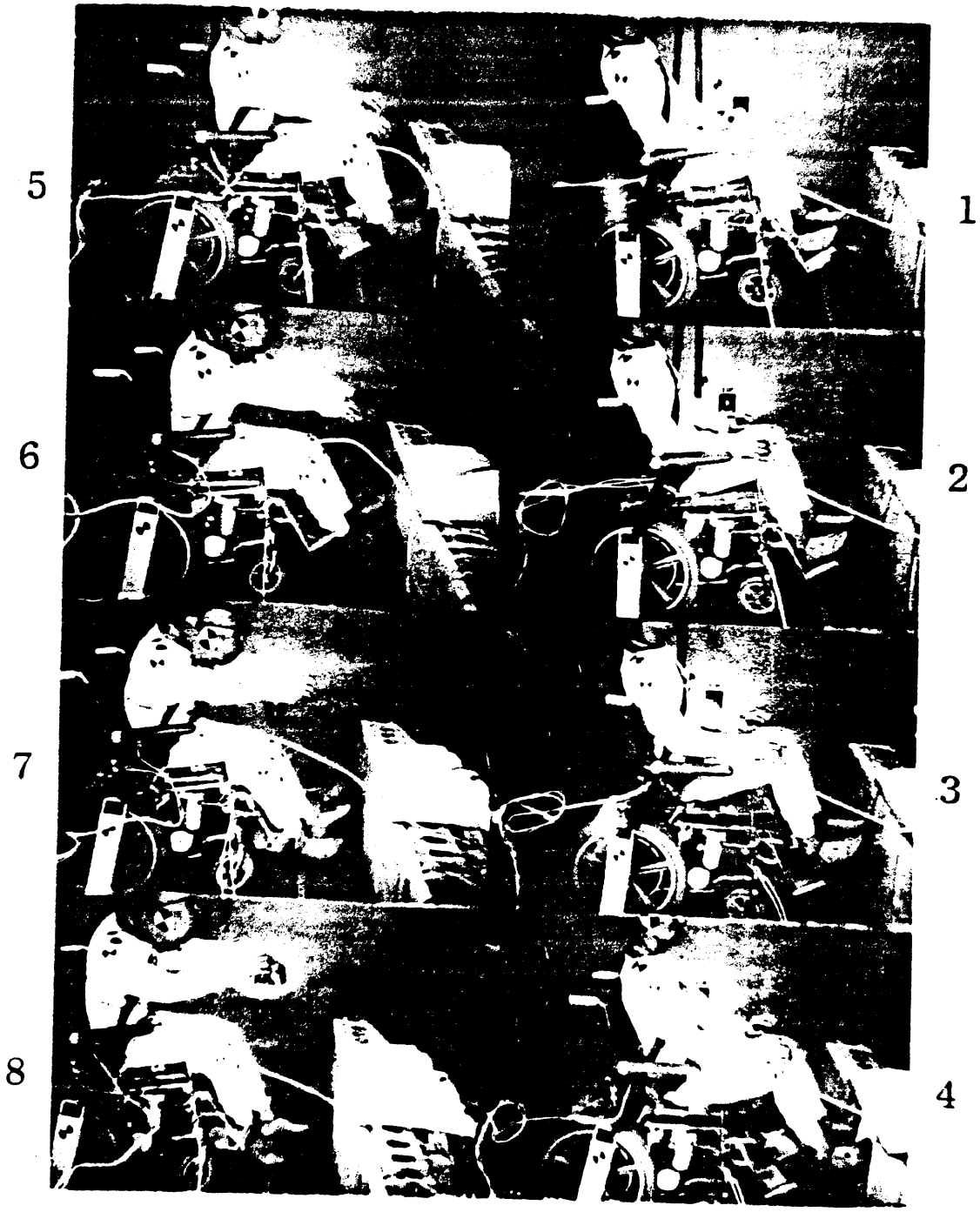




Set-Up Photos for Test 80M020



Post-Impact Photo for Test 80M020



Time Sequence Photo for Test 80M020

TEST NO.
80M021

Set-Up

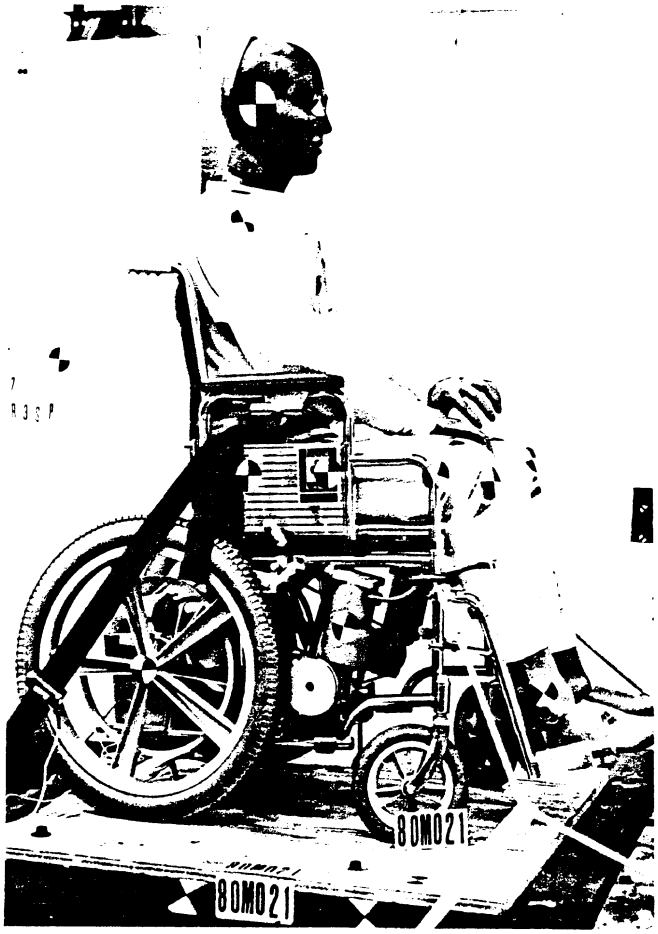
The wheelchair was restrained facing forward on the sled by a lap belt anchored to the floor using lift ring assemblies and a T-bar also fastened to the floor by a hook bolt and lift ring assembly. The set-up is the same as that for test 80M007 (minus the velcro chest belt) but all hardware were supplied from Target Industries. The T-bar nut was torqued down until substantial compression of the pneumatic tires was achieved.

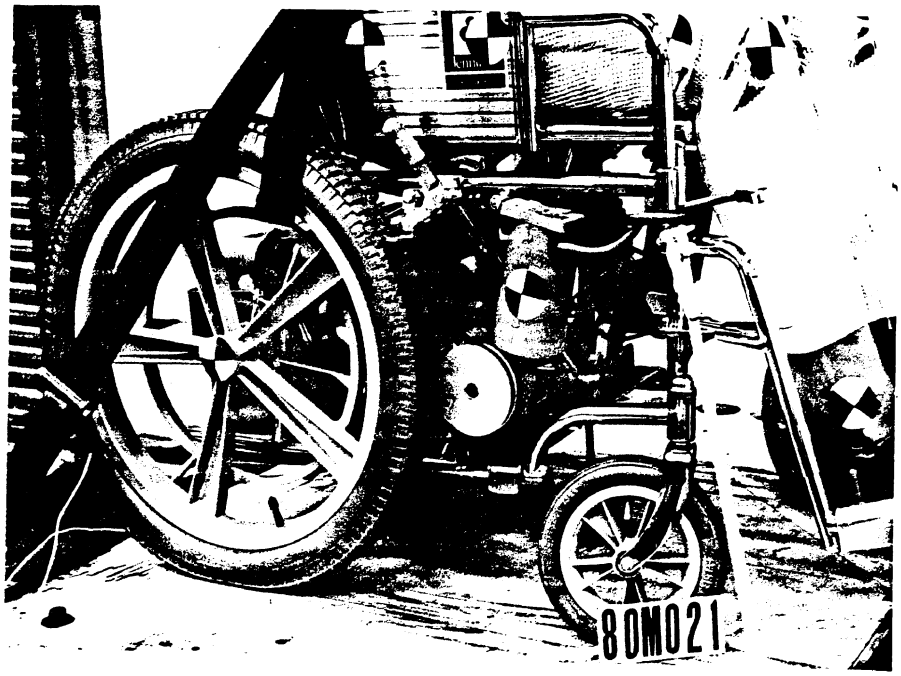
Results

All three of the lift rings broke at the sharp bend completely releasing the chair and dummy to impact into the padded front of the sled. After impact the dummy fell to the floor unrestrained. The wheelchair sustained little or no damage.

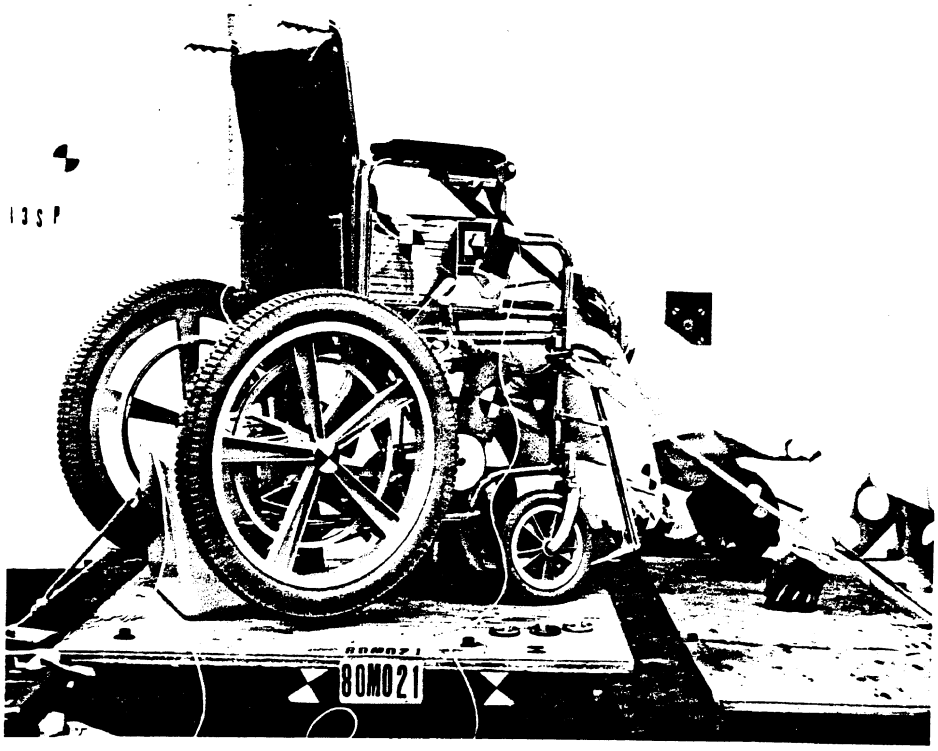
Peak Belt Loads (lbs)

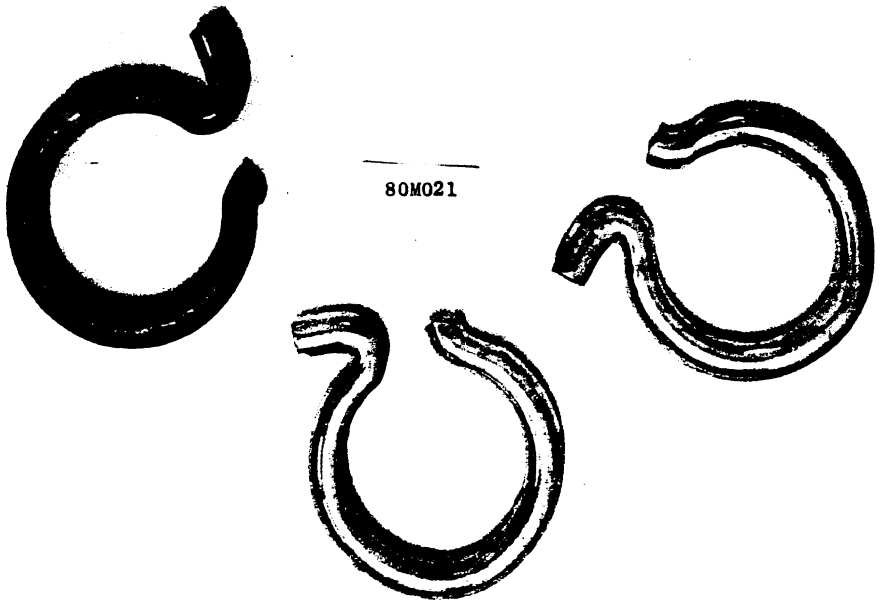
Left lap belt - 1000
Right lap belt - 1350





Set-Up Photos for Test 80M021





Post-Impact Photos for Test 80M021

Time Sequence Photo for Test 80M021

TEST NO.
80M022

Set-Up

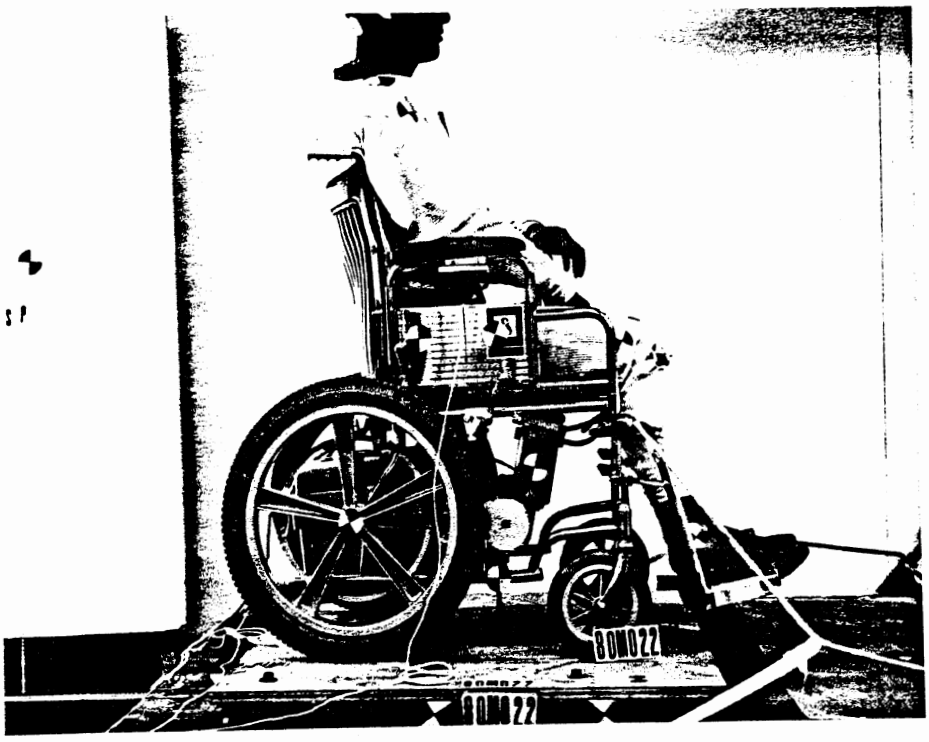
The wheelchair was restrained facing forward on the sled by a T-bar assembly from Target Industries. A heavy duty eye bolt replaced the lift ring assembly and the hook end of the hook bolt was welded closed around the eye bolt. The dummy was secured to the wheelchair by a lap belt attached to the back wheelchair posts. The T-bar was torqued down until substantial compression of the pneumatic tires was achieved.

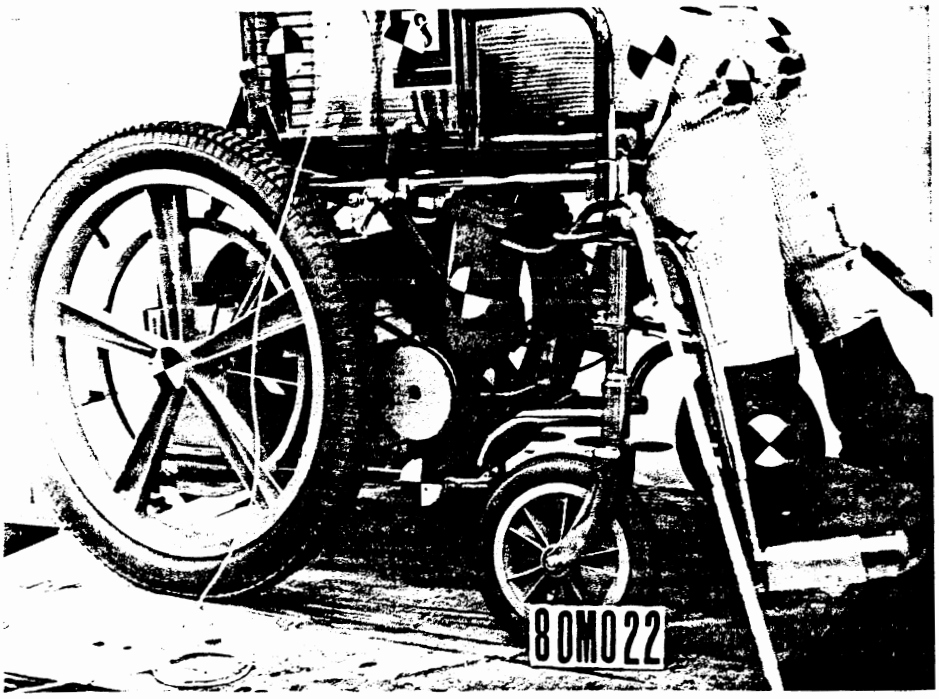
Results

The T-bar bent to nearly a ninety degree angle at the center slot where the hook bolt inserts. This released the chair and dummy to move unrestrained and impact into the padded front of the sled. The lap belt stayed fastened and held the dummy in the chair. After impact the chair and dummy were kept from falling off the back of the sled by tether ropes. The wheelchair frame sustained some significant bending near the front castor shafts and the lower horizontal frame members were dented and crimped from the T-bar.

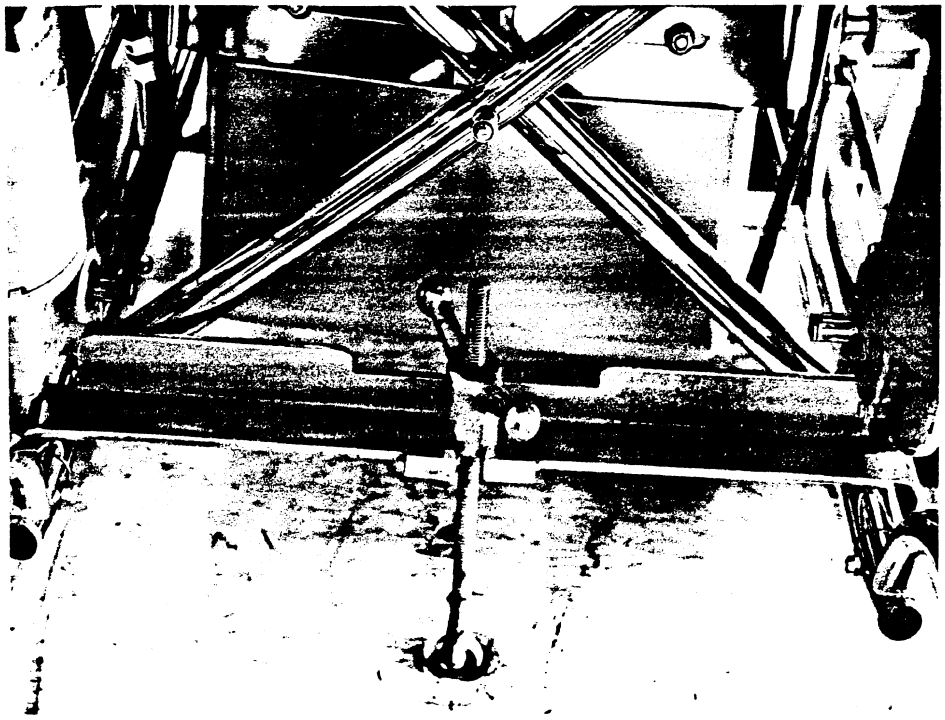
Peak Belt Loads (lbs)

Left lap - 150
Right lap - 125

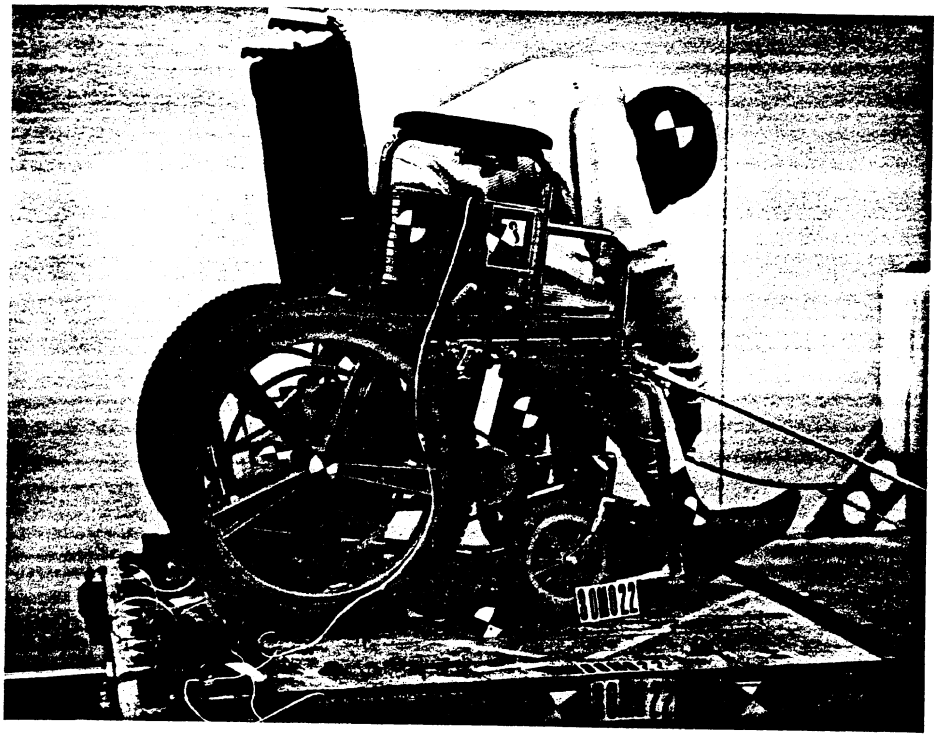




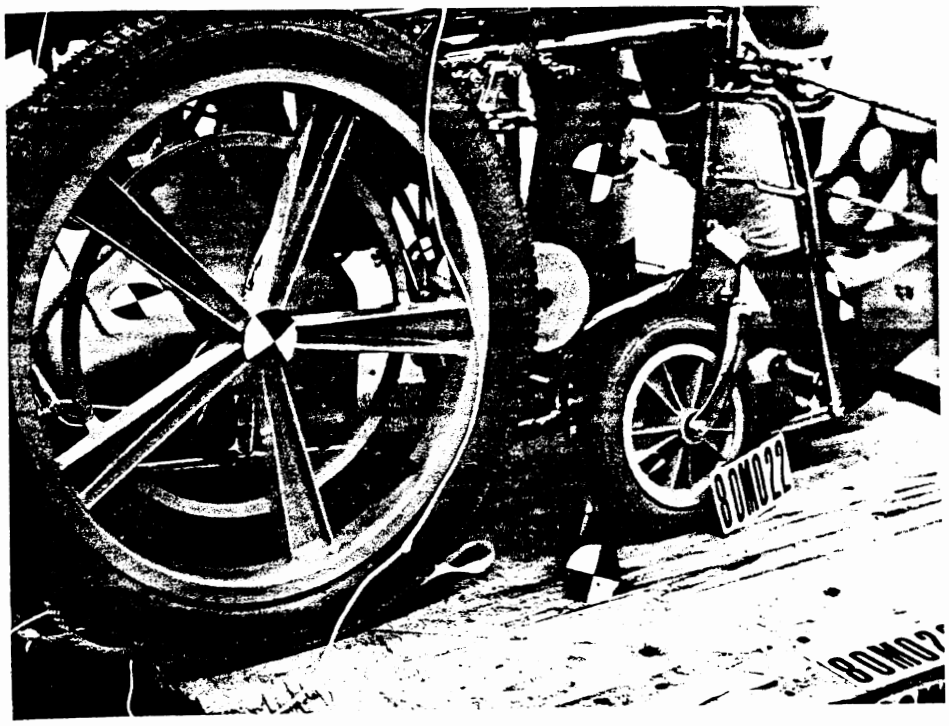
Set-Up Photos for Test No. 80M022

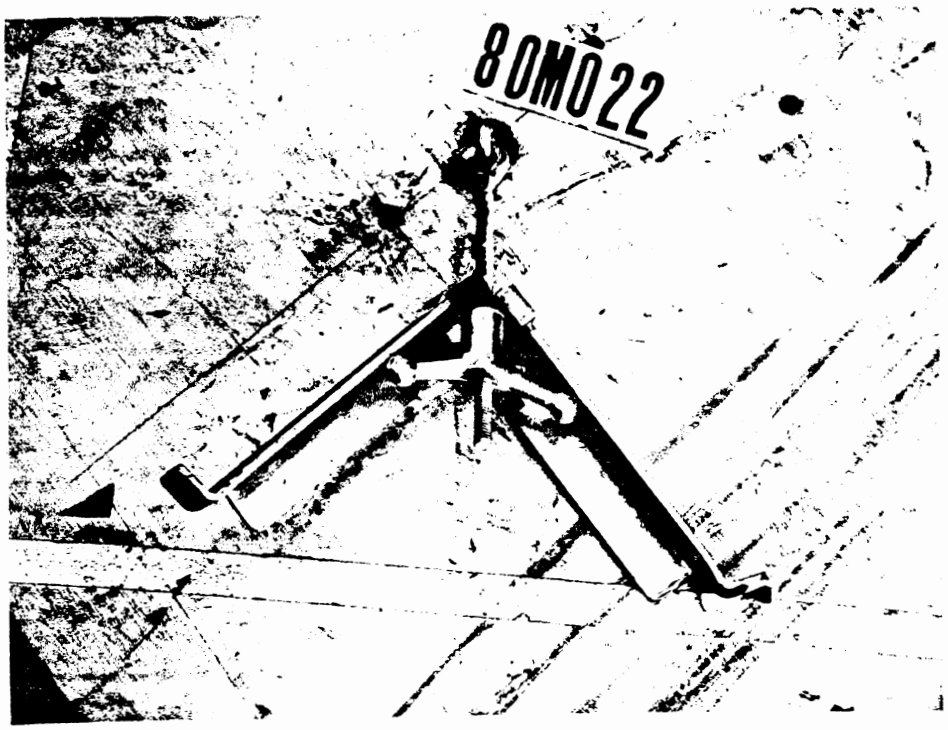


Set-Up Photo for Test 80M022



Post-Impact Photo for Test 80M022





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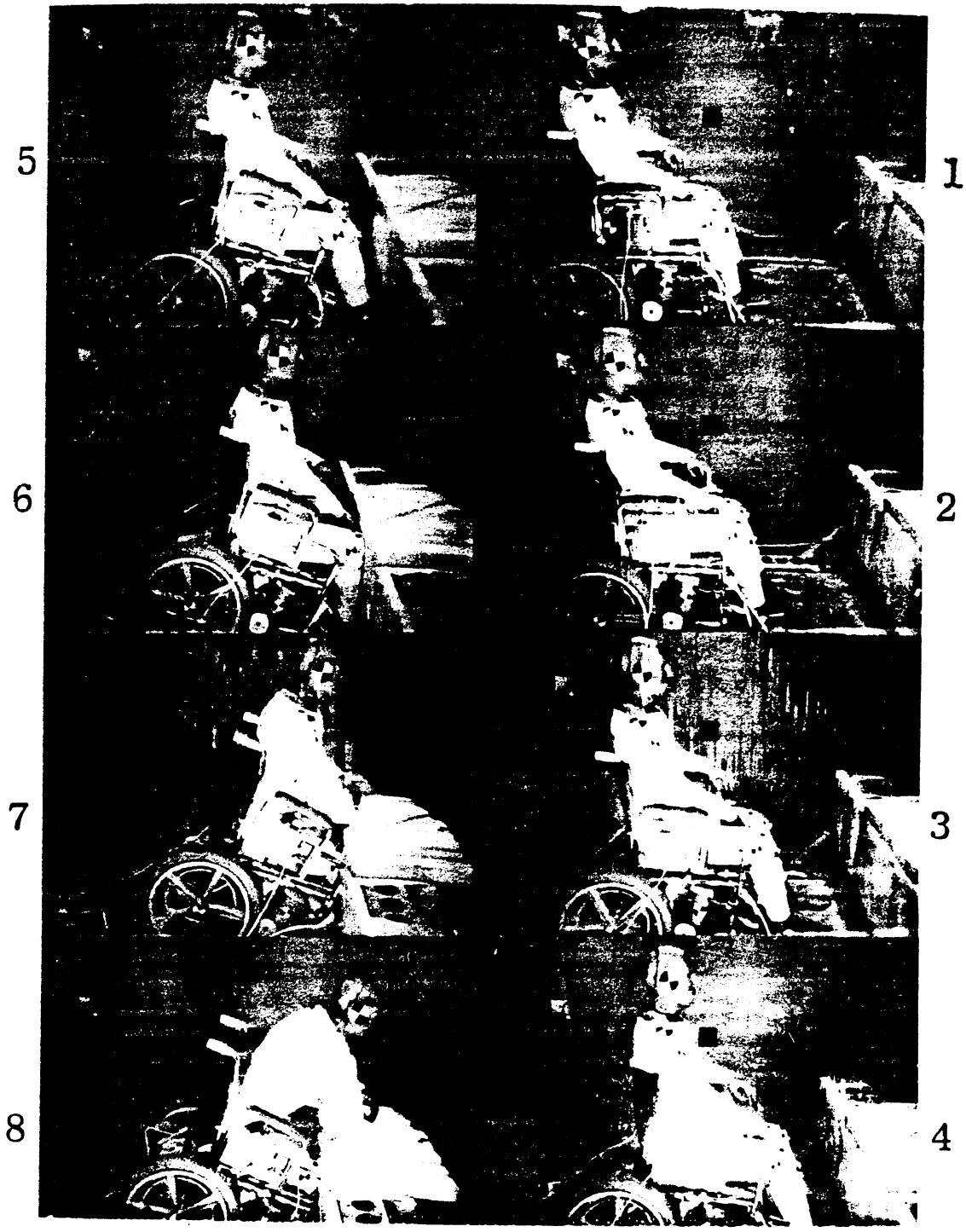

Time Sequence Photo for Test 80M022

IV. SUMMARY AND DISCUSSION

An essential requirement for providing effective crash protection for persons traveling in wheelchairs is that the wheelchair itself be adequately secured so that it will not move or break apart during an impact. For a power wheelchair and/or for situations where the occupant is belted either partially or totally to the chair, the load carrying requirements of the tie-down hardware can be substantial. From the results of these tests it is clear that none of the tie-down system hardware in current use by clients of the Massachusetts Rehabilitation Commission would restrain the wheelchair in even a moderate frontal crash situation and therefore these clients are currently driving at risk of serious injury in the event of an accident.

The lift ring assemblies currently in use for anchoring lap belts and T-bar bolts were simply not intended for forces generated by a 110 pound wheelchair in any kind of a crash. These are "off-the-shelf" trap door rings which can be purchased in most any hardware store. The weak point is clearly the sharp bend in the ring which appears to have been cold bent from a piece of standard rod. Replacement of these ring assemblies by heavy duty eye bolts or some other strengthened hardware is essential for wheelchair restraint and occupant protection.

The adjustable T-bars provided by Bud Industries and the T-bar supplied by Target Industries also do not have the strength needed to hold up under impact. The maximum bending moment is at the center of these bars which is also the weakest point because of the hole or slot for the hook bolt. The fixed length Bud

Industries T-bar which is constructed of a 1" square steel extrusion does appear to have good strength but in test 80M014 where this was used the hook bolt straightened out and released the T-bar. Thus, the hook bolts provided by these manufacturers are also inadequate for the forces generated in an impact.

Because of hardware failures none of the tests conducted to date have successfully investigated the concepts of the T-bar and/or lap belt to floor procedures for wheelchair tie-down. Some points and observations can be made however.

The use of a lap belt to floor as a restraint for the wheelchair and occupant violates one of the main principles of effective restraint design: to secure the seat independent of the occupant. By restraining the chair through a belt placed around the occupant, unduly high loads are placed on the occupant which are likely to result in serious injury especially if the belt rides up off the pelvic bone and onto the soft abdomen. Even if this were not a problem, however, the lap belt only provides restraint for forward motion. The chair is free to move rearward and, as indicated in test 80M001, even the low level sled acceleration of less than .5 G will cause the chair to slide with the brakes applied.

The T-bar approach to restraint, even with good hardware, is also questionable. Not only is the T-bar difficult to get in position and torqued down, especially on a powered wheelchair, but it provides restraint only through friction forces on the slippery steel tubing of the wheelchair frame. Positive securement will only occur when the wheelchair has moved far enough forward for

the T-bar to interact with the motor brackets or tubular cross bars. Whether these structures would provide sufficient resistance to restrain the chair is not yet clear but significant wheelchair damage and motion would probably result before the impact event was over. Also the degree to which the T-bar is tightened down by a driver or attendant will be variable and this will also influence the performance. In addition, frequent use of this clamping down procedure will eventually result in deterioration and weakening of the wheelchair frame itself.

The power lock-down device also operates on the principle of restraint through friction and does even less to secure the wheelchair than the T-bar. Since this is used only on one side of the chair one could not hope for complete restraint even in a direct frontal impact. Since the bar presses on the lower frame member just forward of the curved rise in the tubing, the chair only needs to move a couple of inches before it is completely free. When the motor and cross bars interact with the bar it simply rotates out of the way even though the two mounting bolts on the power lock-down bracket are torqued to deform the washers. The addition of a wheelstop bar across the power pan and against the castor tires adds little or nothing to the restraint provided by this device. The power lock-down is a completely ineffective approach to providing wheelchair securement for impact or even emergency vehicle maneuvering or braking.

When the wheelchair is not restrained properly, the passive restraint belts cannot restrain the occupant effectively. Initial attempts to provide added wheelchair restraint by placing the lap

portion of the passive belt webbing in front of the wheelchair arms were ineffective due to high belt loadings which ripped the belt stitching or webbing material. Tying the webbing in a knot provided an effective means of attaching the floor belt to the metal ring in test 80M011 and then this procedure of placing the webbing in front of the wheelchair arms did improve the wheelchair forward restraint considerably. For an oblique impact, however, this procedure is likely to result in internal injuries to the occupant due to collapse of the chair arm tubing on one side as indicated in test 80M012.

The fact that effective chair restraint can be achieved without damage to the chair is illustrated by the results of test 80M009 in which the chair was effectively secured in place by two Aeroquip straps to the rear posts just above the seat upholstery support tubing. The forward facing Bud stanchion also provides a good means of securing a forward facing chair on frontal impacts. The use of this device in the side facing mode as in test 80M010 clearly indicates the problems of this orientation for the majority of moderate and severe vehicle impacts which are from the front and rear.

The most effective wheelchair restraint was provided by the Creative Controls, Inc. (CCI) automatic tie-down system in which triangular steel plates are attached to the wheelchair side frames and steel cross bars between these plates provide the means for grabbing and supporting the wheelchair. These triangular plates also provide for convenient and well placed seat belt anchor points so that occupant generated seat belt loads are transmitted

to the tie-down platform without loading the wheelchair frame. When this tie-down system was used, both the Bud and ~~Target~~ Falcon nassive restraint belts were effective in providing complete occupant restraint. The Bud cantilevered chair arms were extremely beneficial in allowing the lap portion of these 3-point belt systems to rest on the pelvic region rather than on the abdomen above the chair arm rests. When bolting the CCI platform to sheet metal such as a van floor, it is essential to provide a steel backing plate to distribute the forces.

While the Aeroquip straps can provide an effective means of securing a wheelchair the metal collars on the "G" track plugs fractured in test 80M019 allowing the plugs to pull out and release the chair. The use of a stronger material for this collar should make this an effective manual tie-down procedure.

It should also be pointed out that for the Model 3P powered wheelchairs tested in this study, the containment and securement of the battery during frontal impacts did not present any serious problems. In no case did the battery box cover come off or did the battery itself come completely free of the gimbaled mounts.

V. CONCLUSIONS

1. Wheelchair tie-down systems currently in use by clients of the Massachusetts Rehabilitation Commission are inadequate to restrain a powered wheelchair in any kind of a moderate or severe vehicle accident.

2. The materials and hardware currently in use for securing wheelchairs are generally not of sufficient strength to withstand the forces generated in a crash. The wheelchair, on the other hand, has sufficient strength to be secured if tie-downs are placed at appropriate points.

3. Wheelchair tie-downs which depend on friction forces to hold the chair in place are not adequate for effective wheelchair restraint.

4. Effective wheelchair restraint, independent of the occupant restraint, is essential for crash protection of persons traveling in wheelchairs.

5. The Creative Controls, Inc. wheelchair tie-down system provided excellent wheelchair securement in all tests for which it was used. The Aeroquip straps can provide good wheelchair securement for frontal impacts but the "G" track plugs need to be strengthened.

6. Passive belt systems by Bud and Falcon Industries offer good occupant restraint when used with a chair lap belt and when the wheelchair is effectively secured by other means. The stitching of the Bud system floor belt at the metal ring must be strengthened, however. The cantilevered chair arms by Bud Industries provide for improved placement of the passive lap belt over the bony pelvic region rather than the soft abdomen.