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

FINAL REPORT

to

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I. INTRODUCTION

The biomedical and biomechanics departments at the Highway Safety Research Institute (HSRI) has conducted a series of thirty sled impact tests of wheelchair tie-downs and wheelchair occupant restraint systems for the Massachusetts Rehabilitation Commission. This report describes the setup conditions and results of each of these tests.

II. PROCEDURES

All impacts tests were 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 60-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 approximately 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 160 lbs. Table 1 shows the matrix of thirty tests conducted under these 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. In test 80M029 triaxial head and chest accelerometers were used to measure resultant accelerations and compute head injury criteria (HIC).

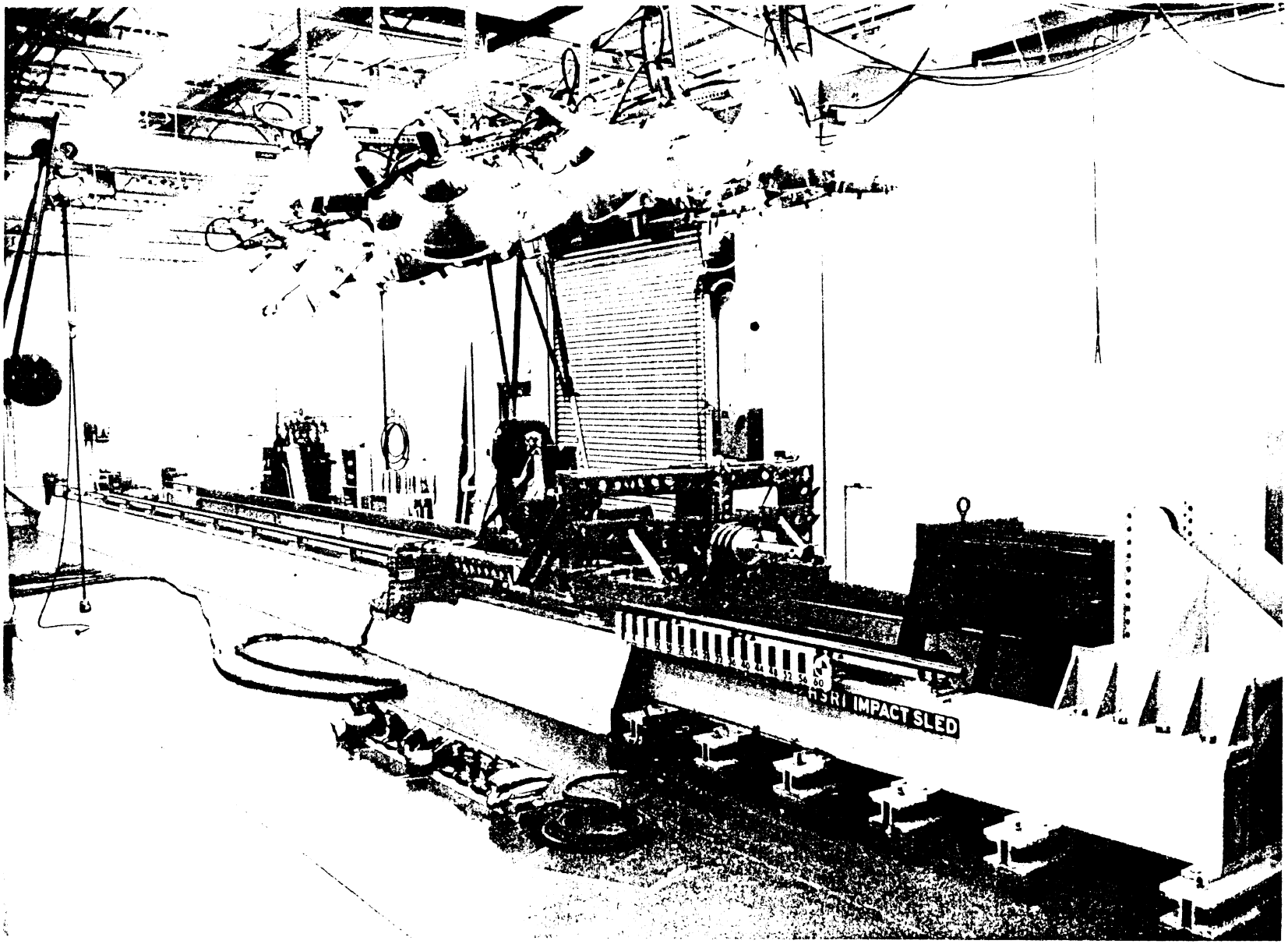

Figure 1. HSRI's Impact Sled Facility

TABLE 1

MATRIX OF TESTS

Test No.	Wheelchair Tie-Down	Occupant Restraint	Impact Direction	Page
30M001	Lap belt to floor via lift rings	Lap belt to floor plus velcro chest belt	frontal	4
30M002	Lap belt to floor via lift rings plus angle iron behind wheels	Lap belt to floor plus velcro chest belt	frontal	8
30M003	Bud adjustable T-bar to floor via lift rings	Velcro chest belt to chair back	frontal	12
30M004	Bud T-bar plus lap belt to floor via lift rings	Lap belt to floor plus velcro chest belt	frontal	16
30M005	Bud power pan and power lock-down	Lap belt to chair	frontal	21
30M006	Bud power pan and power lock-down	Bud passive belt (roof to floor) plus lap belt to chair	frontal	25
30M007	Bud power pan and power lock-down plus lap portion of Bud passive belt in front of chair arms	Bud 3-point belt (floor mount) plus lap belt to chair	frontal	29
30M008	Same as 30M007 except webbing of passive floor belt bolted at metal ring	Same as 30M007 except webbing of passive floor belt bolted at metal ring	frontal	33
30M009	4-point Aeroquip tied to sled	Bud 3-point belt plus lap belt to chair	frontal	37
30M010	Bud power pan and power lock-down plus bar wheel stop	Bud 3-point belt with webbing tied to metal ring plus lap belt to chair	frontal	41
30M011	Bud power pan and power lock-down plus lap portion of passive belt in front of chair arms (webbing tied at metal ring)	Bud 3-point belt plus lap belt to chair	frontal	45
30M012	Same as 30M011	Same as 30M011	45°	49
30M013	Bud T-bar (smaller adjustment holes) to floor via eye bolt	Lap belt to chair plus velcro chest belt	frontal	54
30M014	Bud fixed length T-bar plus lap belt to floor via eye bolt	Lap belt to floor plus velcro chest belt	frontal	59
30M015	Bud rim pin stanchion	Lap belt to stanchion	frontal	61
30M016	Two chairs in double rim pin stanchion	Lap belt to stanchion	side	65
30M017	CCI tie-down to sheet metal	Bud 3-point belt system plus lap belt to triangles	frontal	71
30M018	CCI tie-down to sheet metal	Falcon 3-point belt system plus lap belt to triangles	frontal	75
30M019	3-point Aeroquip straps to "G" track fastened to sheet metal	Bud 3-point belt system plus lap belt to chair	frontal	79
30M020	CCI tie-down to sheet metal	Falcon 3-point belt system (improved anchor welds) plus lap belt to chair	frontal	83
30M021	Target T-bar plus lap belt to floor via lift rings	Lap belt to floor	frontal	87
30M022	Target T-bar to floor via hook bolt welded closed on eye bolt	Lap belt to chair	frontal	91
30M023	CCI retrofit with Bud power pan	Bud 3-point passive belt plus lap belt to CCI triangles	frontal	105
30M024	Same as 30M023	Same as 30M022	45°	111
30M025	CCI retrofit with adjustable triangles and Bud power pan	Same as 30M023	frontal	115
30M026	Same 30M025	Bud 3-point belt only	frontal	119
30M027	Same as 30M026	Same as 30M026, floor belt strengthened	frontal	123
30M028	Non-tilt CCI bolt-down platform	Bud 3-point passive belt plus lap belt to CCI triangle	frontal	127
30M029	Same as 30M028	Same as 30M028	frontal 30mph,20G	131
30M030	Bud rim-pin staunchion	Lap belt to staunchion	side	137

*All tests for 20 mph, 16G impact except as noted.

III. RESULTS

The following pages describe and illustrate the test setups and results observed from films for each of the thirty tests conducted. 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

Setup

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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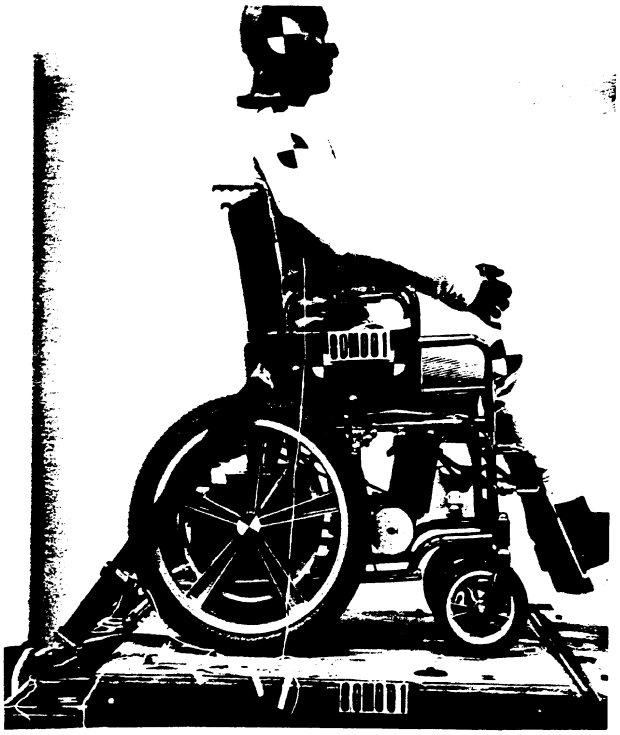
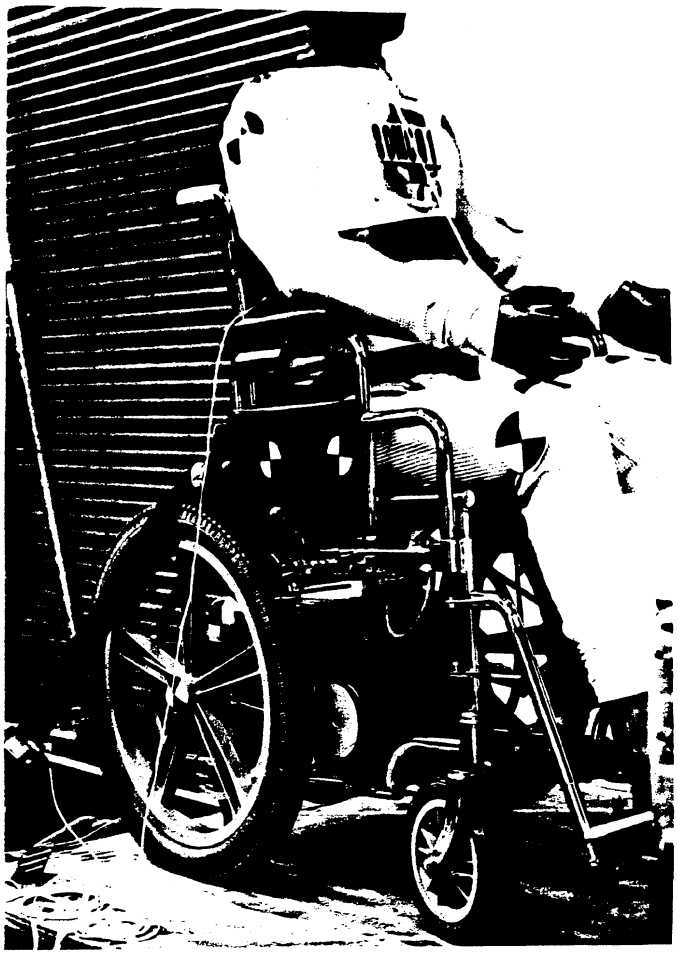
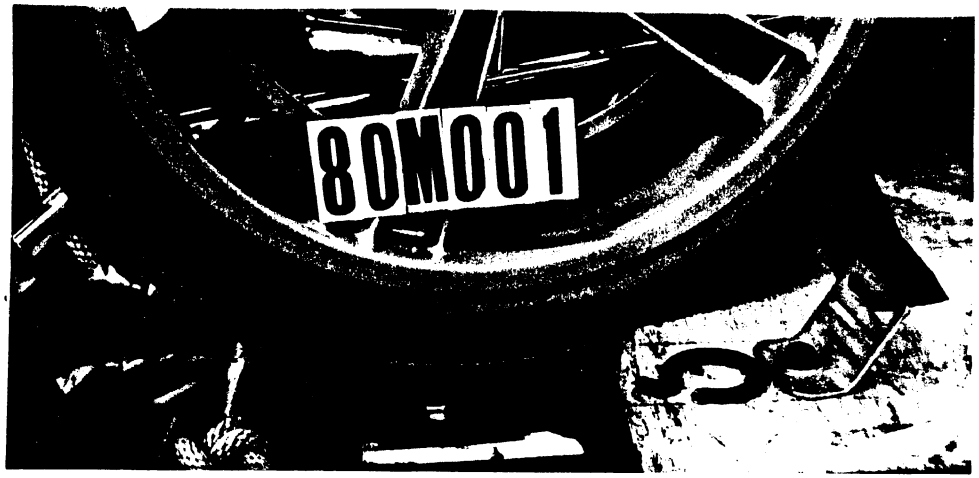
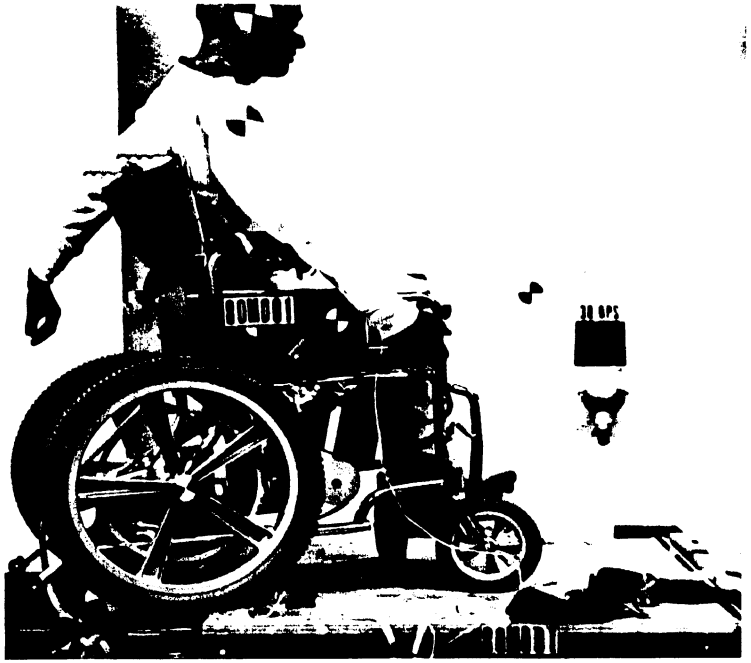
[1]Hereafter referred to as velcro chest belt.



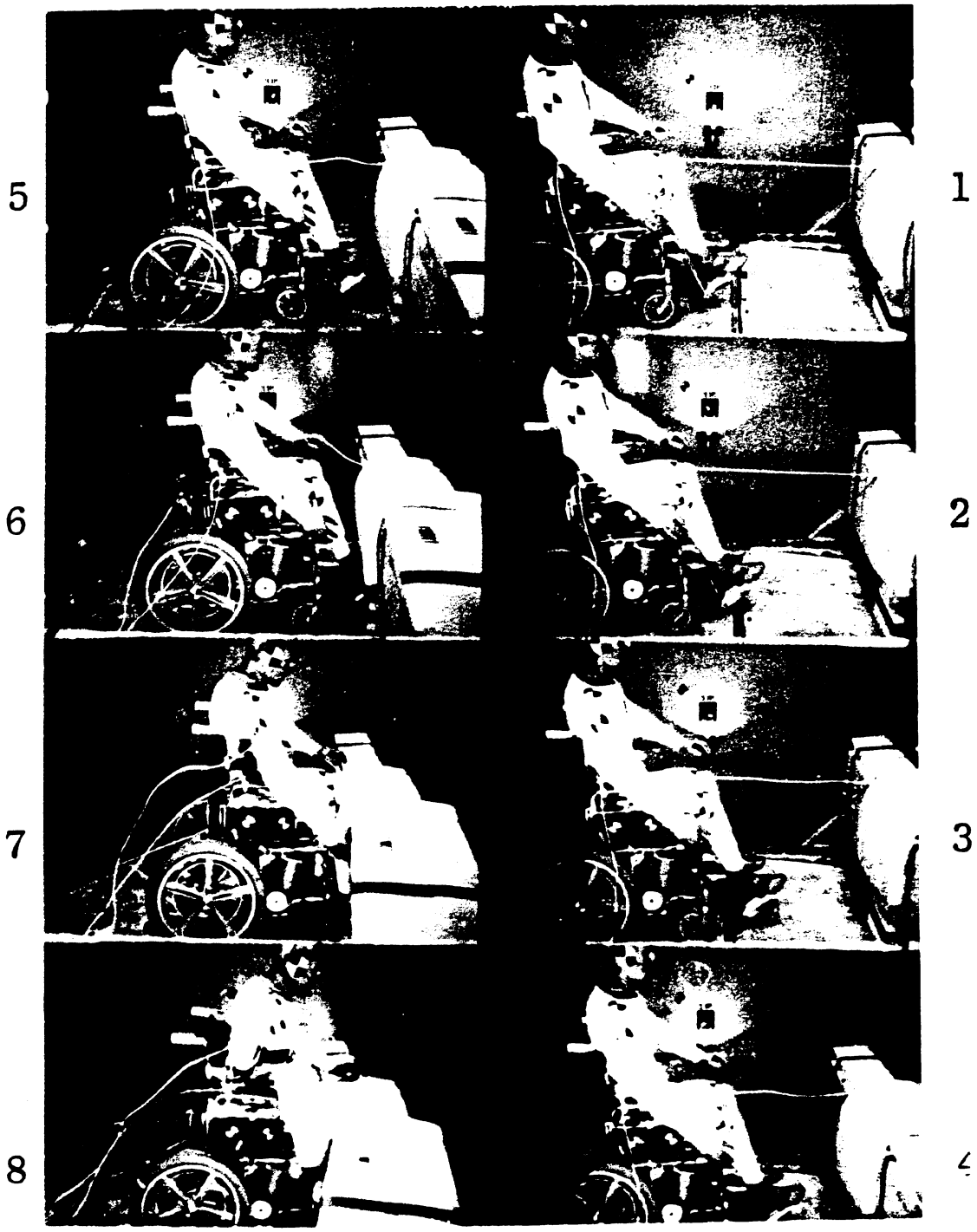


Set-up Photos for Test 80M001





Post-Impact Photos for Test 80M001



Time Sequence Photo for Test 80M001

TEST NO.
80M002

Setup

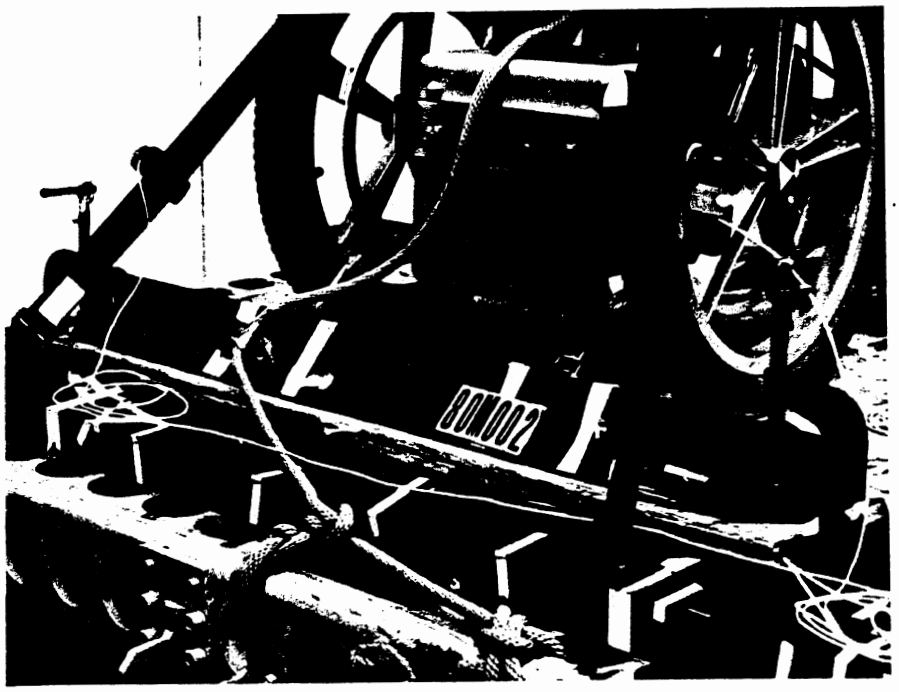
The wheelchair and dummy were secured facing forward on the sled in the same manner as test 80M001 by a lap belt around the dummy anchored to the sled by two lift ring assemblies. In addition, a steel angle was clamped to the floor behind the chair wheels to prevent backward movement of the chair during 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

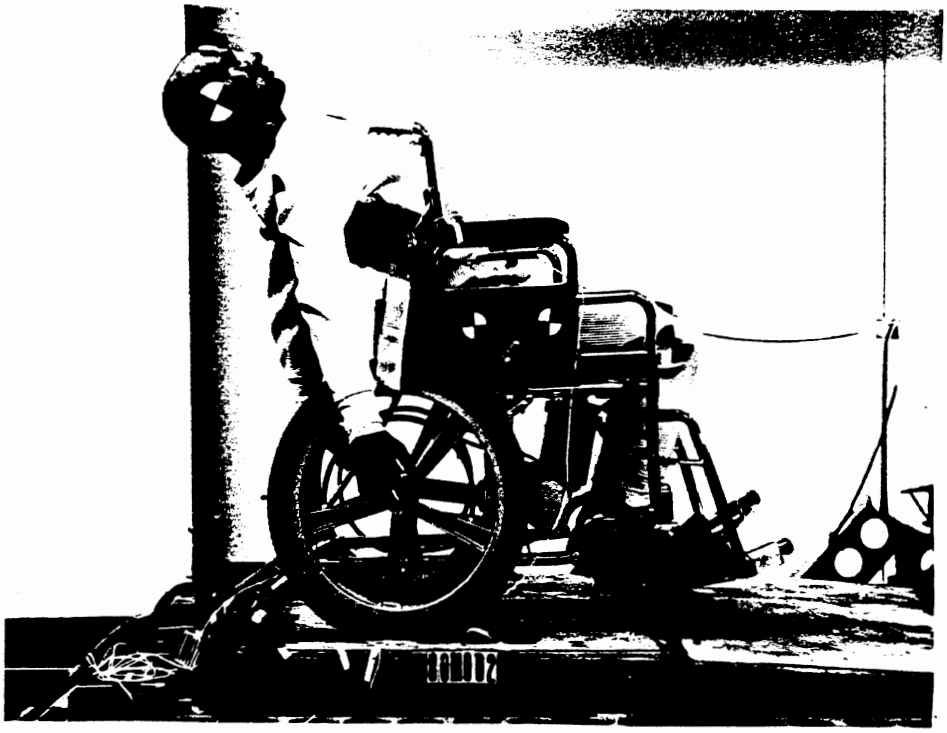
The chair did not move on sled acceleration and the lap belt remained taut until impact. Upon impact the ring of the left ring assembly broke at the sharp bend, releasing the chair and dummy, which moved forward and impacted with the padded front of the sled. The velcro belt released, allowing the dummy's 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.)

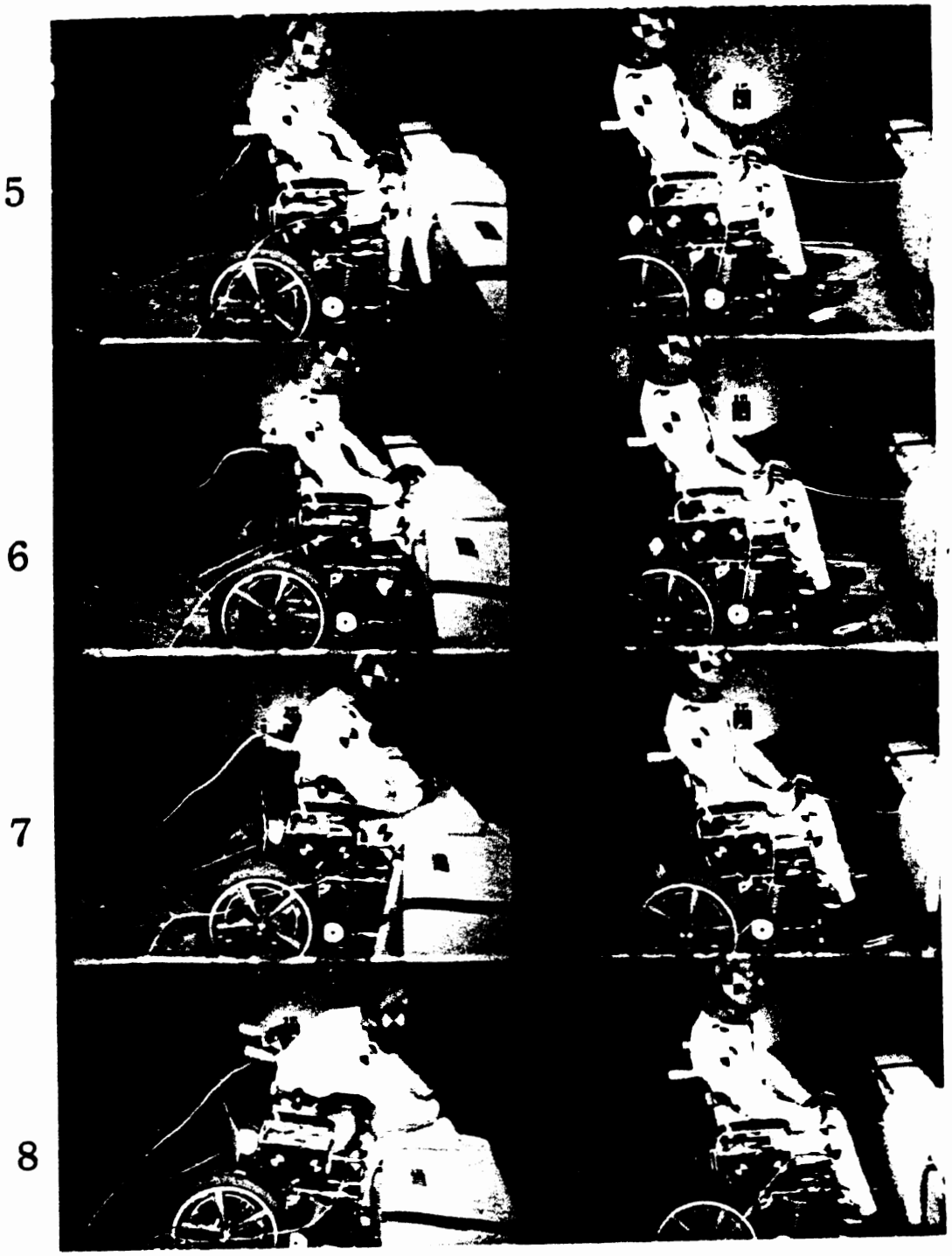
Left lap	- 1050
Right lap	- 900
Chest	- 200



Set-Up Photo for Test 80M002



Post-Impact Photos for Test 80M002



Time Sequence Photos for Test 80M002

TEST NO.
80M003

Setup

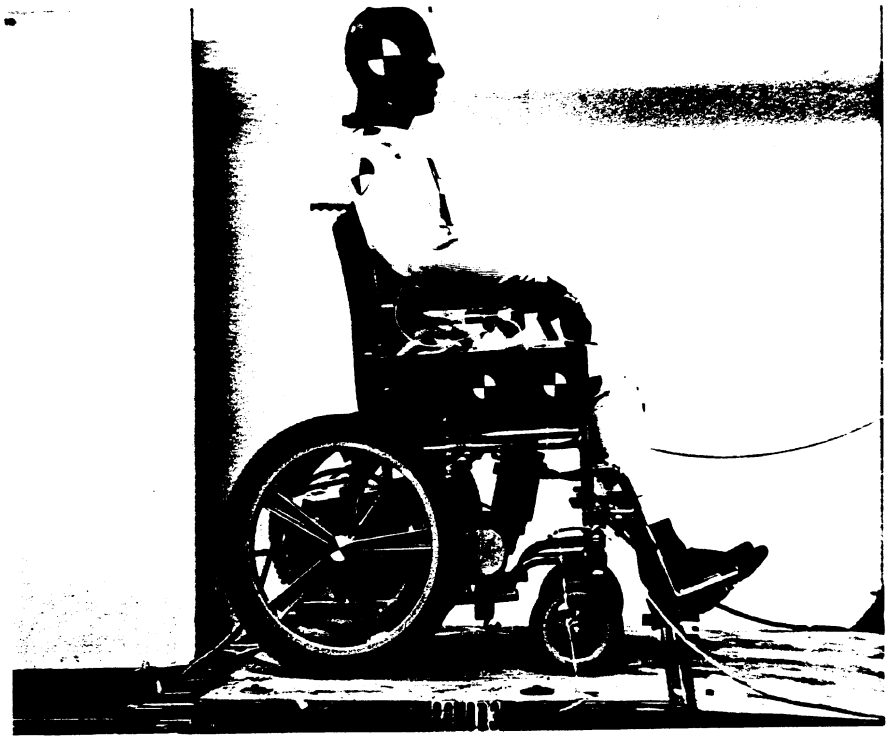
The wheelchair was secured facing forward on the sled by a Bud Industries adjustable T-bar placed across the lower horizontal frame members just behind the rising curved portion. A hook bolt through the center of the T-bar fastened to a lift ring assembly, which was bolted to the sled. The T-bar was 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

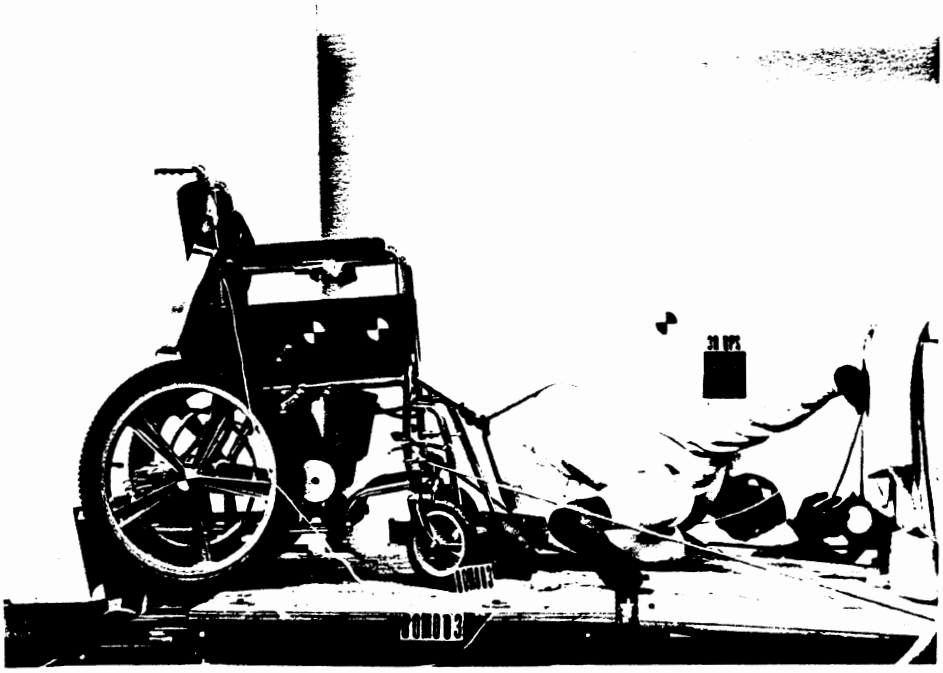
The ring of the lift ring assembly broke at the sharp bend, releasing the wheelchair to move forward into the padded front of the sled. The T-bar and hook bolt bent significantly and the velcro belt came loose, allowing the dummy to fall to the floor.

Peak Belt Loads (lbs.)

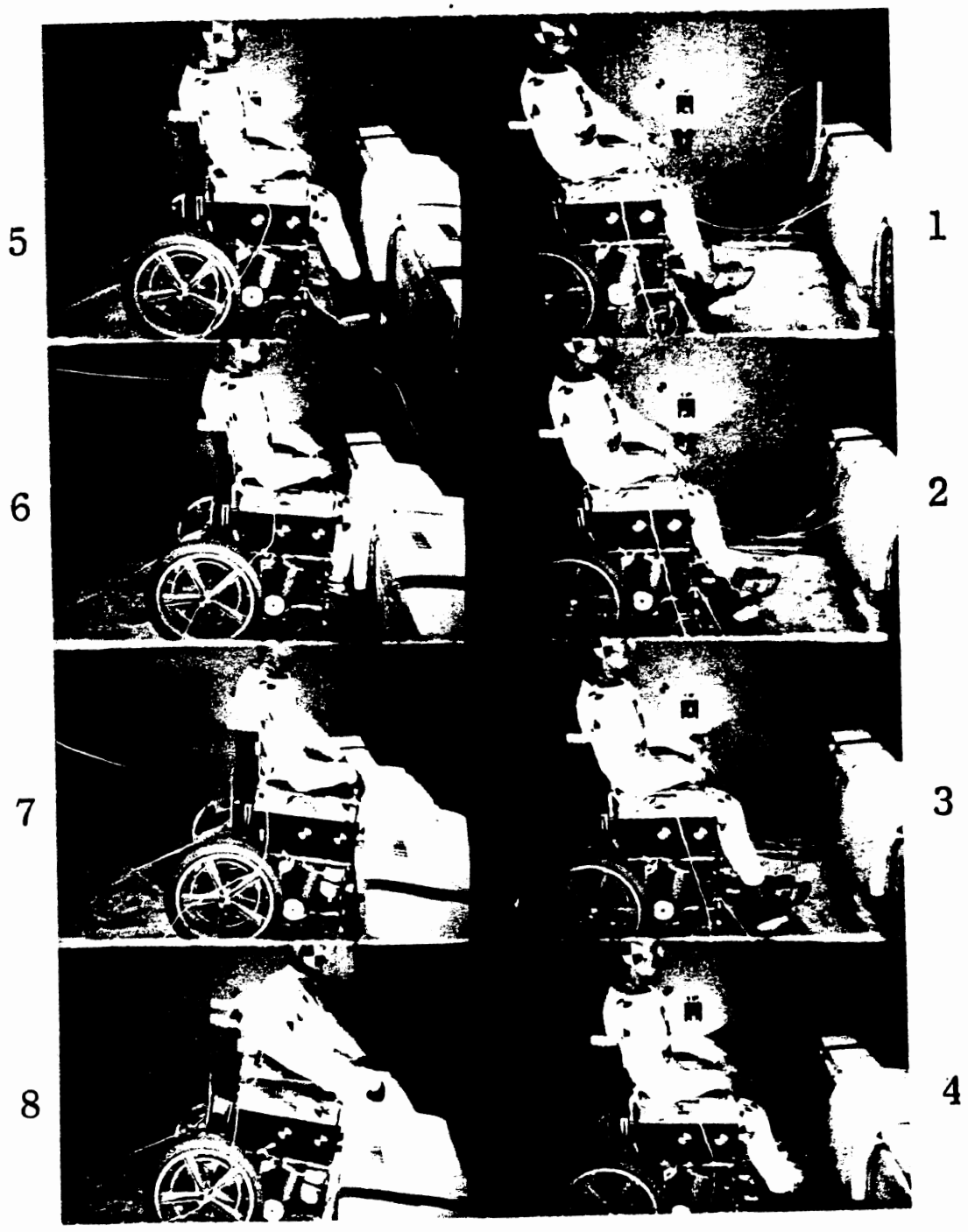
Velcro chest belt - 200



Set-Up Photos for Test 80M003



Post-Test Photos for Test 80M003



Time Sequence Photo for Test 80M003

TEST NO.
80M004

Setup

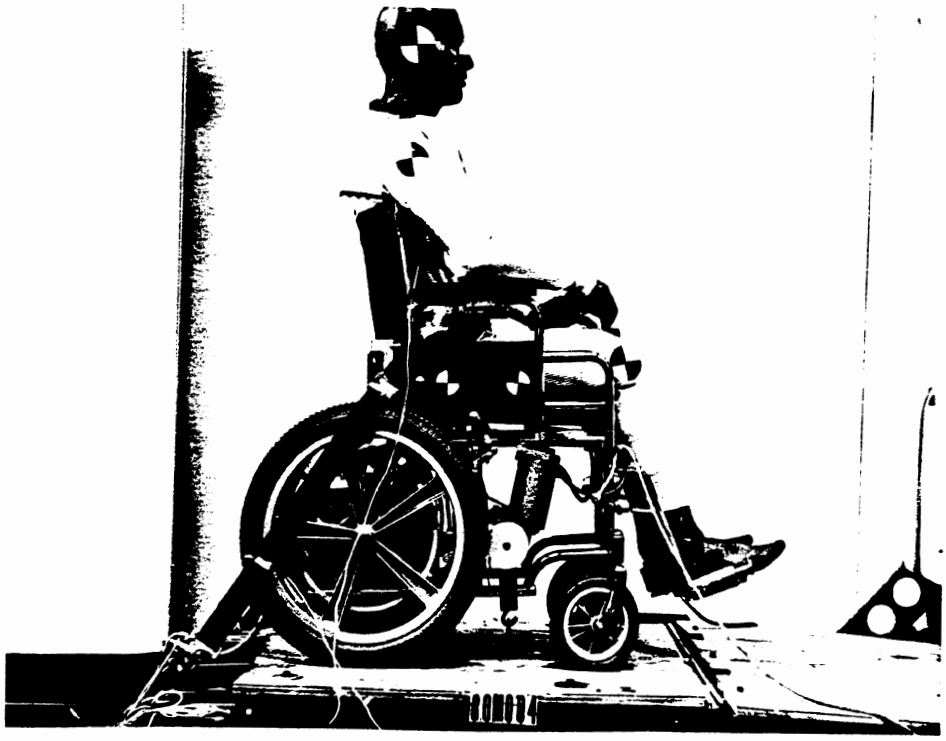
The adjustable T-bar described in test 80M003 and the lap belt to floor described in test 80M001 were used to secure the chair and dummy in a forward-facing direction. All three anchor points used lift ring assemblies to fasten to the sled. The dummy was also restrained by a velcro chest belt looped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

Results

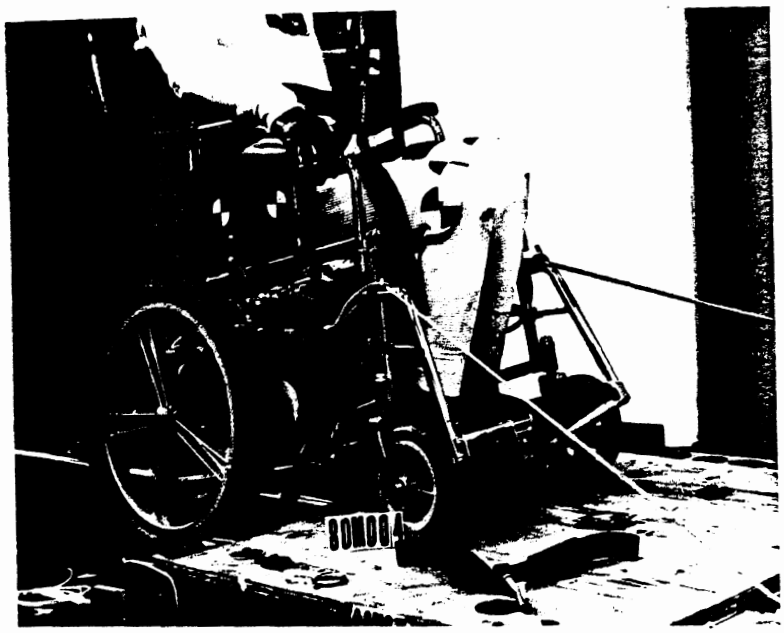
The rings from the lift ring assemblies securing the T-bar and one side of the lap belt broke at the sharp bends, allowing the wheelchair to move into the padded front of the sled. The T-bar itself bent and fractured, and the lap belt also unbuckled. Although the velcro on the chest belt held, the stitching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

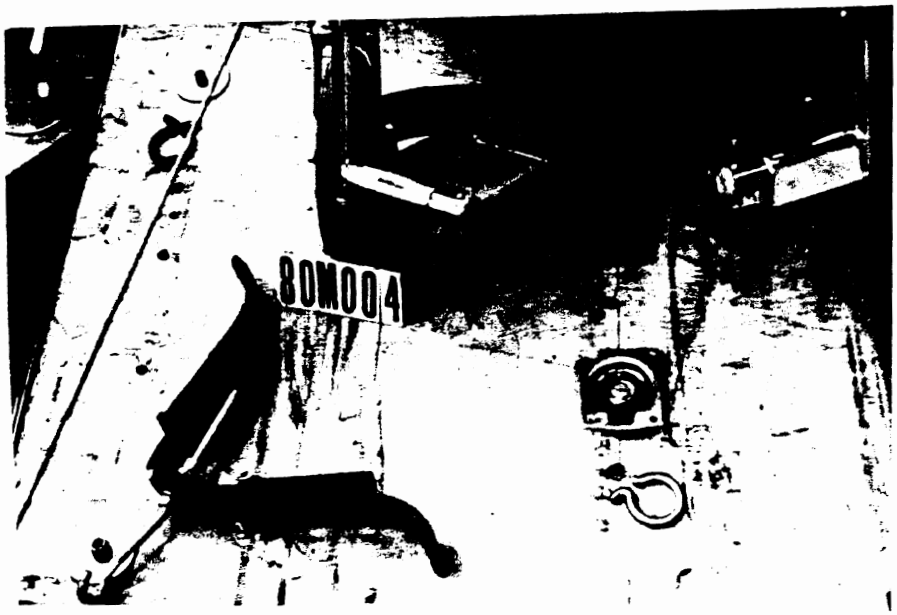
Peak Belt Loads (lbs.)

Left lap - 1150
Right lap - 1100



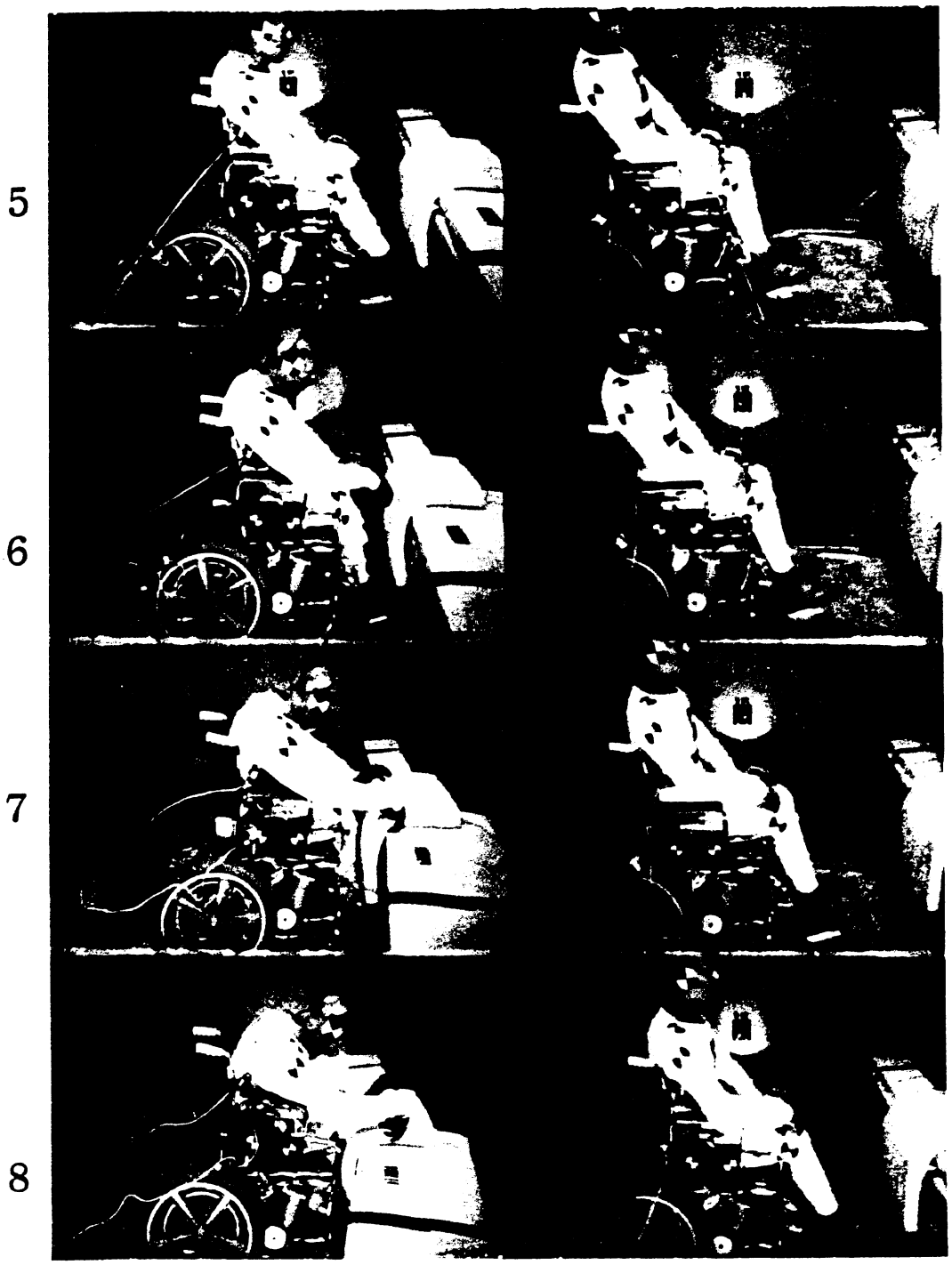
Set-Up Photos for Test 80M004





Post-Test Photos for Test 80M004

Post-Test Photo for Test 80M004



Time Sequence Photo for Test 80M004

TEST NO.
80M005

Setup

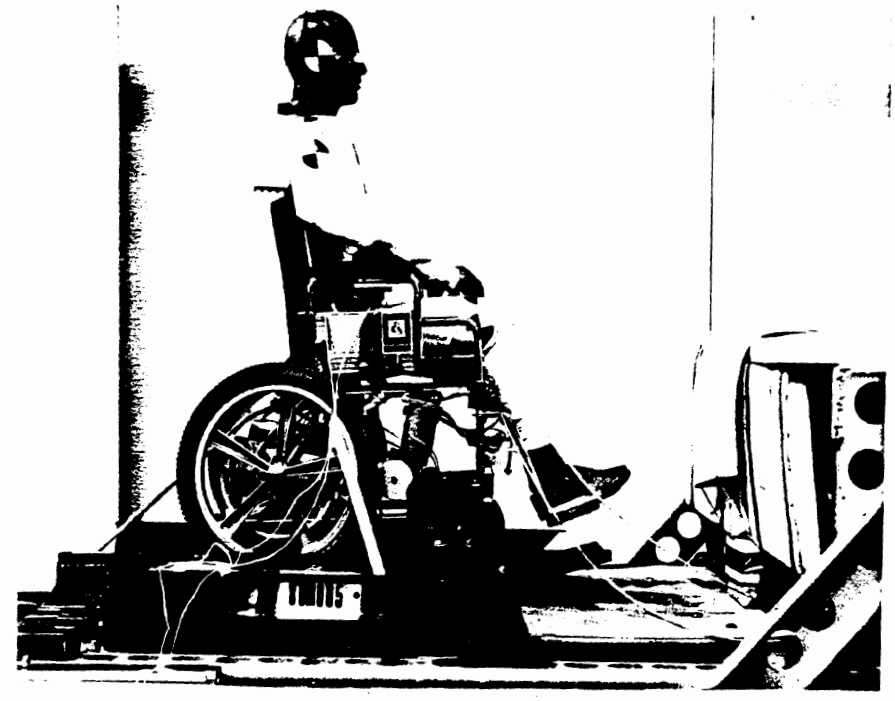
The forward-facing wheelchair was secured on the sled in the Bud Industries power pan by the Bud power lock-down pressing on the raised portion of the right lower horizontal frame member. The power lock-down was bolted to the sled using two bolts and washers provided by Bud Industries and tightened until significant deformation 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.

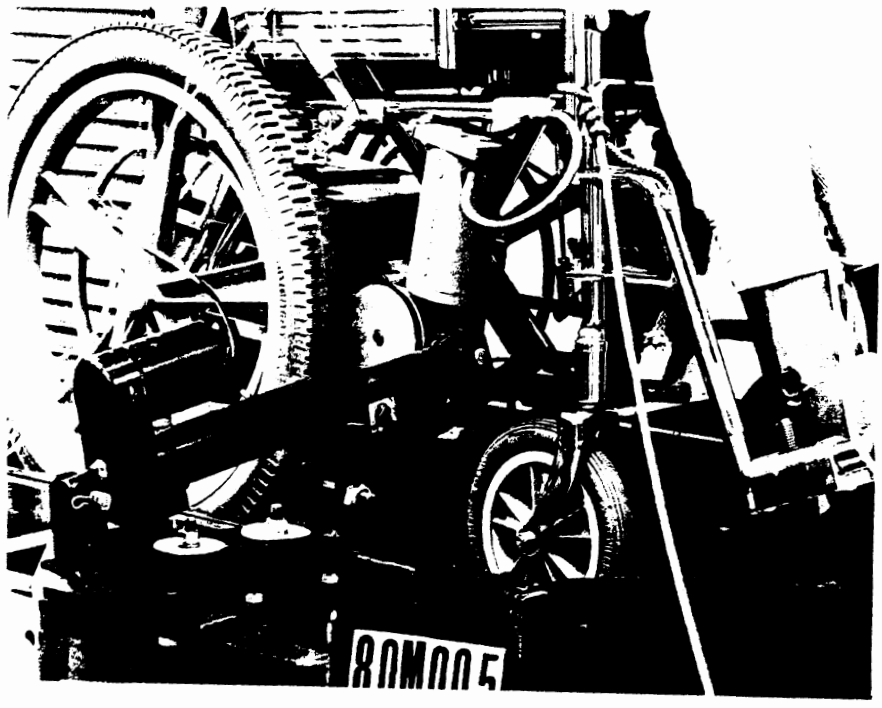
Results

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.

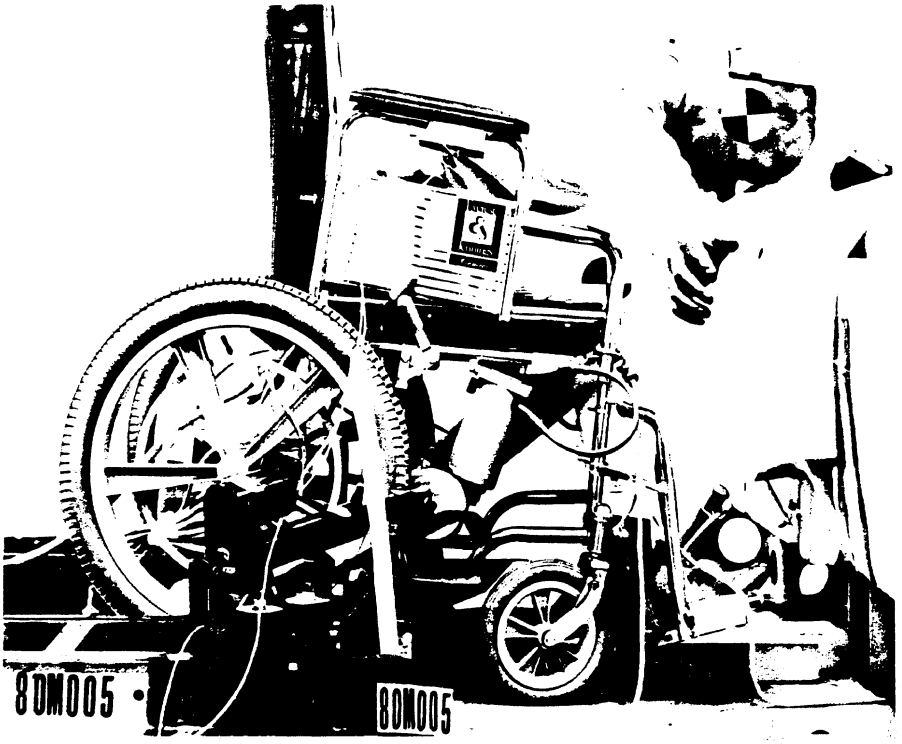
Peak Belt Loads (lbs)

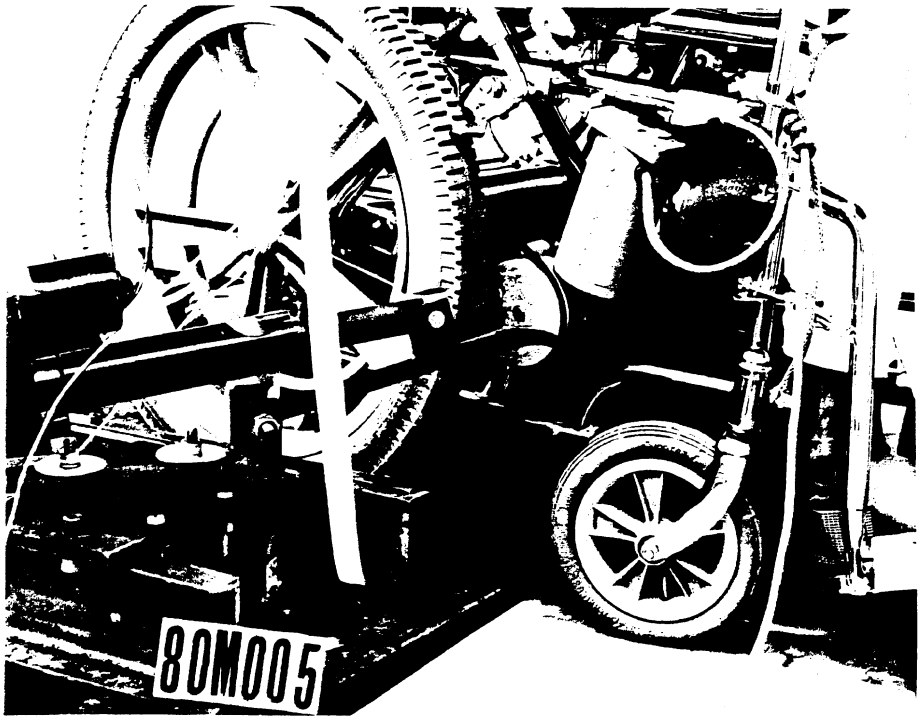
Left lap - 220
Right lap - 280



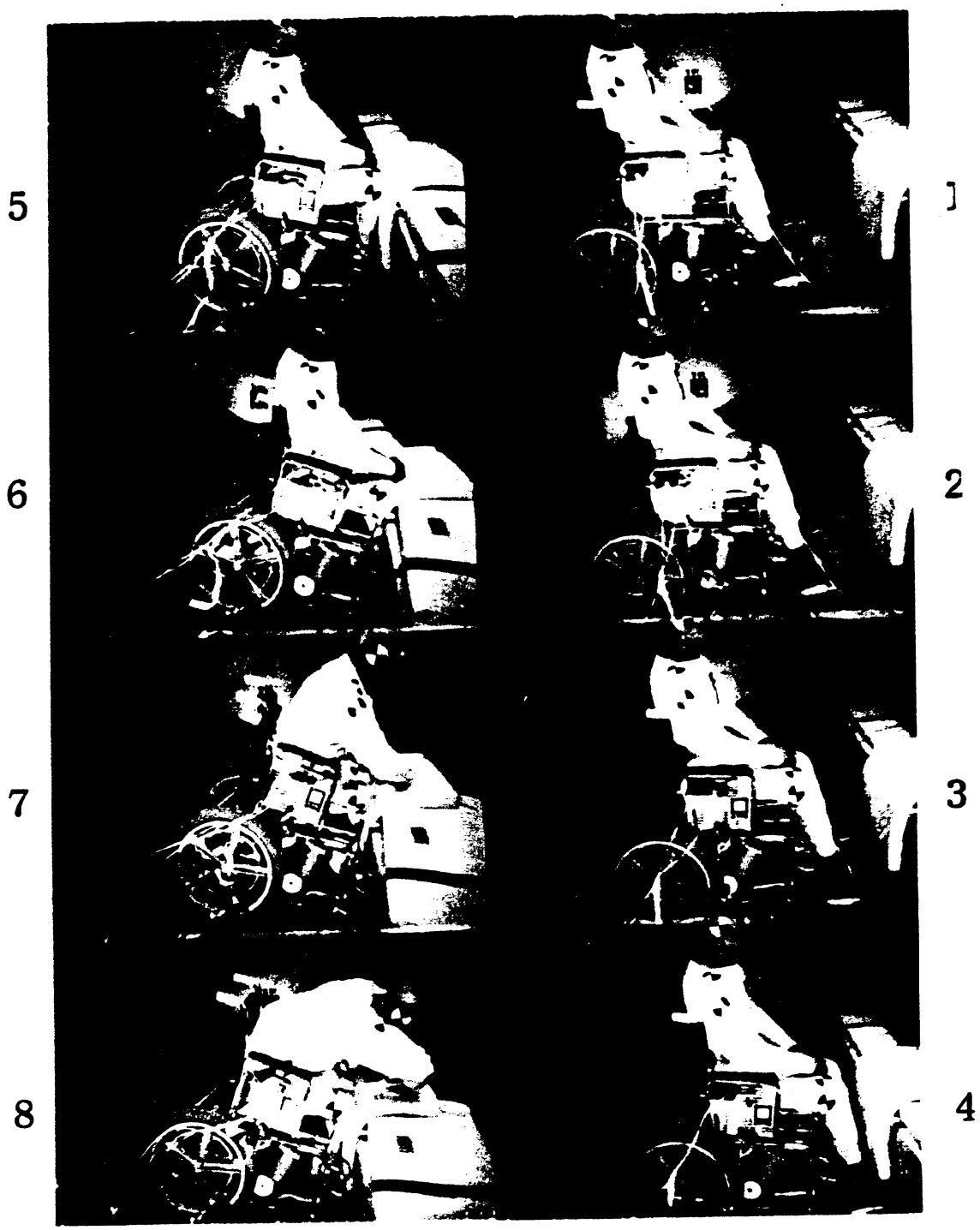


Set-Up Photos for Test 80M005





Post-Impact Photos for Test 8OM005



Time Sequence Photo for Test 80M005

TEST NO.
80M006

Setup

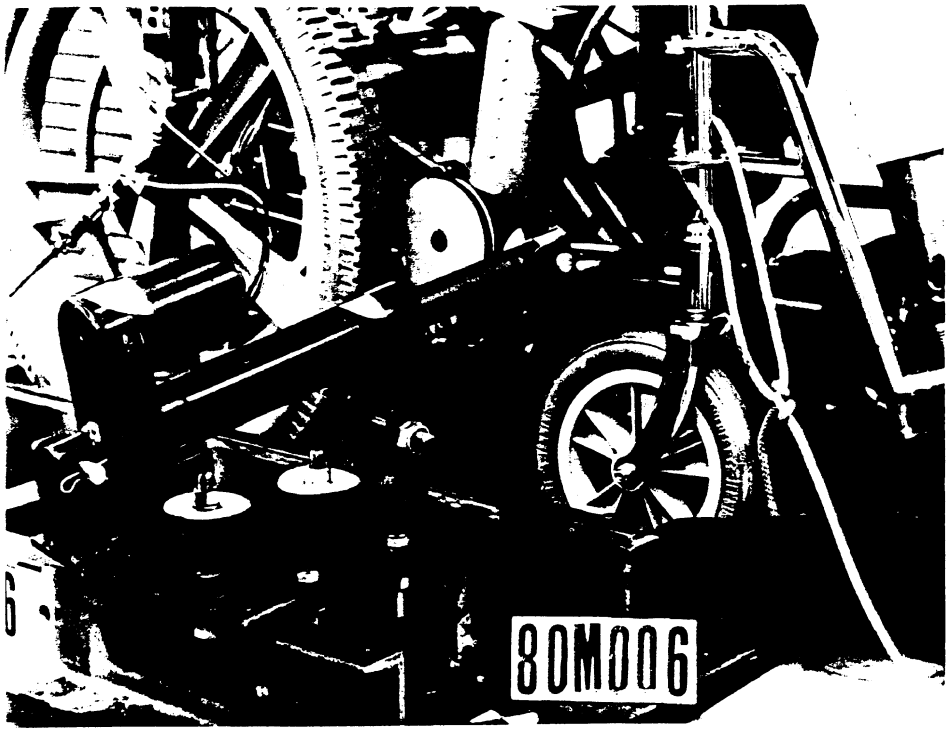
The wheelchair was secured to the sled in the forward-facing direction, using the Bud power lock-down and power pan system described in test 80M005. The dummy was restrained to the chair as in test 80M005, using a lap belt to the chair posts. In addition, a Bud passive belt restraint system (old style) was used to restrain the dummy. This system consists of a vehicle-mounted shoulder and lap belt 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

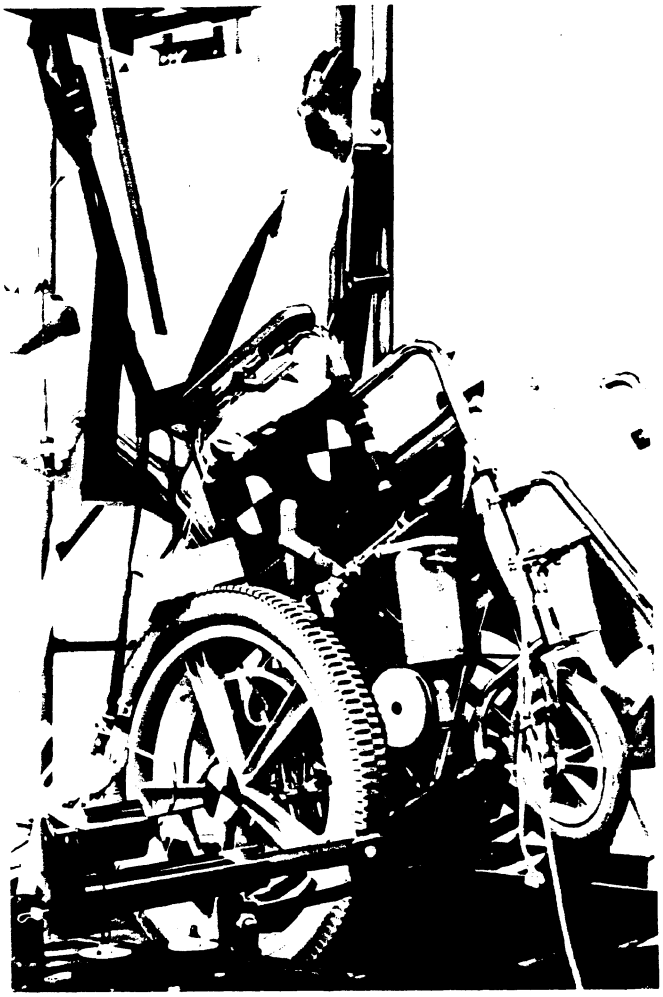
The power lock-down did not secure the chair, which became restrained by the passive belt system through loading on the dummy. The lower part of the chair, being unrestrained, moved forward, causing the dummy and chair to tilt backwards. A tether rope caught on a sled bolt, preventing the chair from 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



Post-Test Photo for Test 80M006

Time Sequence Photo for Test 80M006

TEST NO.
80M007

Setup

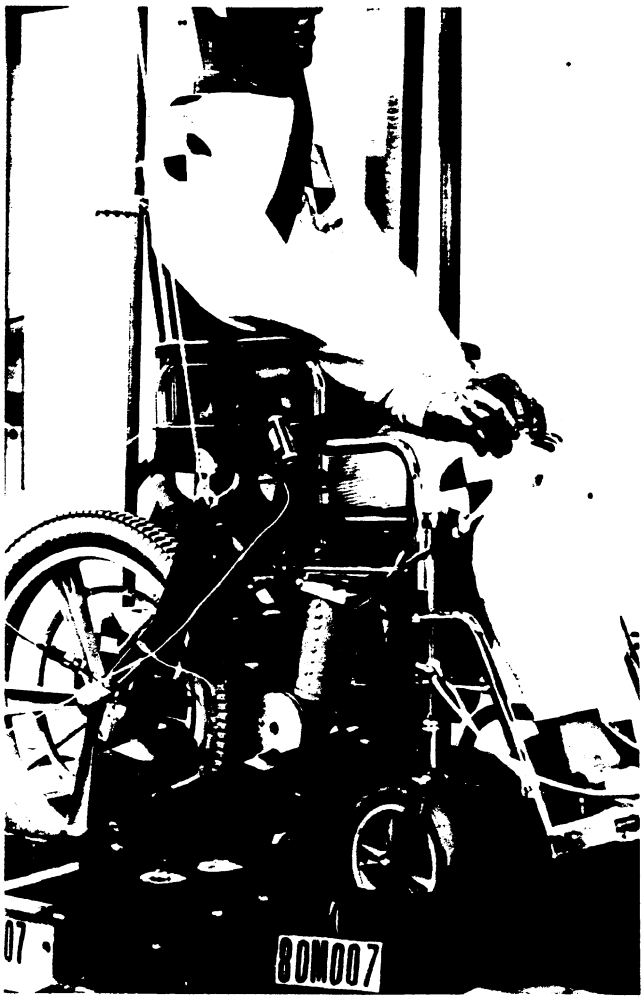
The wheelchair was secured to the sled in the forward-facing direction, using the Bud power lock-down and power pan system described in test 80M005. The dummy was restrained to the chair as in test 80M005, using a lap belt to the chair posts. In addition, a Bud passive belt restraint (new style) was 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.

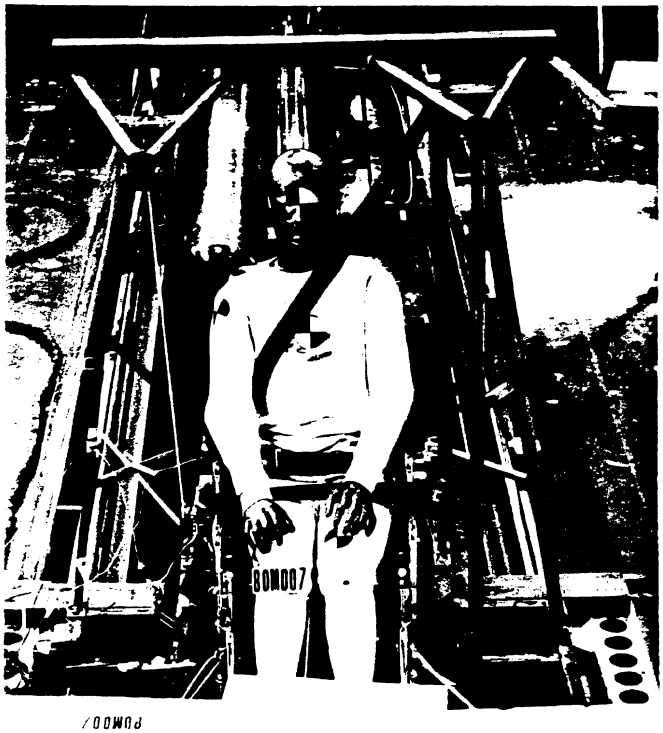
Results

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.

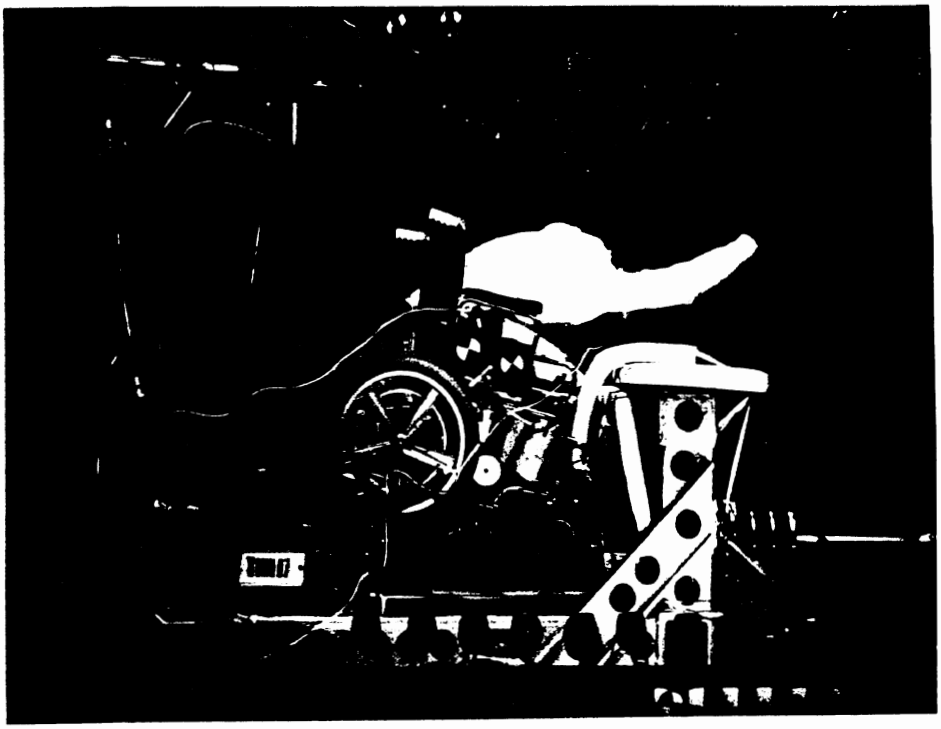
Peak Belt Loads (lbs)

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

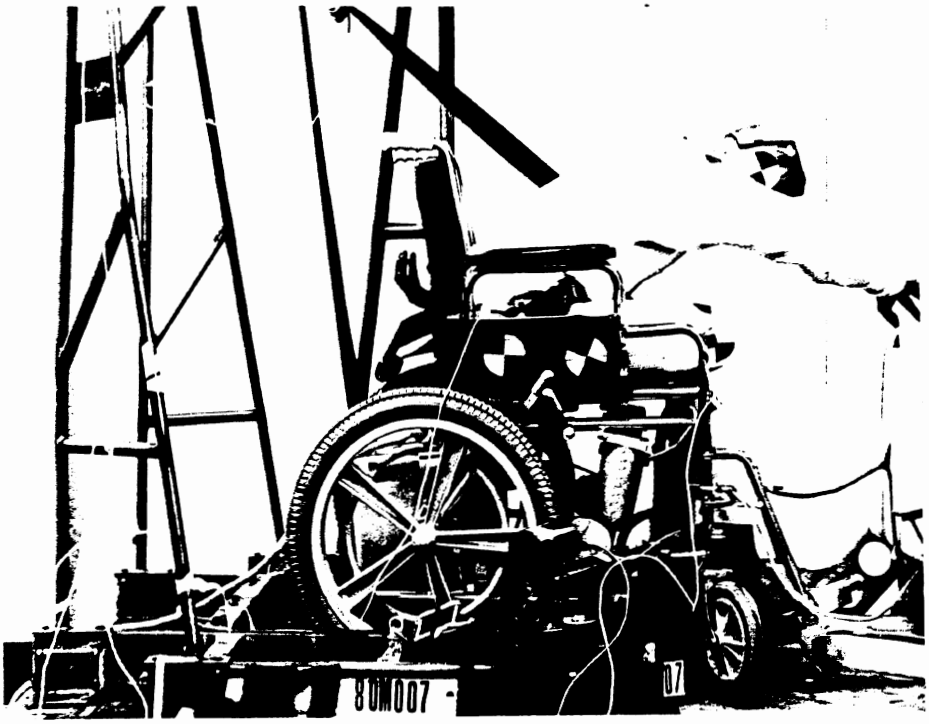




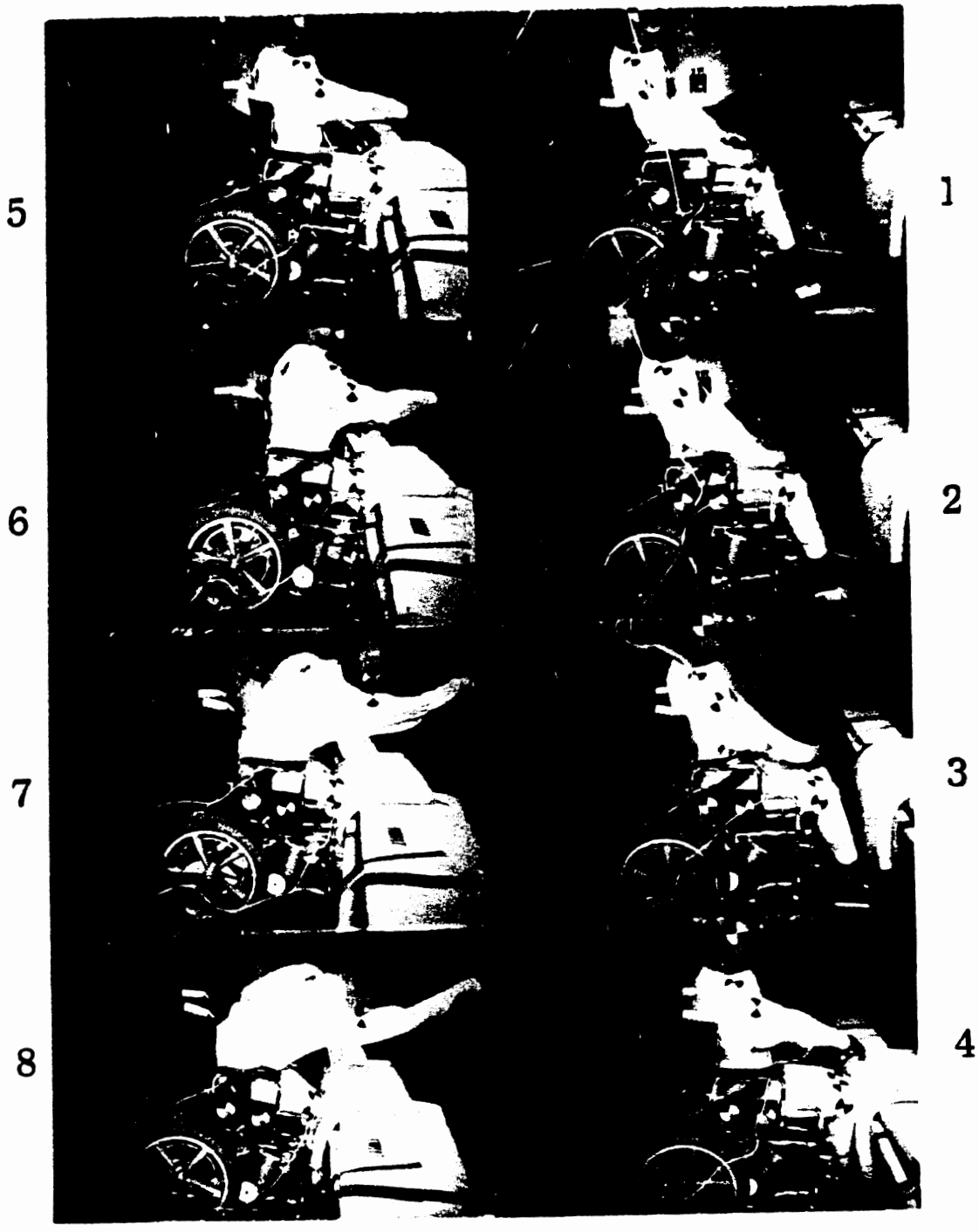
Set-Up Photos for Test 80M007



Stop Action During Impact Test 80M007



Post-Test Photo for Test 80M007



Time Sequence Photo for Test 80M007

TEST NO.
80M008

Setup

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.

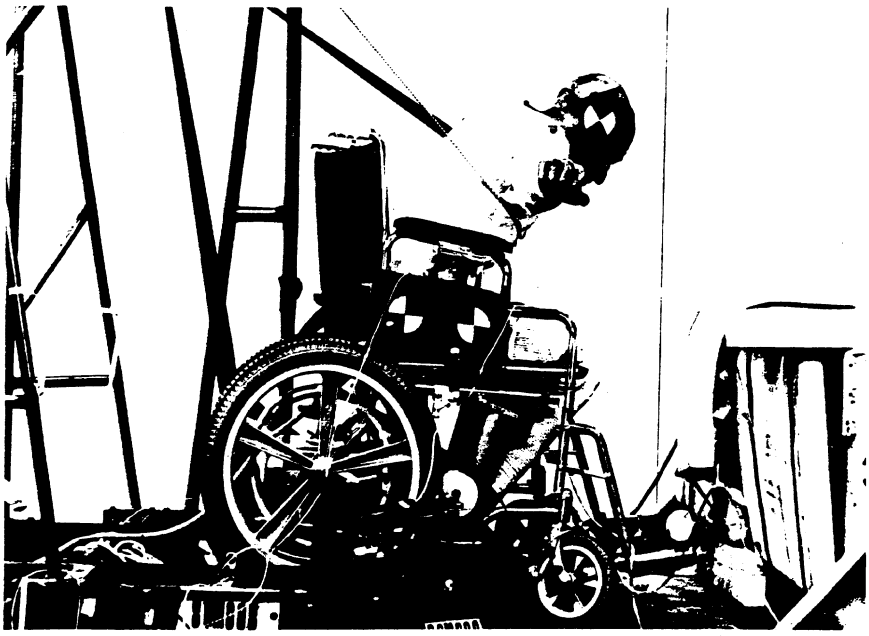
Results

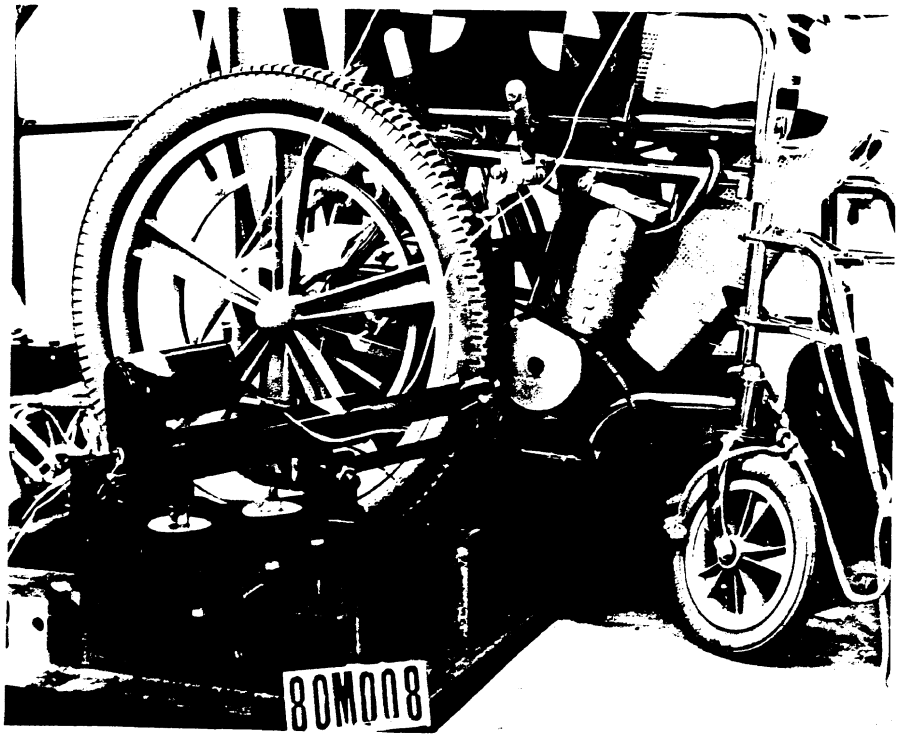
The results were the same as in test 80M007, except that higher belt loadings were achieved before the belt webbing ripped through the bolts at the metal ring, releasing the chair and dummy. The chair arms and frame were bent during impact.

Peak Belt Loads (lbs)

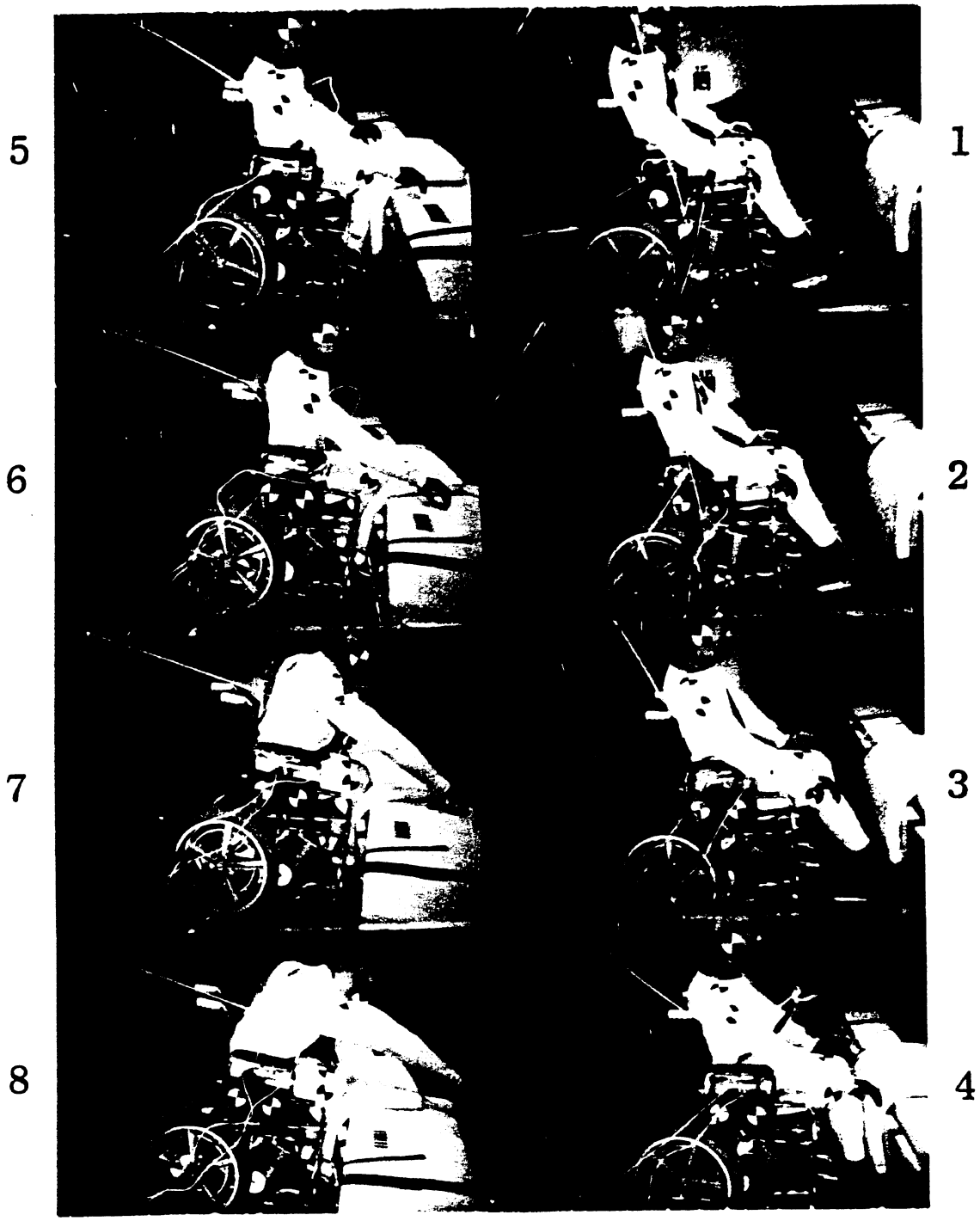
Shoulder	- 1200
Right lap	- 220
Passive belt (left)	- 1150
Passive belt (right)	- 1050
Right floor belt	- 1950

Set-Up Photos for Test 80M008





Post-Test Photos for Test 80M008



Time Sequence Photo for Test 80M008

TEST NO.
80M009

Setup

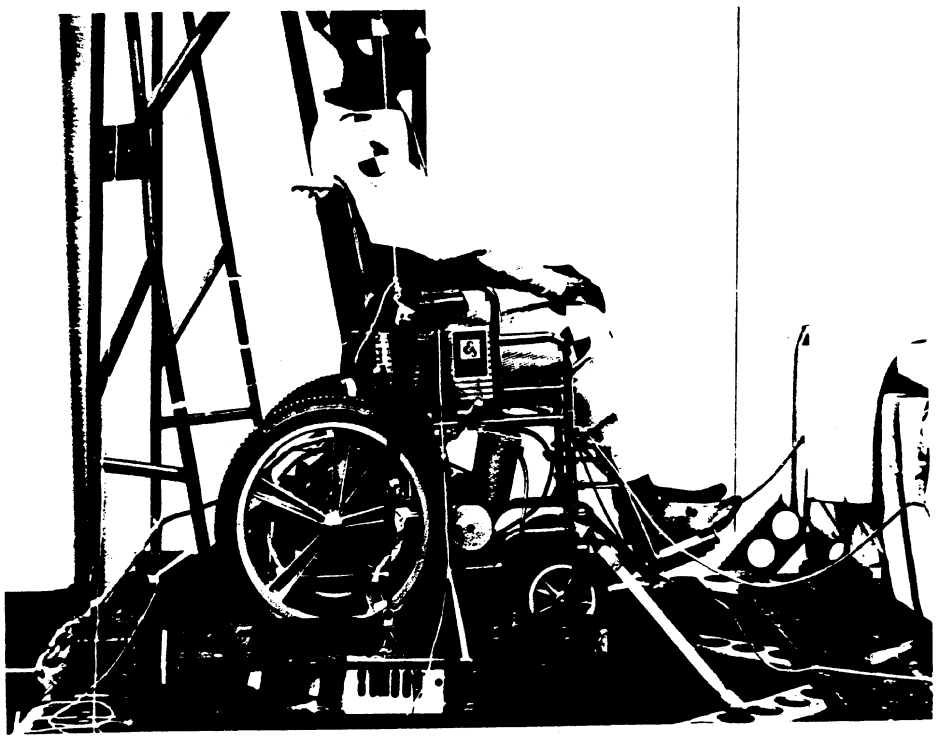
The wheelchair was secured to the sled in the forward-facing position, using four Aeroquip tie-down straps. Two straps were wrapped around the front chair frame members just above the castors and angled forward and outward, being tied to the sled structure itself. Two other straps wrapped around the 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.

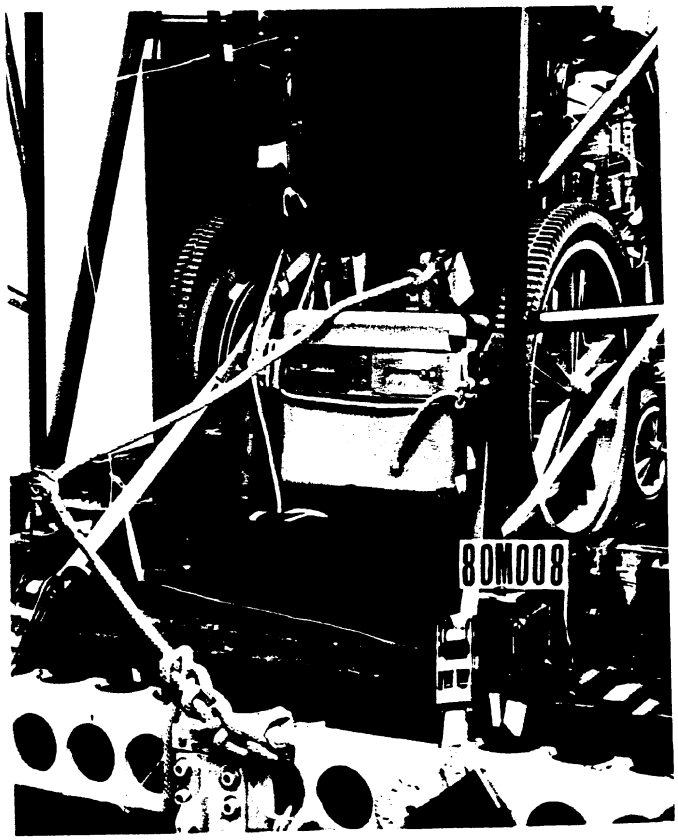
Results

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.

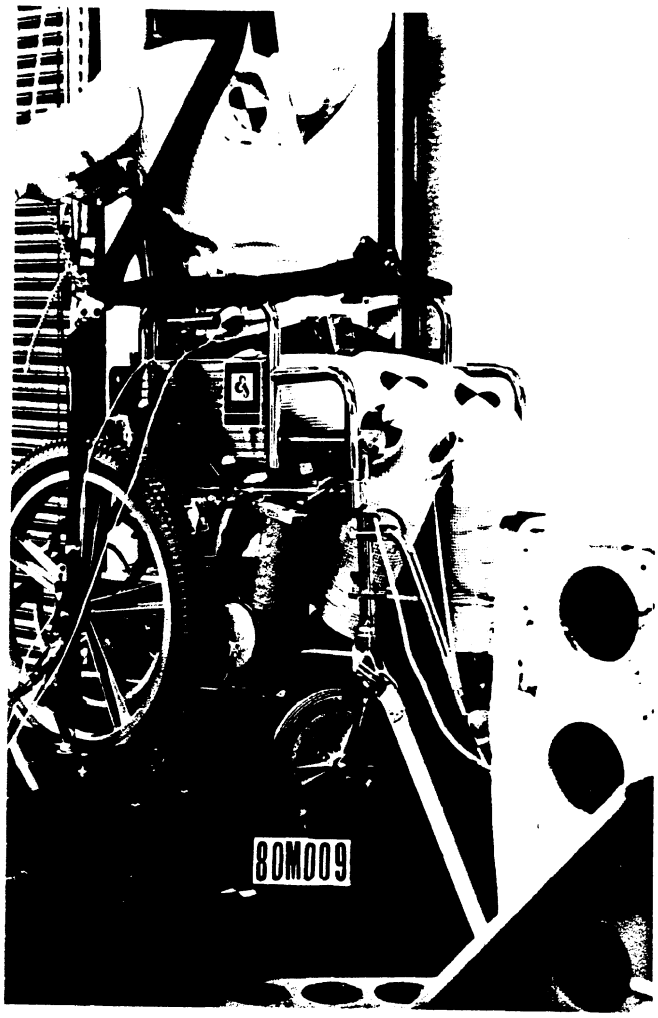
Peak Belt Loads (lbs)

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

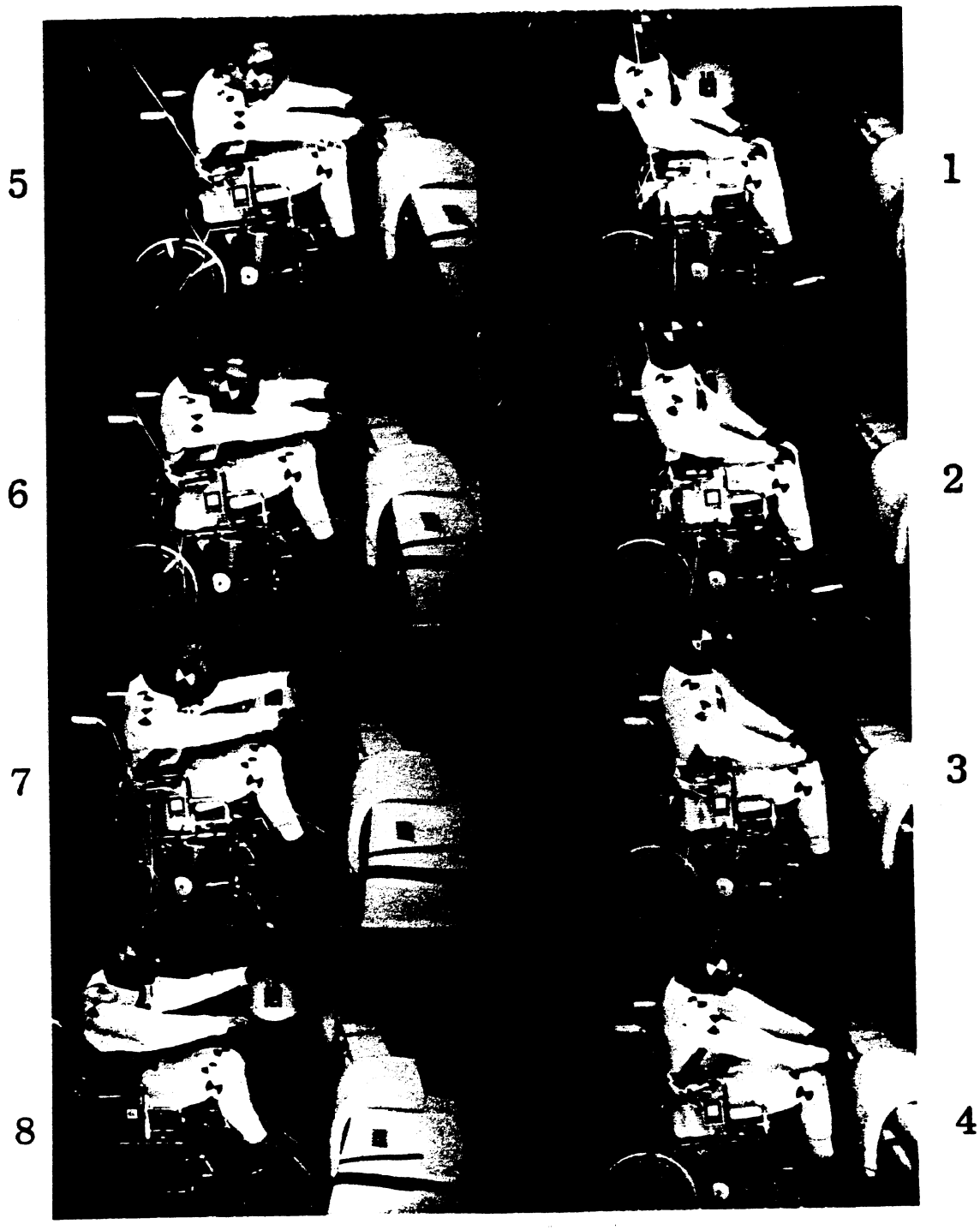




Set-Up Photos for Test 80M009



Post-Impact Photo for Test 80M009



Time Sequence Photo for Test 80M009

TEST NO.
80M010

Setup

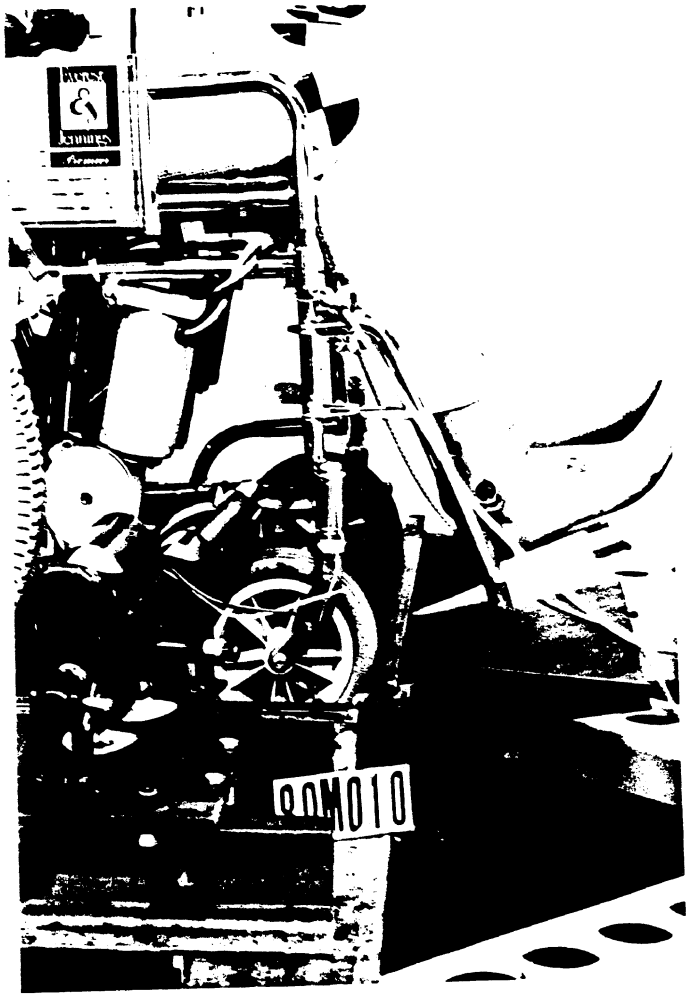
The wheelchair and dummy were restrained facing forward on the sled with the Bud power pan and power lock-down, as in test 80M007, except that (1) The lap portion of the passive belt system was passed over the wheelchair arms; (2) a steel bar was welded in place across the top edge of the power pan to 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

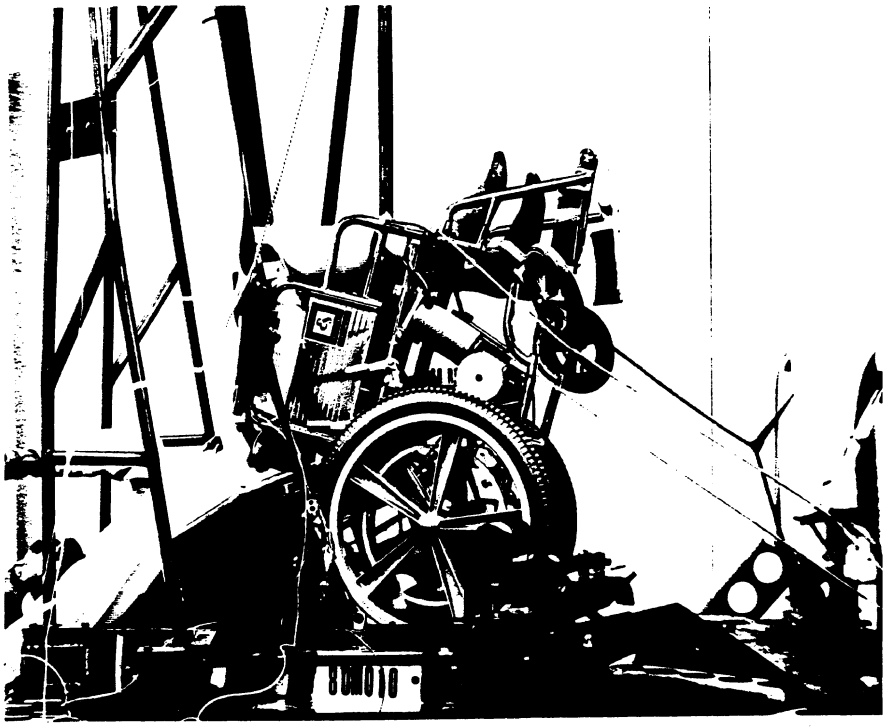
The wheelchair jumped the wheel stop bar almost as if it were not there, and the dummy's knees impacted with the front of the sled. The dummy was restrained at the upper torso by the passive belt system, causing the chair to flip over backwards, so that the back of the dummy's head impacted the sled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

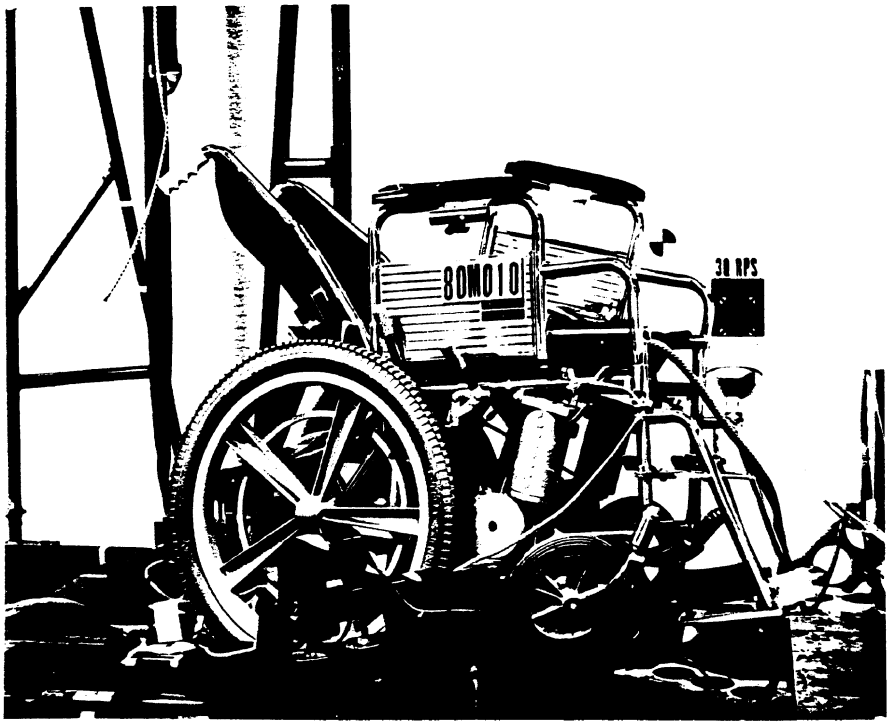
Peak Belt Loads (lbs)

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

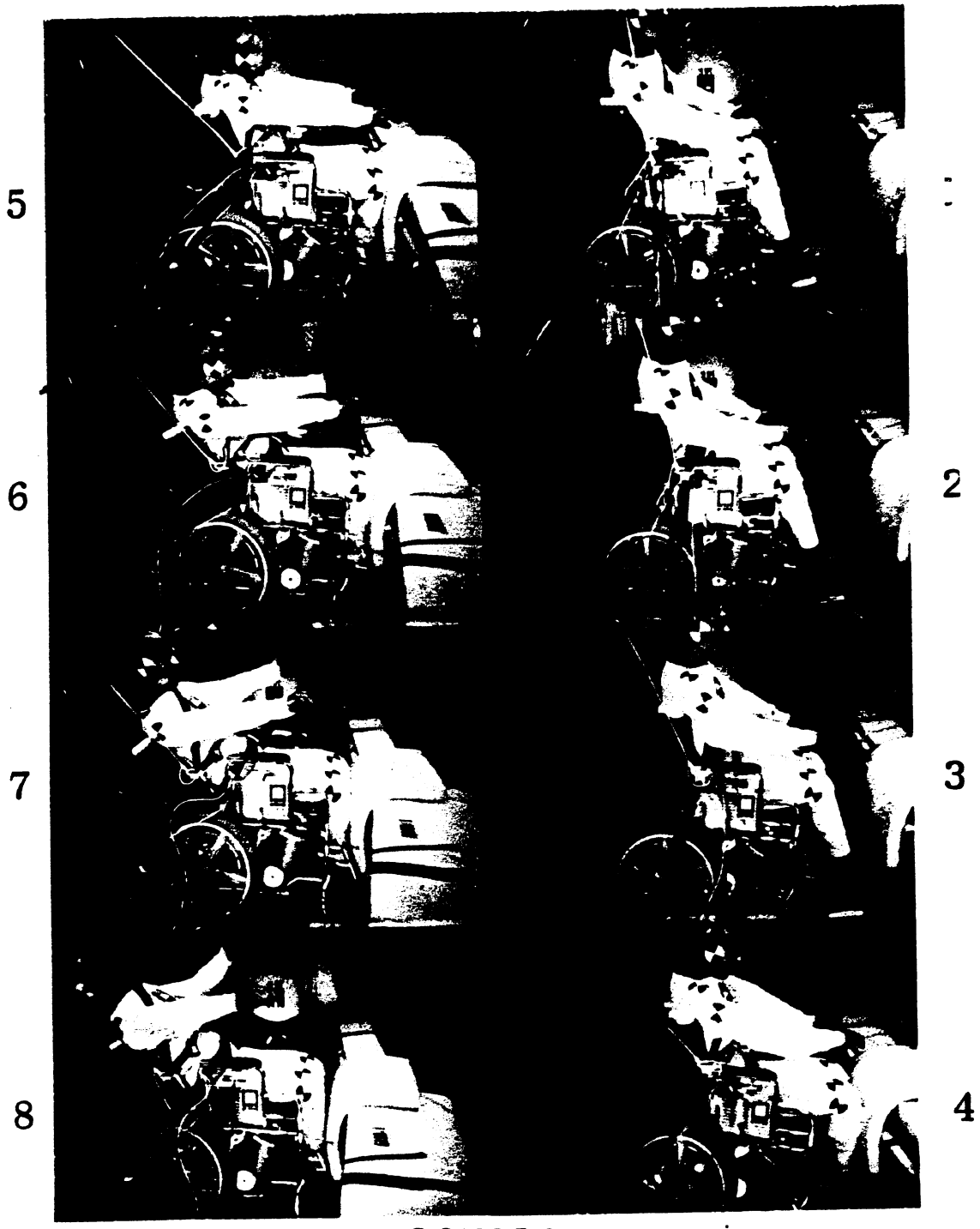


Set-Up Photo for Test 80M010





Post-Impact Photos for Test 80M010



Time Sequence Photo for Test 80M010

TEST NO.
80M011

Setup

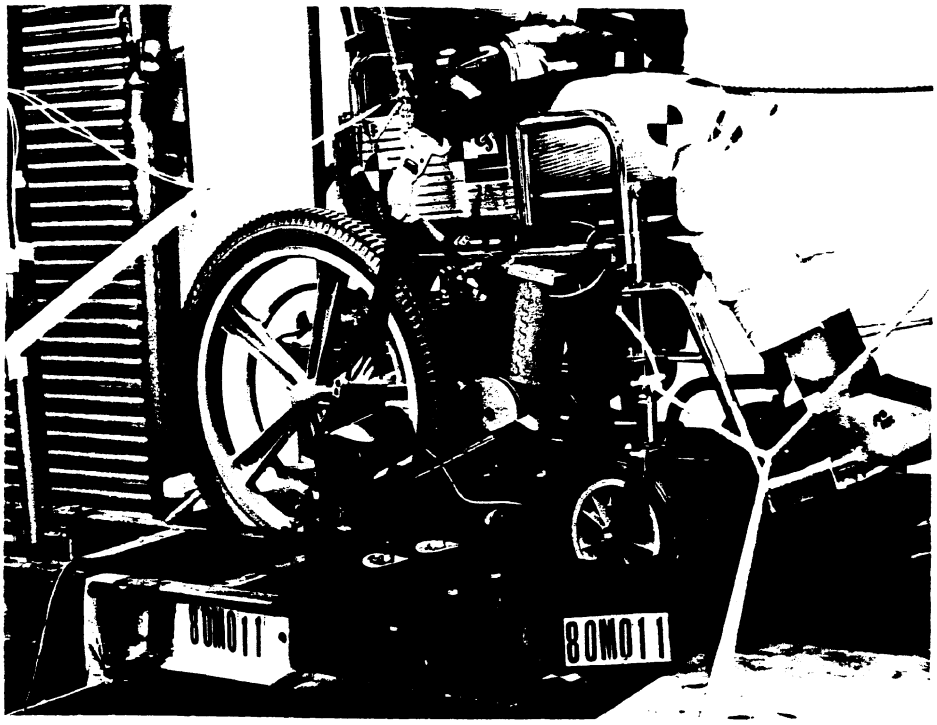
The wheelchair and dummy were restrained facing forward on the sled with the Bud power pan and power lock-down, as in test 80M010, except that the lap portion of the Bud passive restraint webbing was placed in front of the wheelchair arms, as in test 80M007. As in test 80M010, the floor belt webbing 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

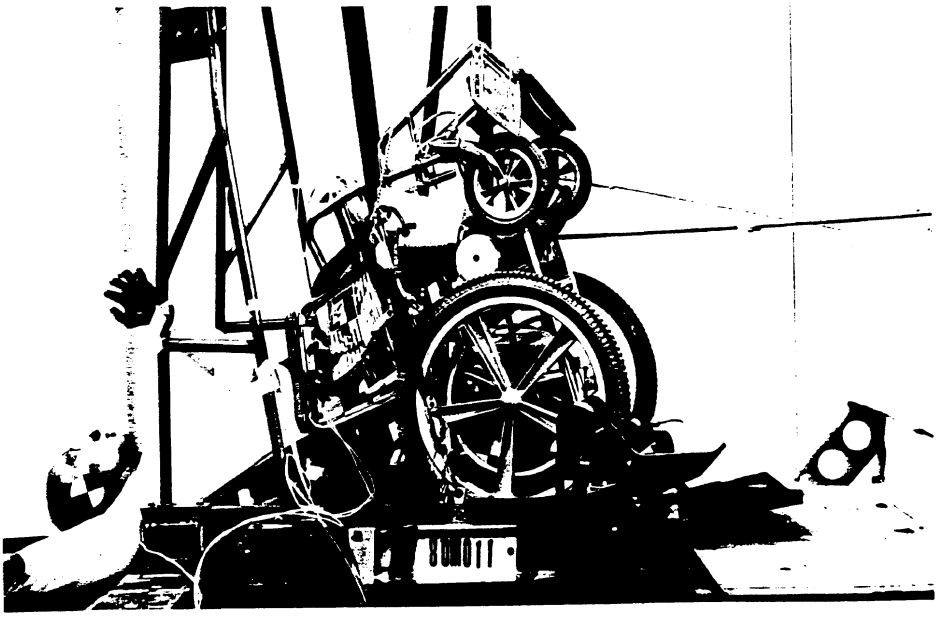
This system provided fairly good restraint of the chair and occupant in the forward direction, but both the chair and occupant were restrained by the passive belt system, as indicated by the high belt loads. After impact the chair flipped backward to the sled floor. The chair arms sustained considerable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

Peak Belt Loads (lbs)

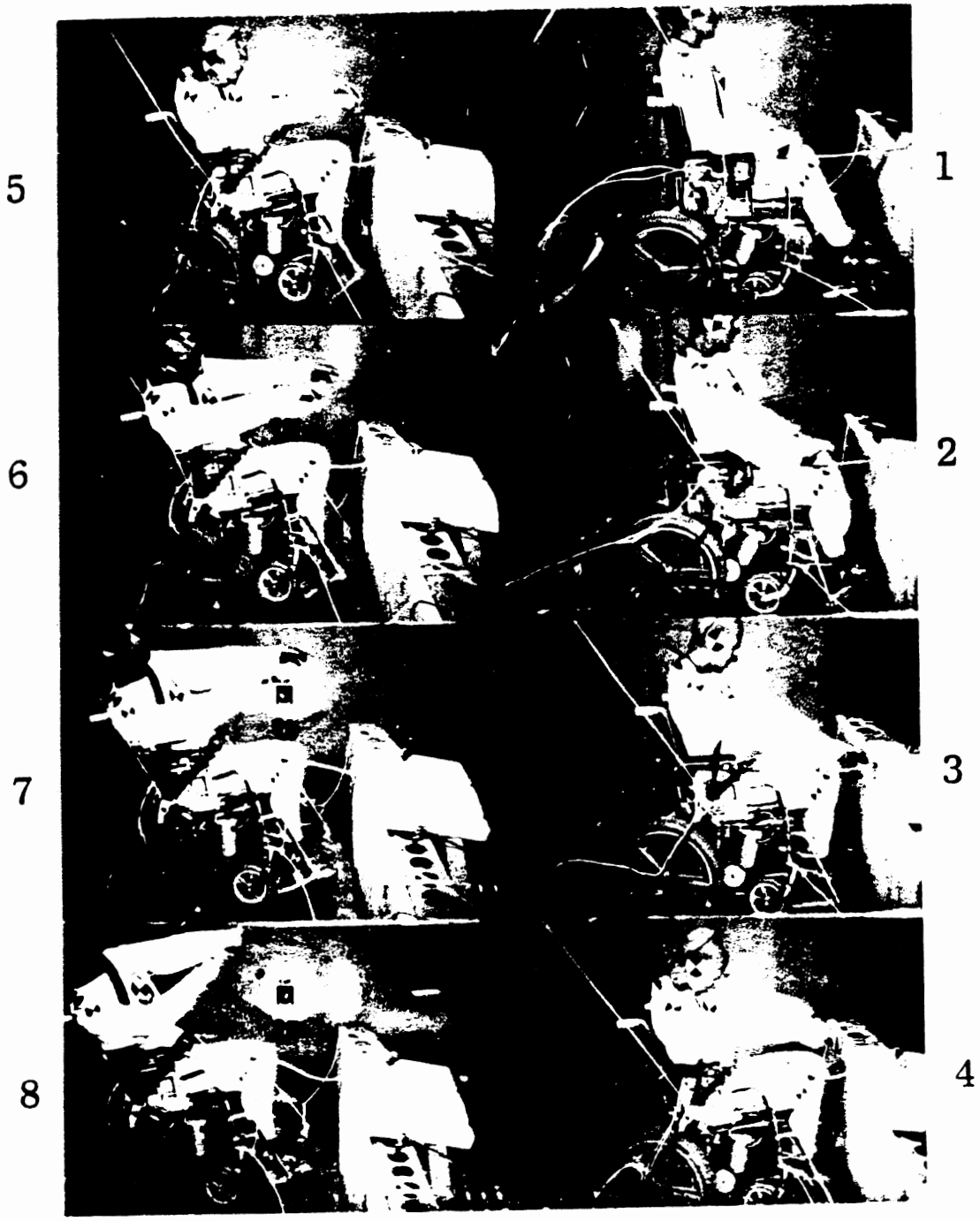
Shoulder	- 1800
Left lap	- 340
Passive lap	- 1450
Right floor anchor	- 2200
Left floor anchor	- 1500



Set-Up Photos for Test 80M011



Post-Impact Photos for Test 80M011



Time Sequence Photo for Test 80M011

TEST NO.
80M012

Setup

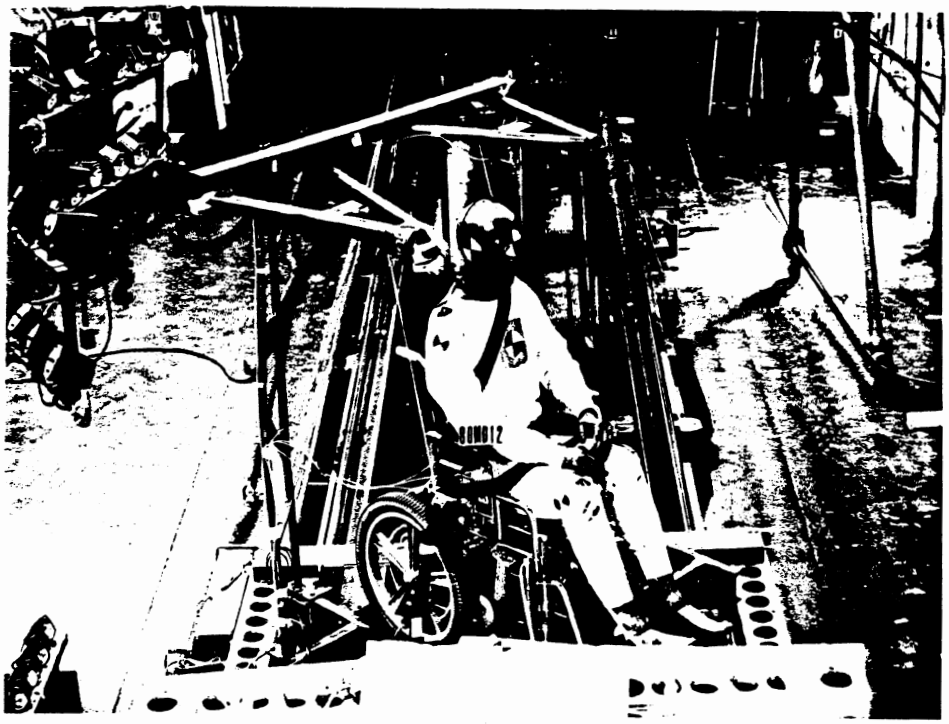
The wheelchair and dummy were restrained to the sled identically to test 80M011 but were orientated at 45 degrees to the sled track, with the dummy's right shoulder toward the impact direction.

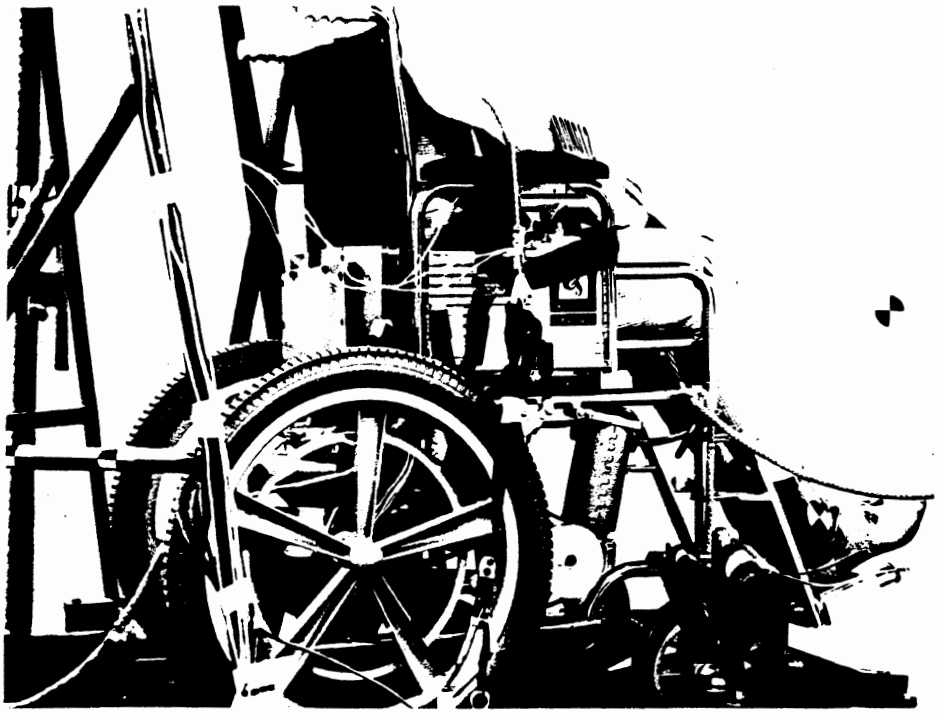
Results

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.

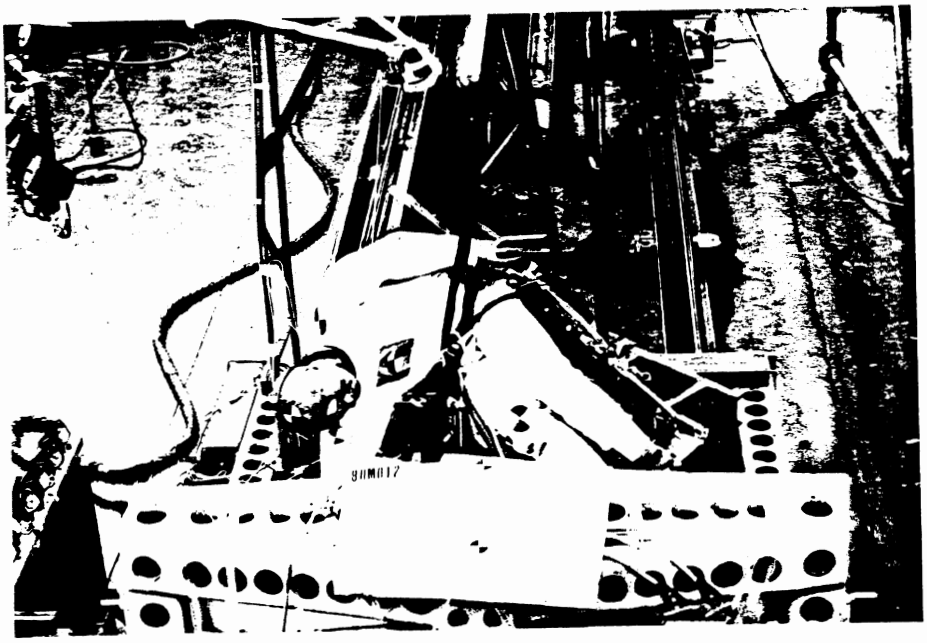
Peak Belt Loads (lbs)

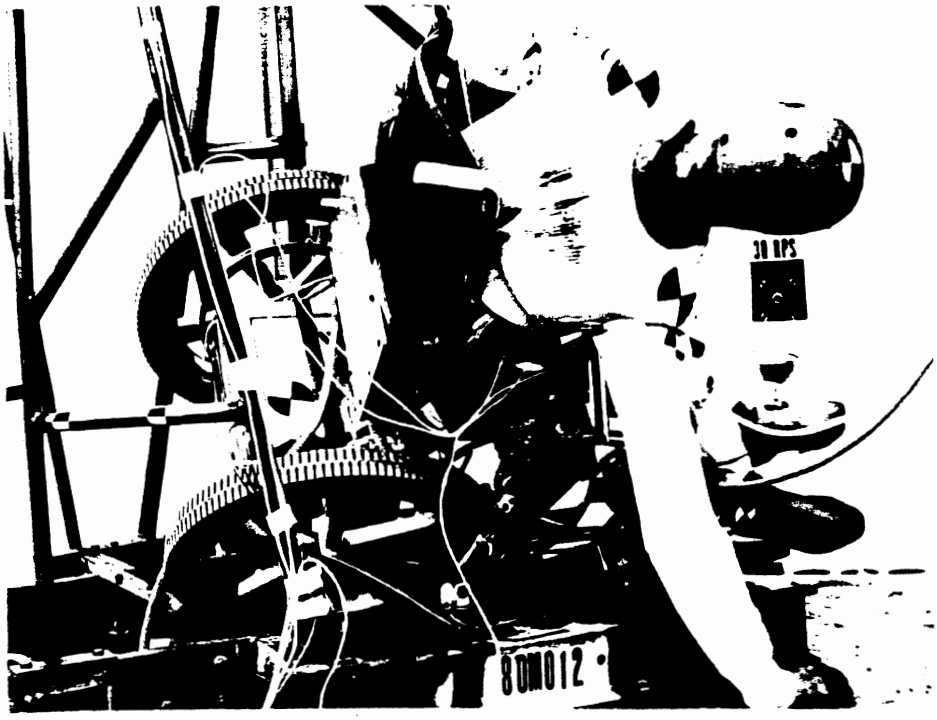
Shoulder	- 1700
Right lap	- 80
Left lap	- 280
Passive lap	- 1500



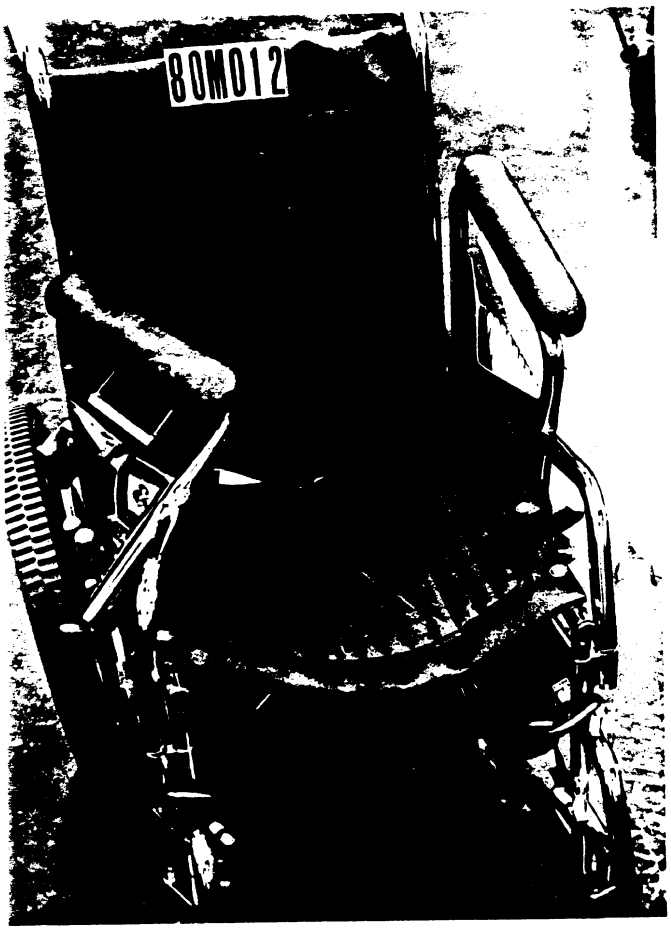


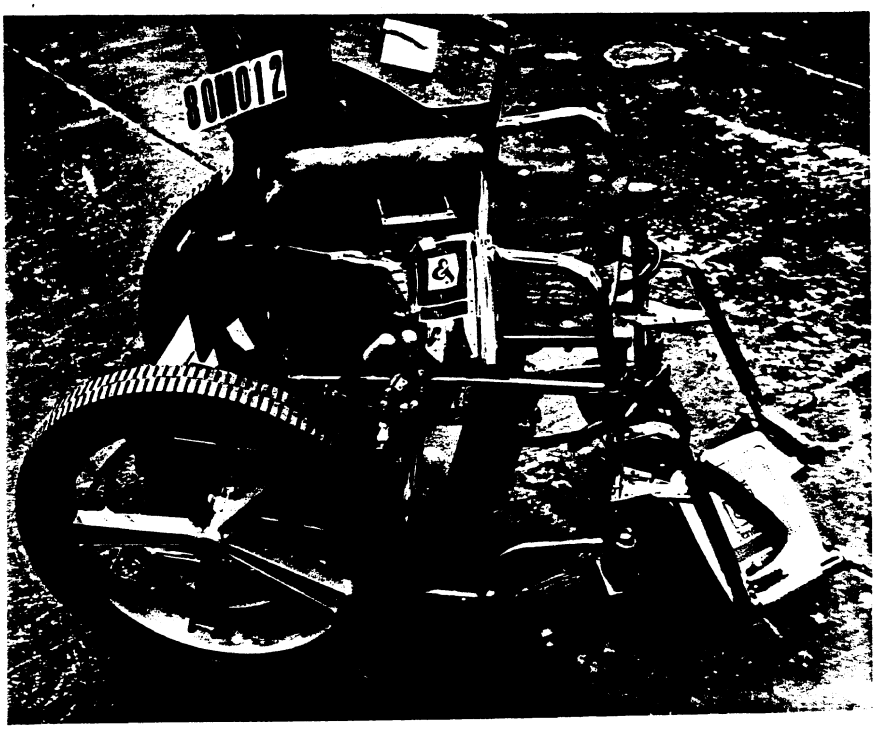
Set-Up Photos for Test 80M012



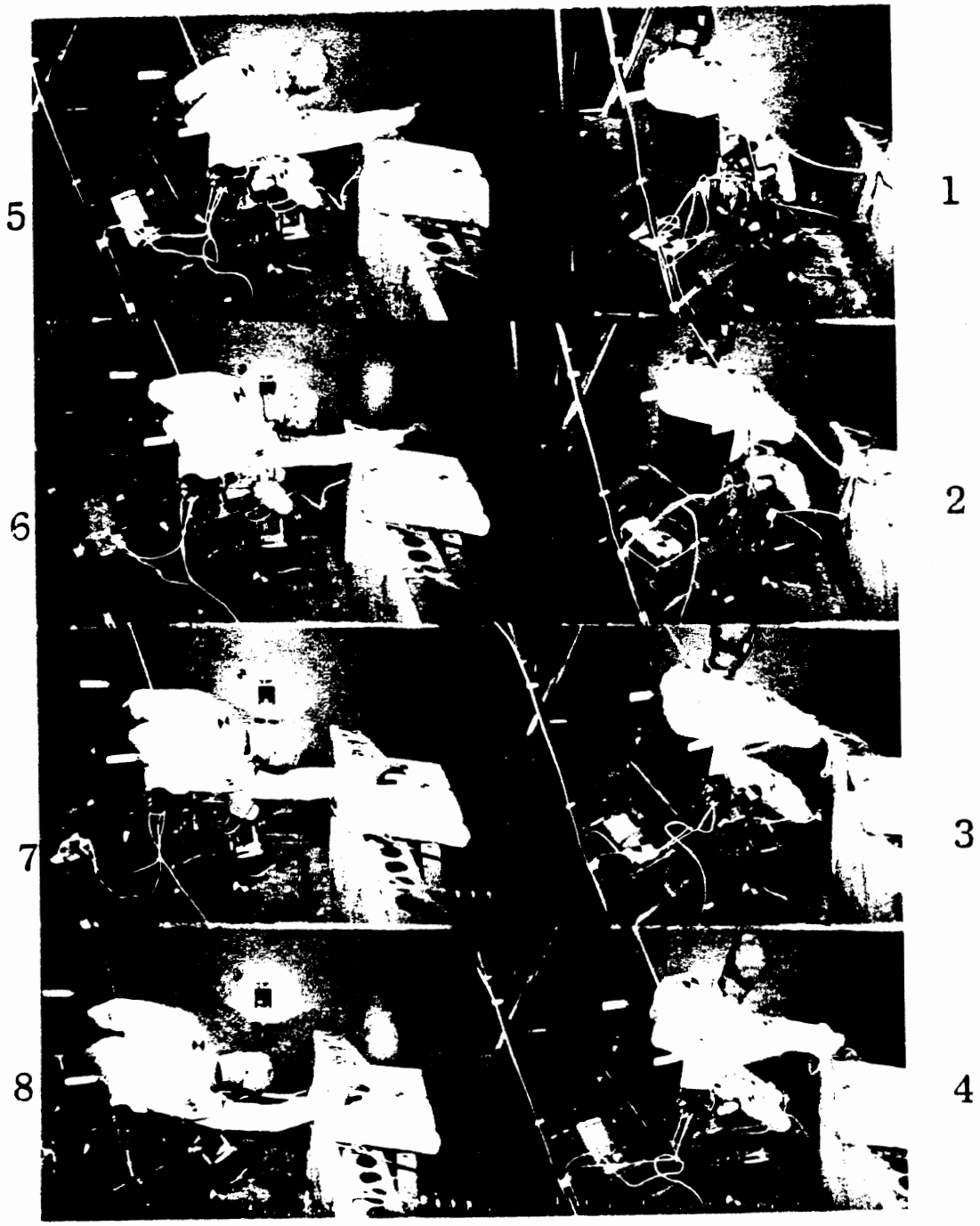


Post-Impact Photos for Test 80M012





Post-Impact Photos for Test 80M012



Time Sequence Photo for Test 80M012

TEST NO.
80M013

Setup

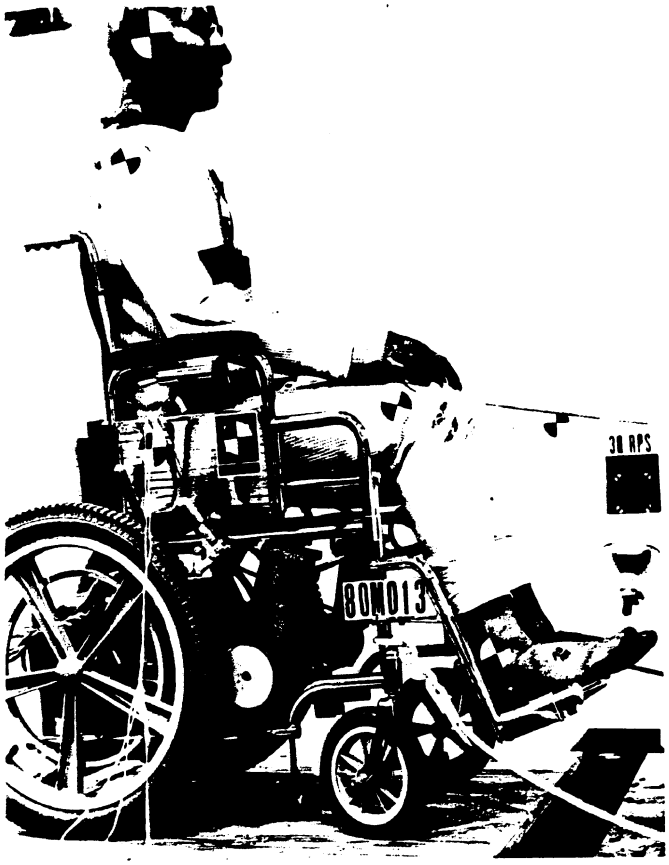
The wheelchair was restrained facing forward on the sled by a Bud Industries T-bar similar to that used in test 80M003. The adjustment holes in the T-bar were reduced to about 1/8" diameter for increased strength, and a heavy duty eye bolt was used in place of a lift ring for attachment to the floor.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

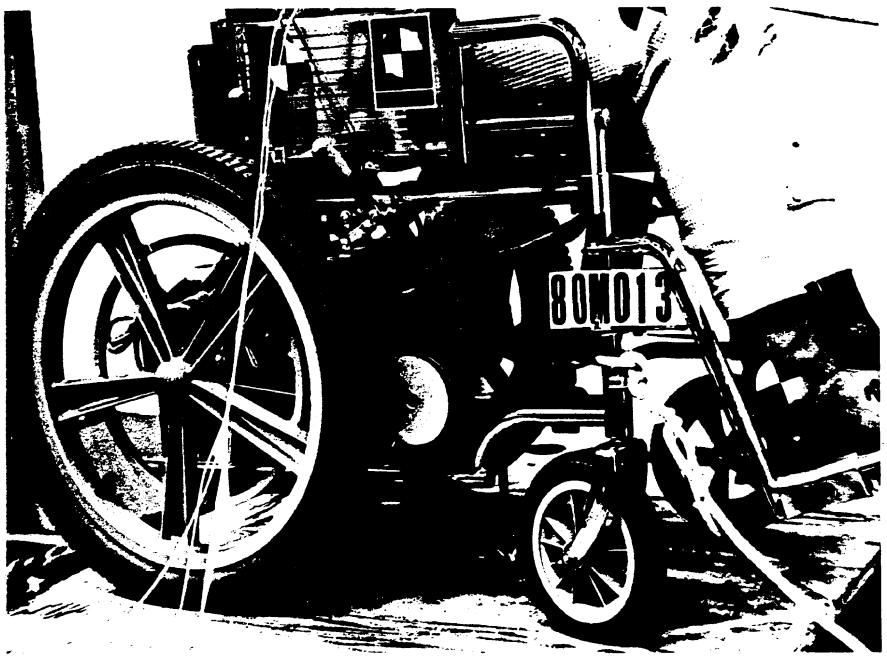
Results

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.

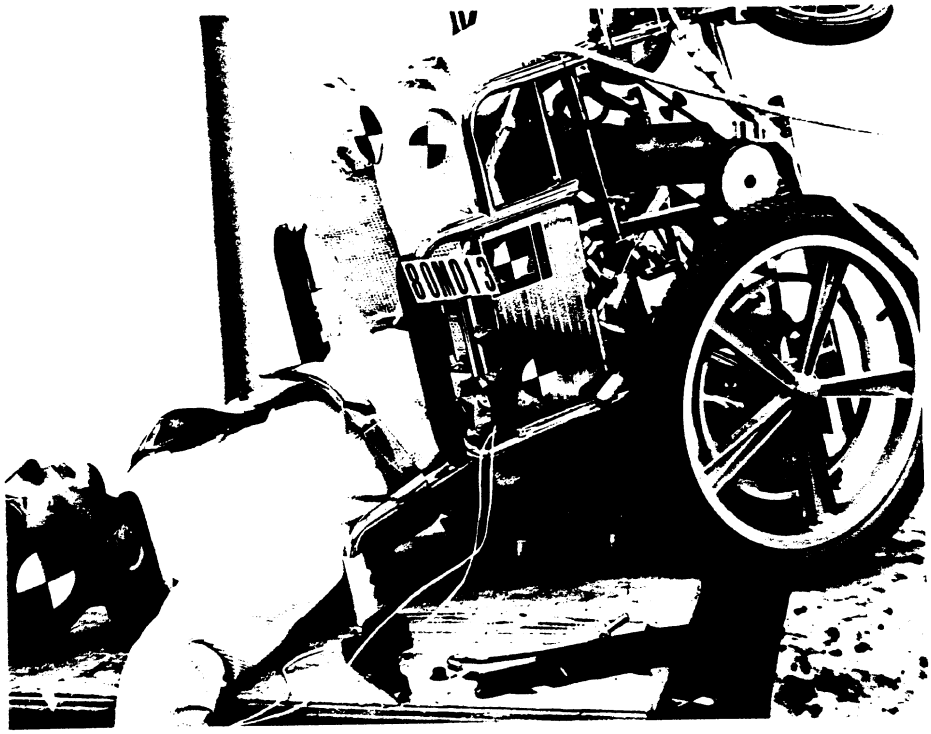
Peak Belt Loads (lbs)

Left lap - 200
Right lap - 150

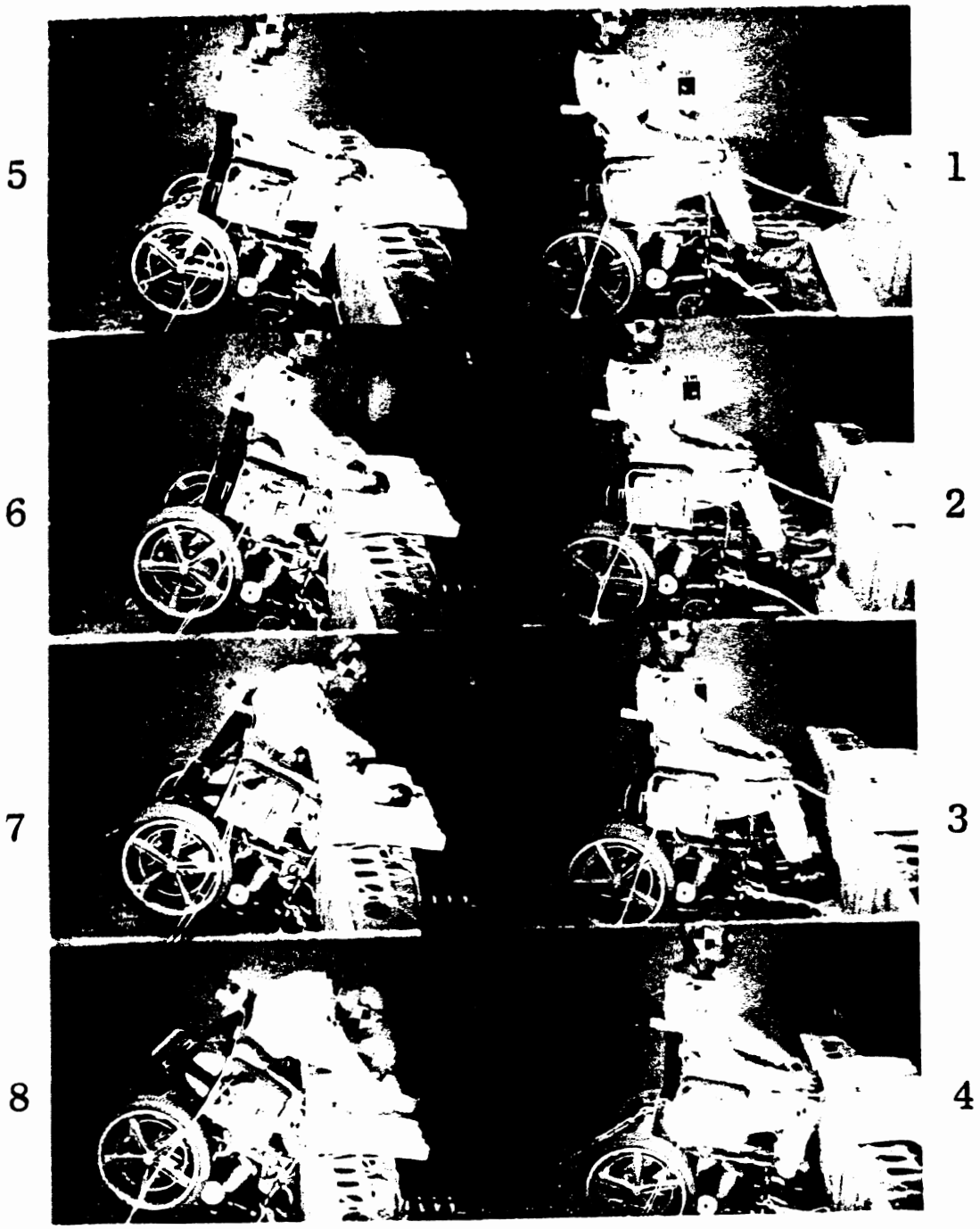




Set-Up Photos for Test 80M013



Post-Impact Photo for Test 80M013



Time Sequence Photo for Test 80M013

TEST NO.
80M014

Setup

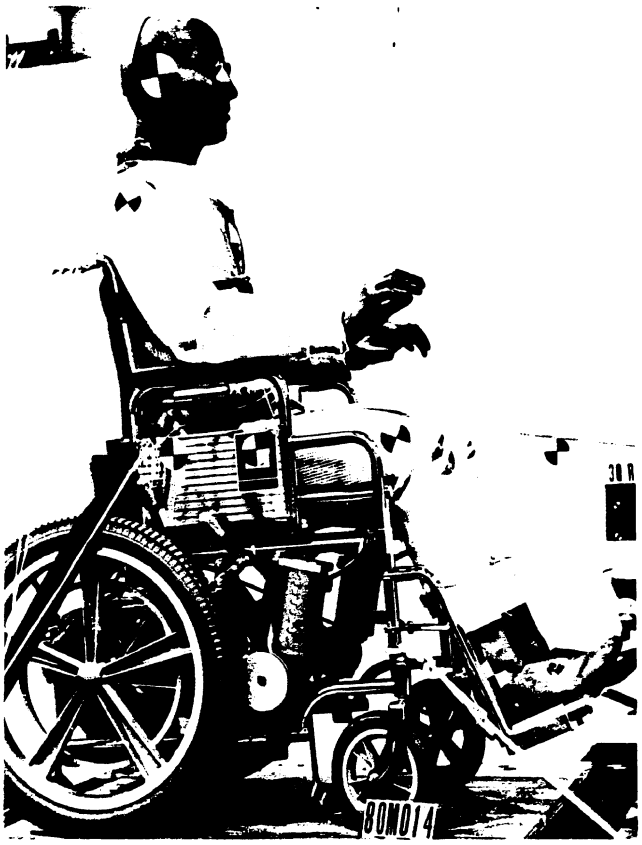
The wheelchair was restrained facing forward on the sled by a Bud Industries fixed length T-bar made of a piece of 1" square steel extrusion and a lap belt to the floor. The T-bar attached to the floor by a hook bolt through a center hole to a heavy-duty eye bolt. The lap belt anchor points were also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

Results

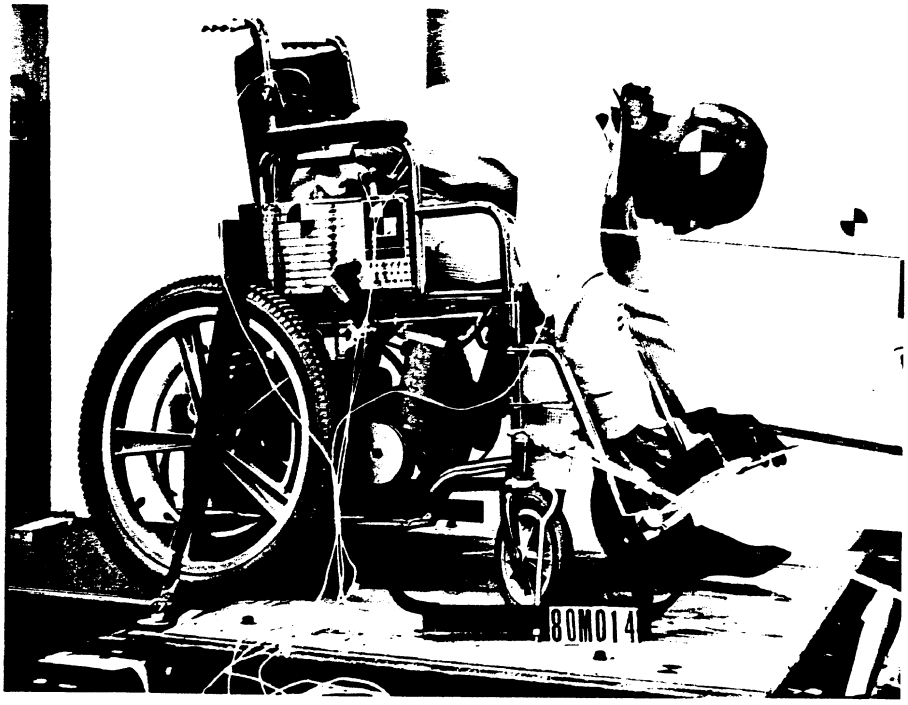
The hook portion of the T-bar hook bolt straightened out, releasing the chair from the T-bar tie-down. The lap belt restrained the chair and dummy from any significant forward motion, but the chair was only restrained from falling off the back of the sled by tether ropes. The velcro fastenings on the 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)

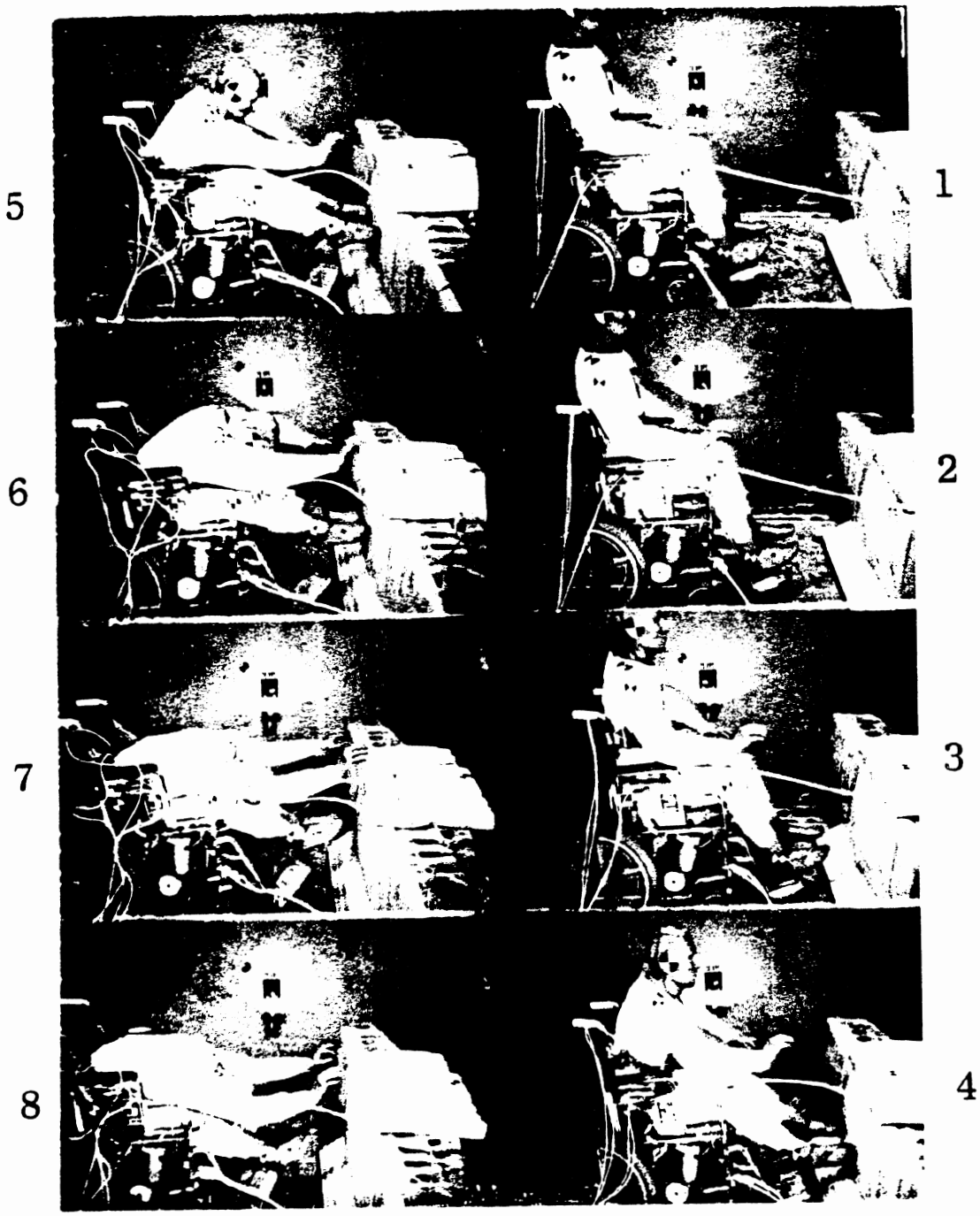
Left floor lap	- 1850
Right floor lap	- 1500
Left chest	- 290
Right chest	- 390



Set-Up Photo for Test 80M014



Post-Impact Photo for Test 80M014



Time Sequence Photo for Test 80M014

TEST NO.
80M015

Setup

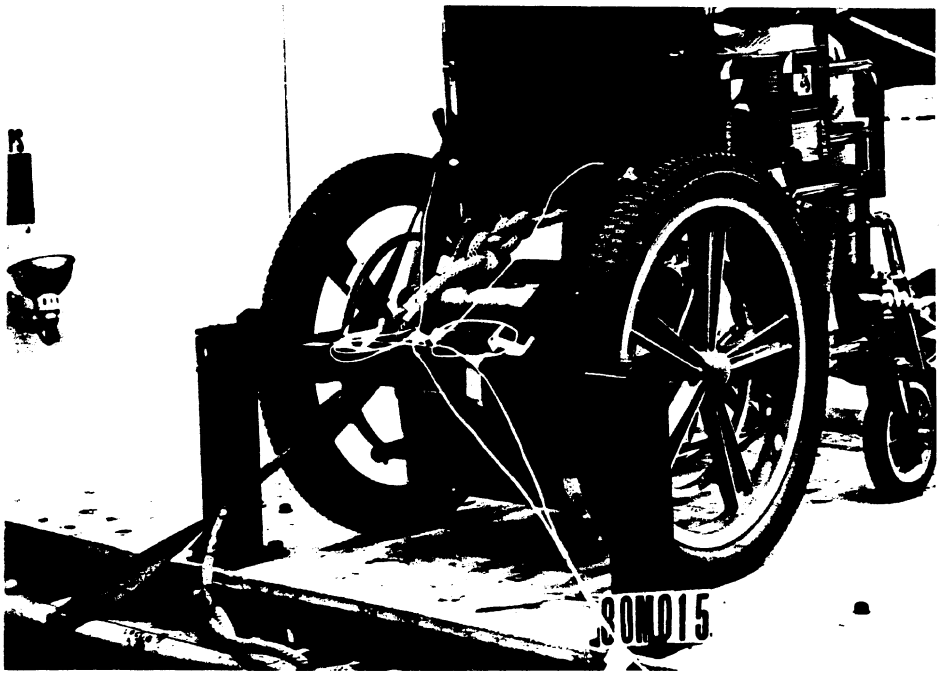
The wheelchair was restrained facing forward on the sled by a Bud Industries single chair rim pin stanchion. The dummy was restrained by a lap belt anchored to holes in the rim pin brackets.

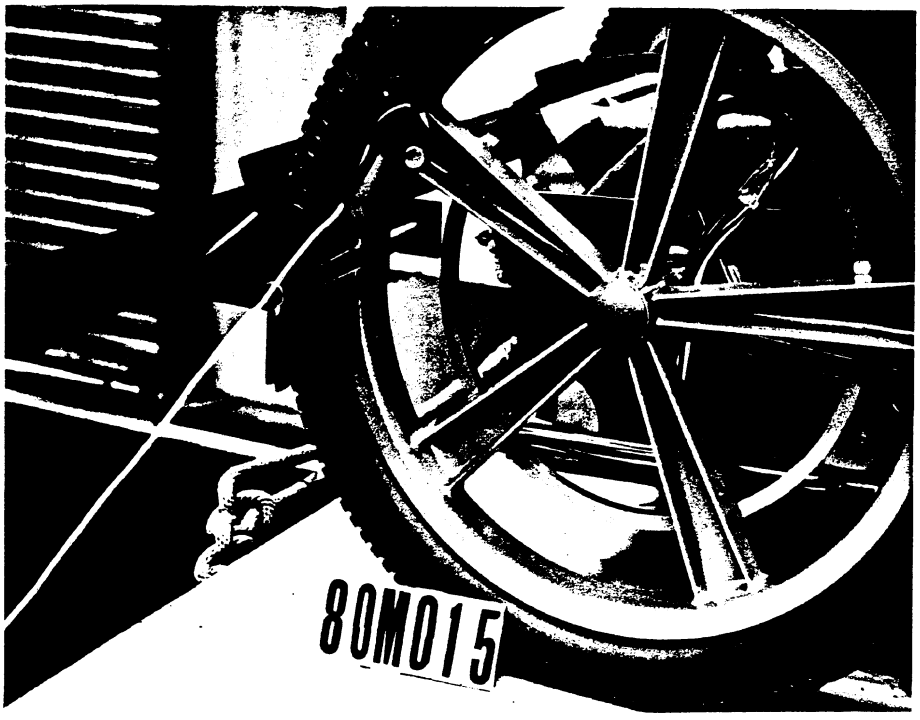
Results

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

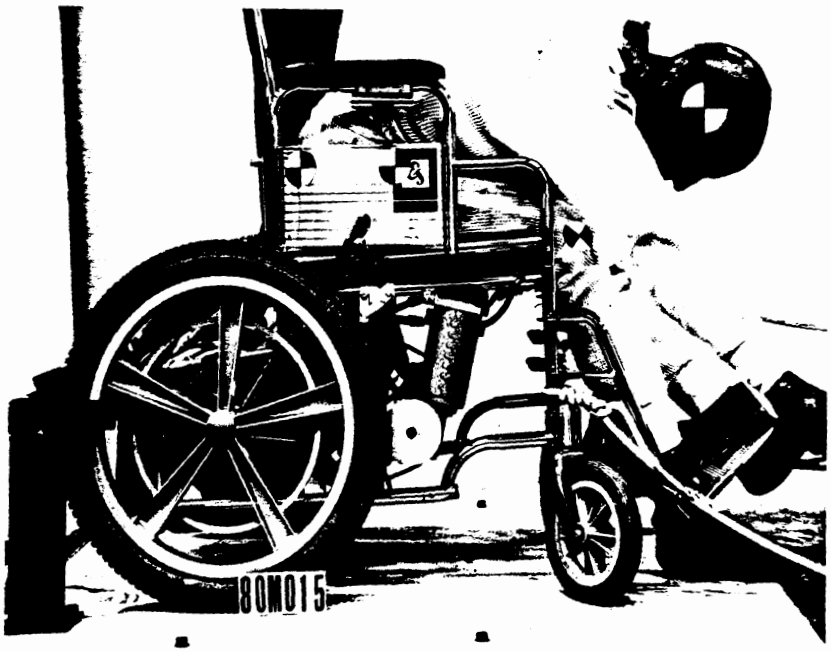
Peak Belt Loads (lbs)

Left lap - 1350
Right lap - 1100

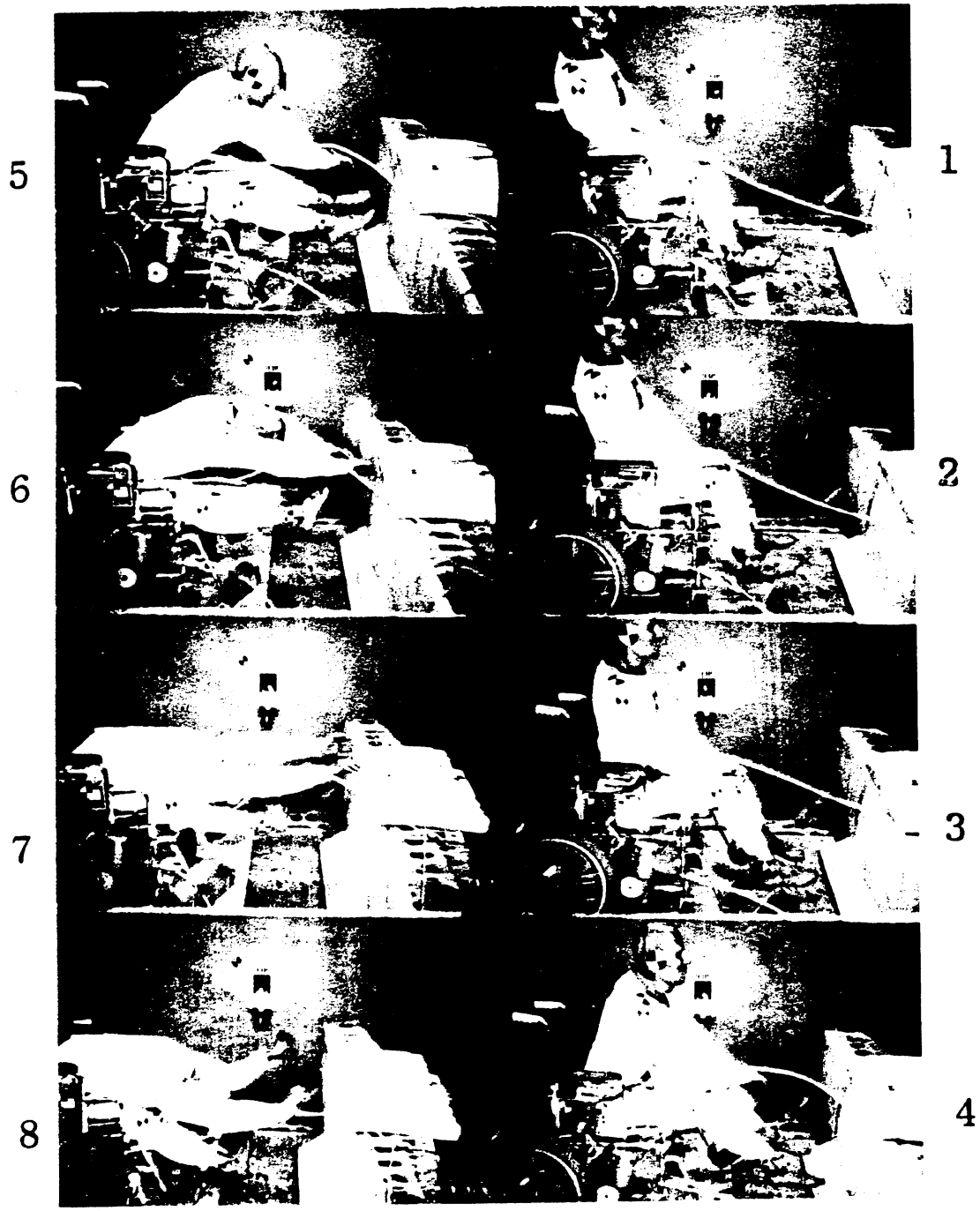




Set-Up Photos for Test 80M015



Post-Impact Photo for Test 80M015



Time Sequence Photo for Test 80M015

TEST NO.
80M016

Setup

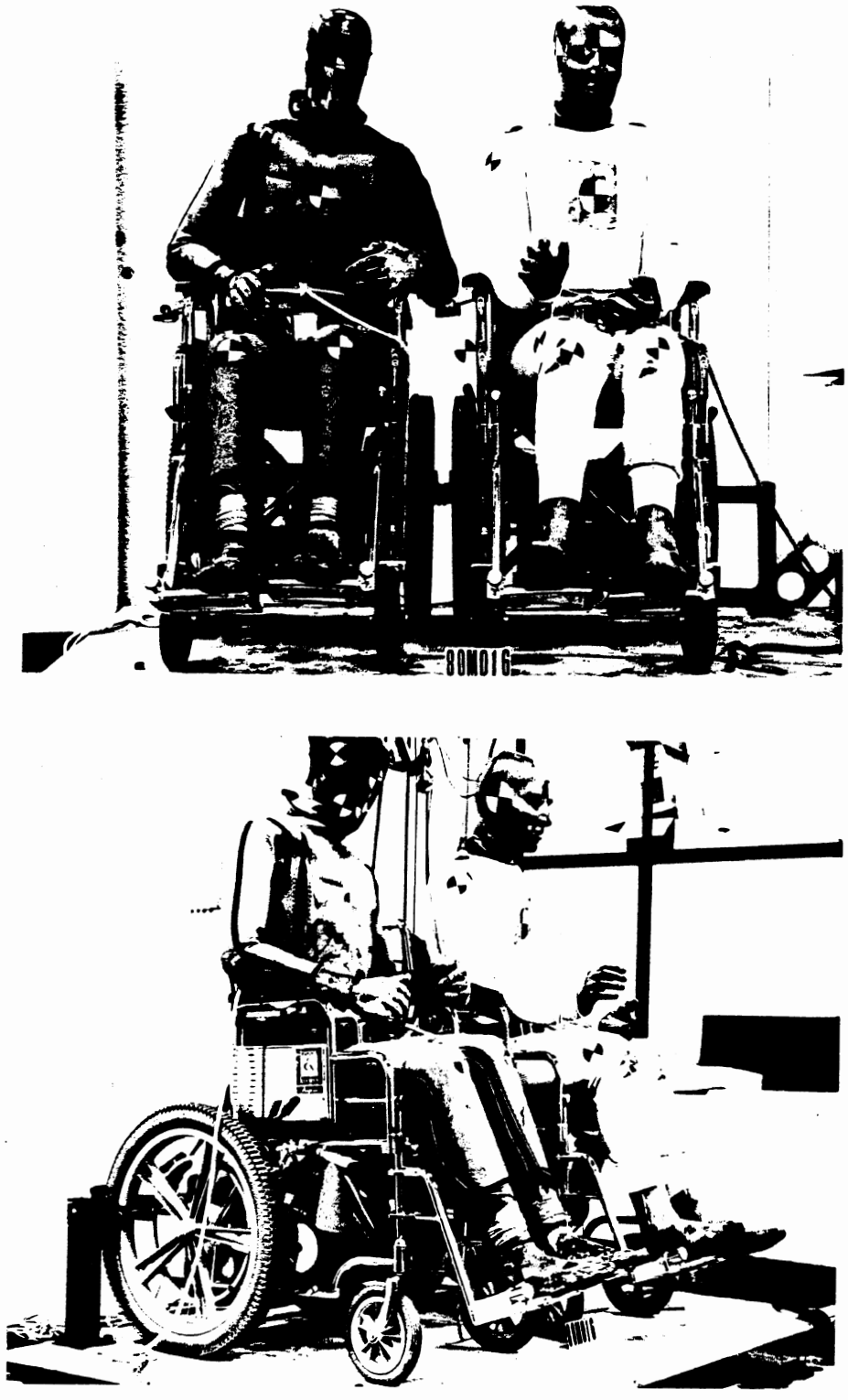
Two wheelchairs were restrained facing sideways on the sled by a Bud Industries double chair rim pin stanchion. Two 50th-percentile male dummies were restrained by lap belts anchored to the rim pin brackets on the stanchion. The chairs were positioned as far to the rear of the sled as possible, and the 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 dummies in the chairs.

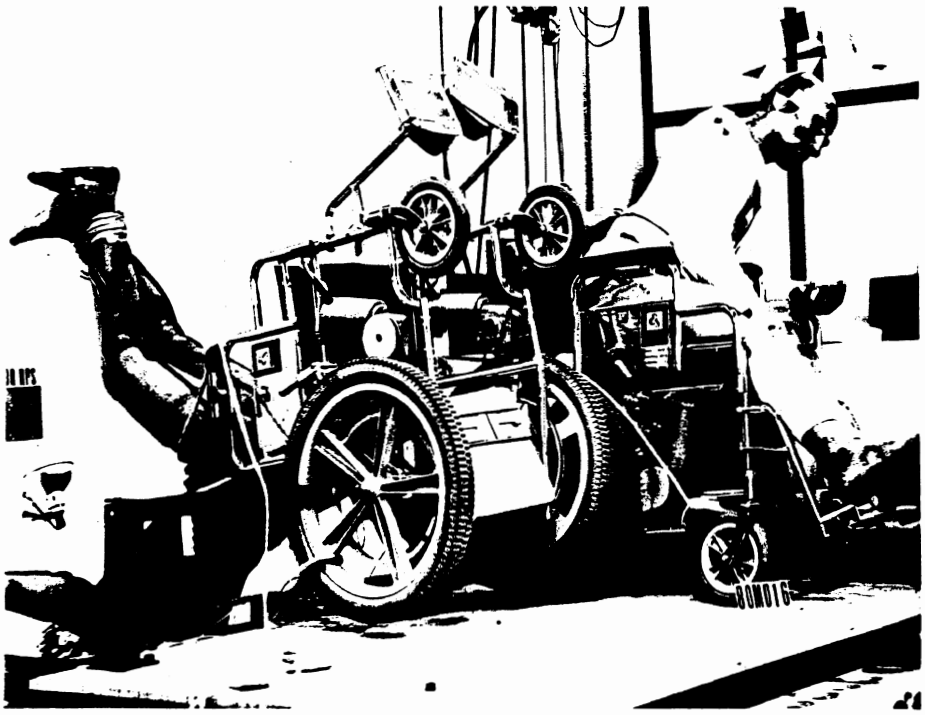
Peak Belt Loads (lbs)

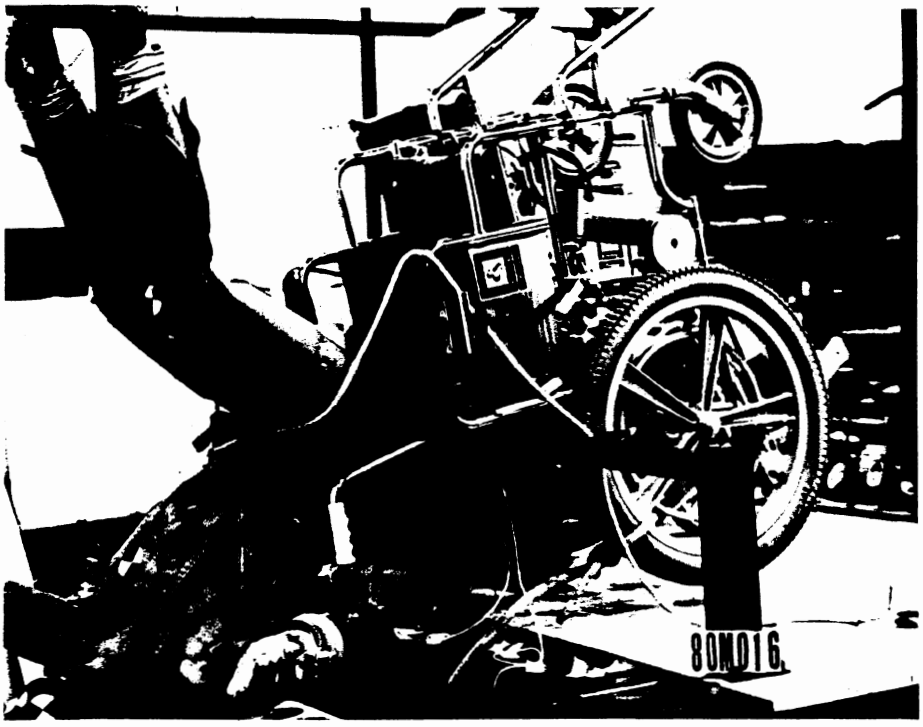
Left lap (front)	- 600
Right lap (front)	- 470
Left lap (rear)	- 350
Right lap (rear)	- 720



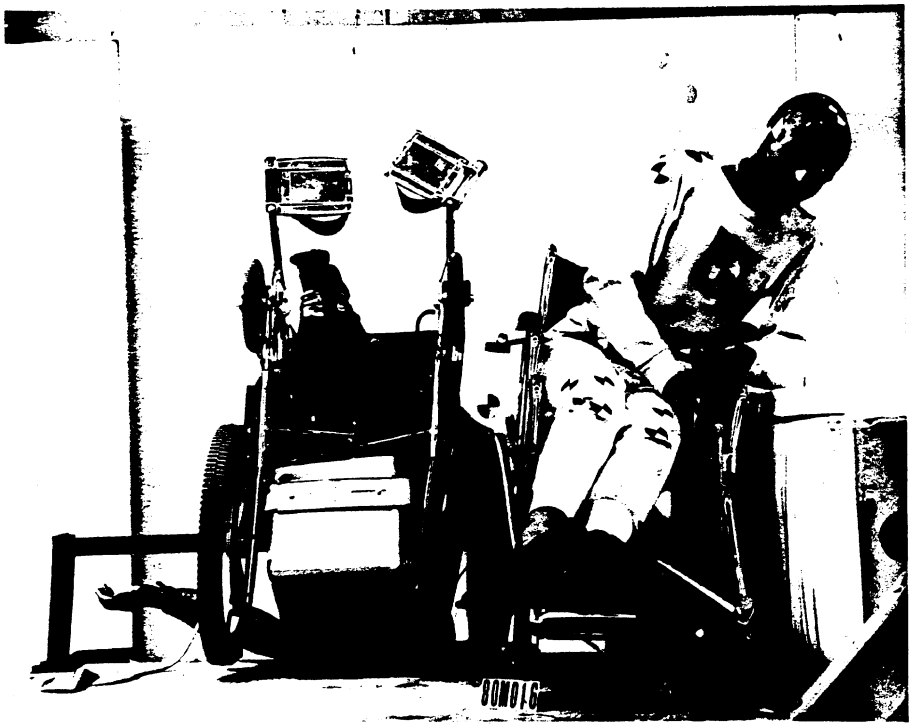
Set-Up Photos for Test 80M016

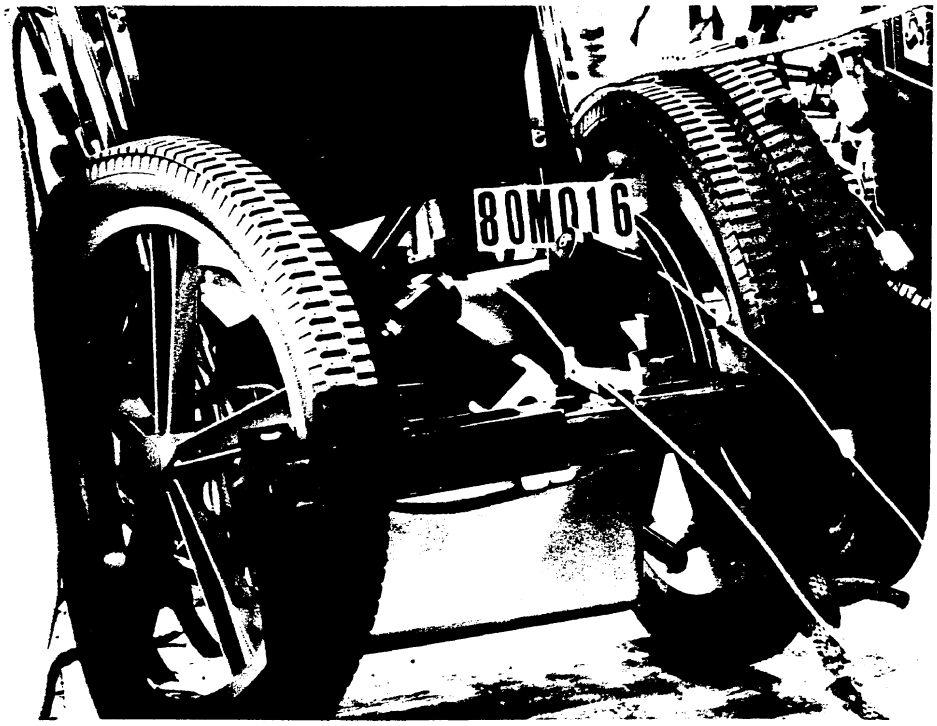
Set-Up Photo for Test 80M016



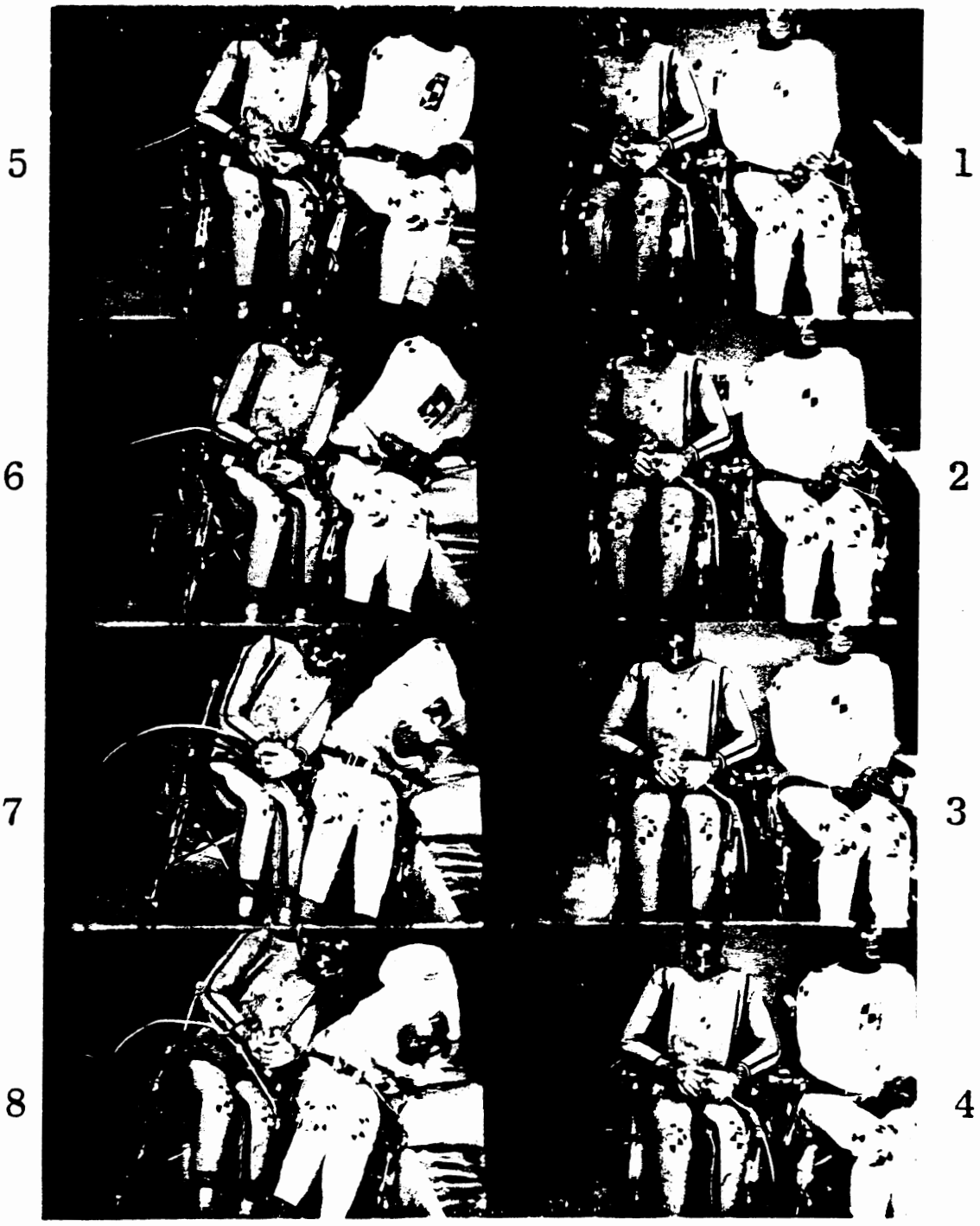


Post-Impact Photos for Test 80M016





Post Impact Photos for Test 80M016



80M016

Time Sequence Photo for Test 80M016

TEST NO.
80M017

Setup

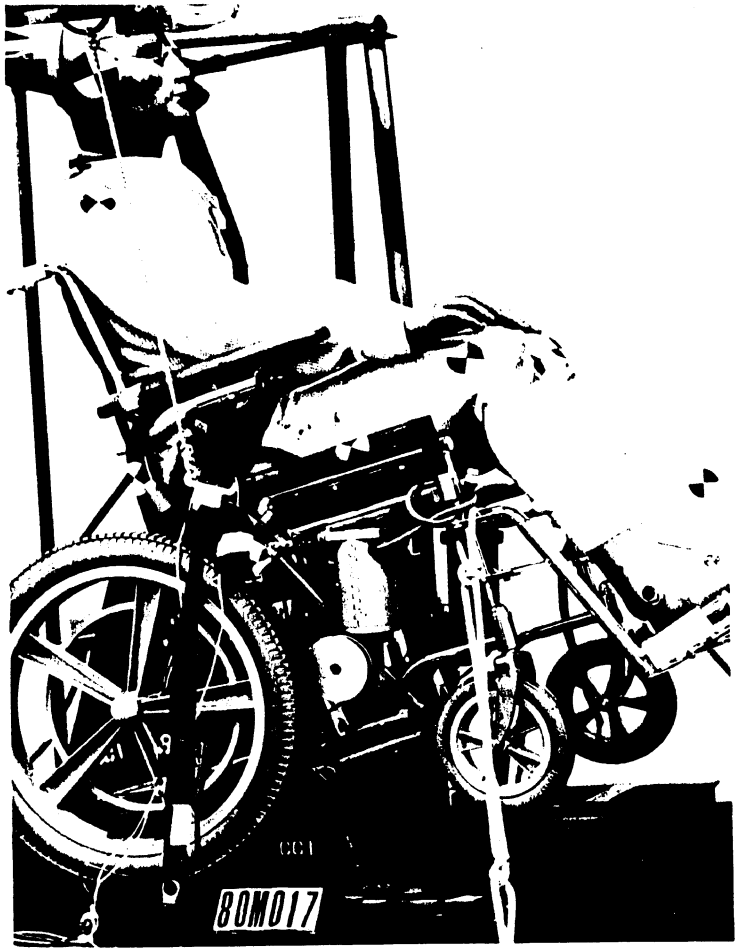
The wheelchair was restrained facing forward on the sled by a Creative Controls, Inc. (CCI) tie-down system consisting of a restraint platform bolted to the sled and triangular steel plates and bars attached to the wheelchair itself. A van sheet metal floor was bolted to the sled and the CCI platform was bolted to the sheet metal with 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.

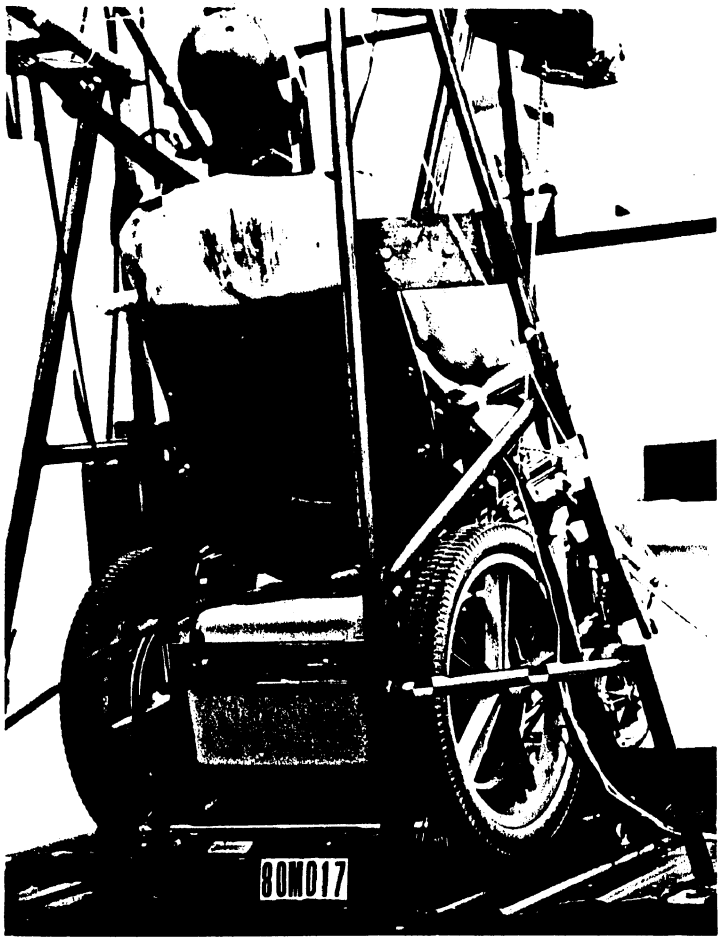
Results

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

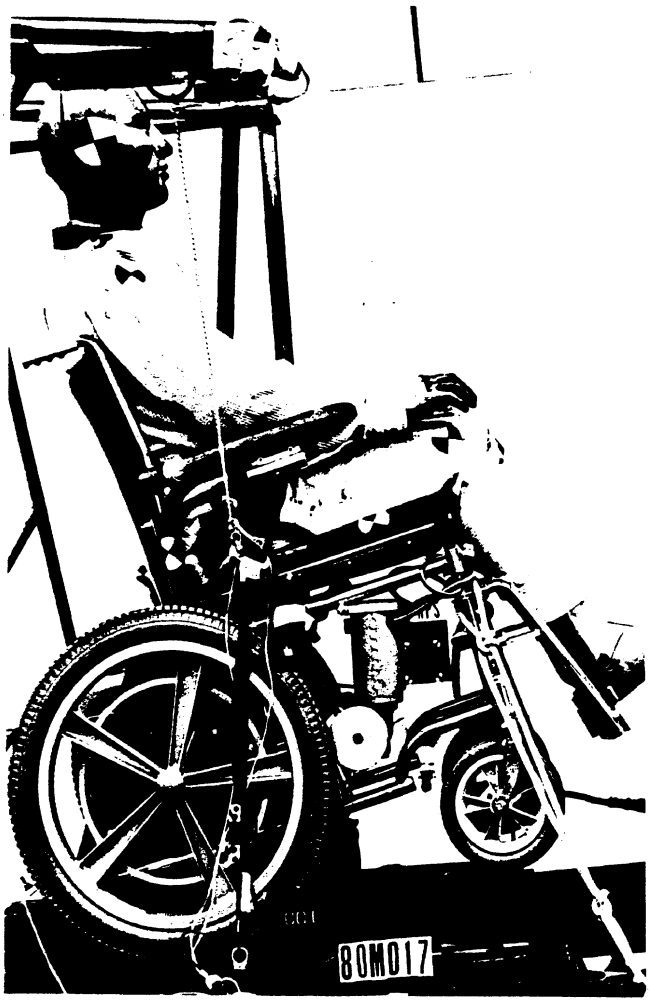
Peak Belt Loads (lbs)

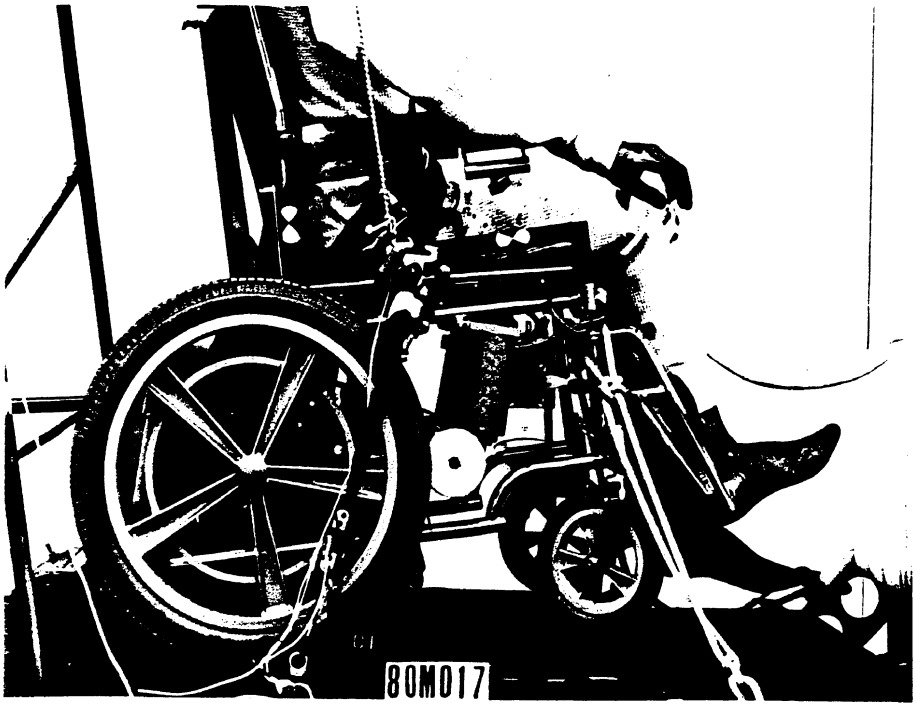
Shoulder - 1300
Right lap - 1000
Left lap - 1050



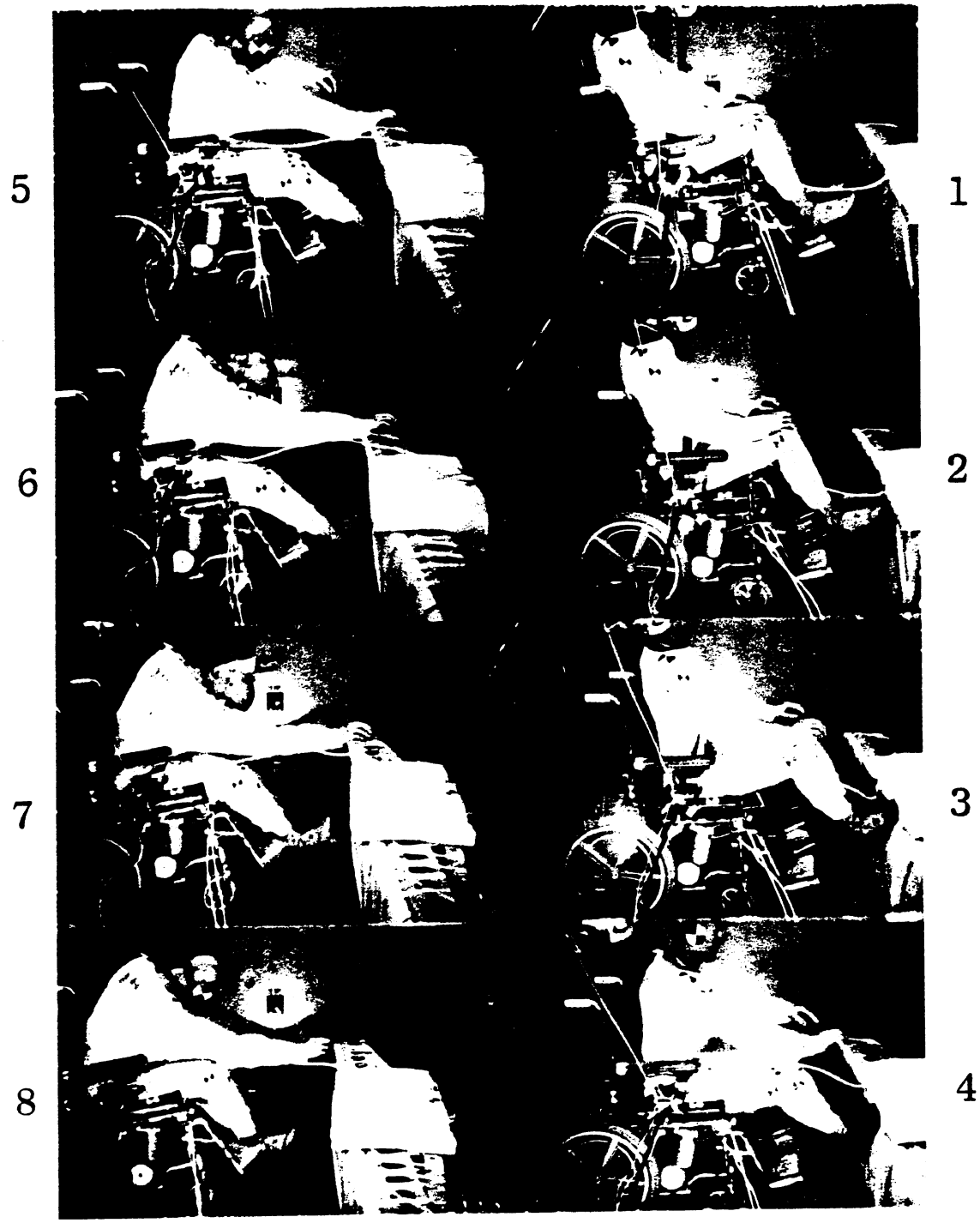


Set-Up Photos for Test 80M017





Post-Impact Photos for Test 80M017



80M017

Time Sequence Photo for Test 80M017

TEST NO.
80M018

Setup

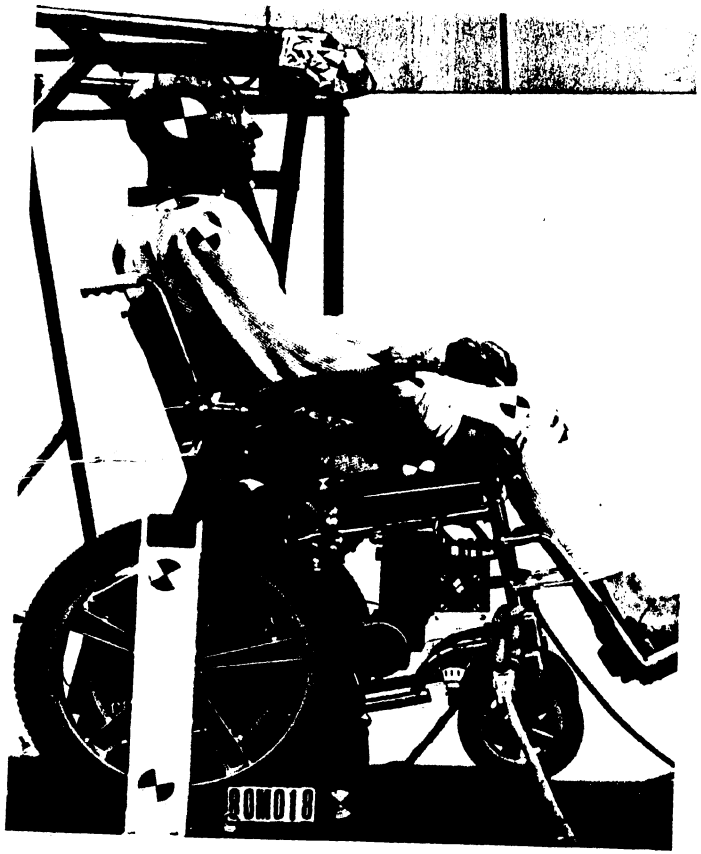
The wheelchair was restrained facing forward on the sled, using the CCI tie-down system as in test 80M017. The dummy was secured to the chair by a lap belt anchored to the CCI triangles. A passive belt system by Falcon, Inc. was used with the Bud Industries wheelchair arms to provide upper torso restraint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

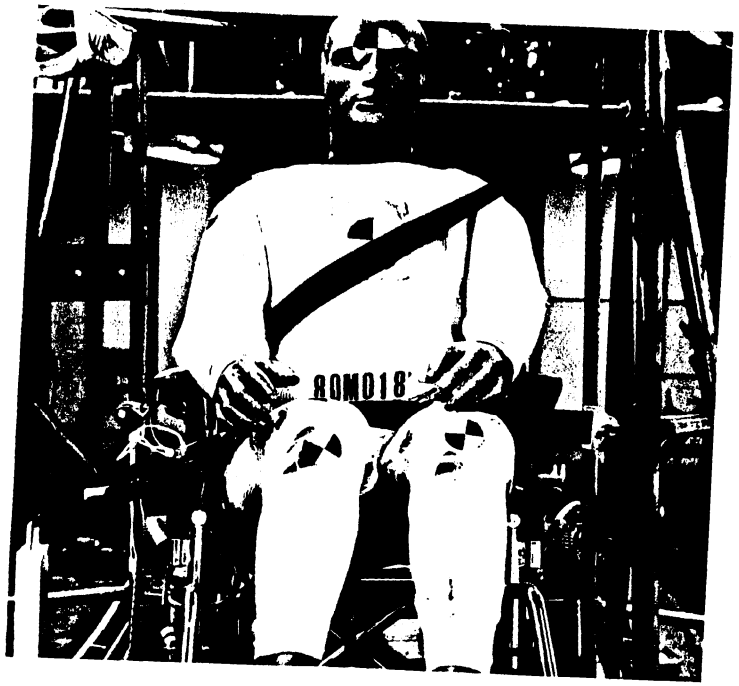
Results

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.

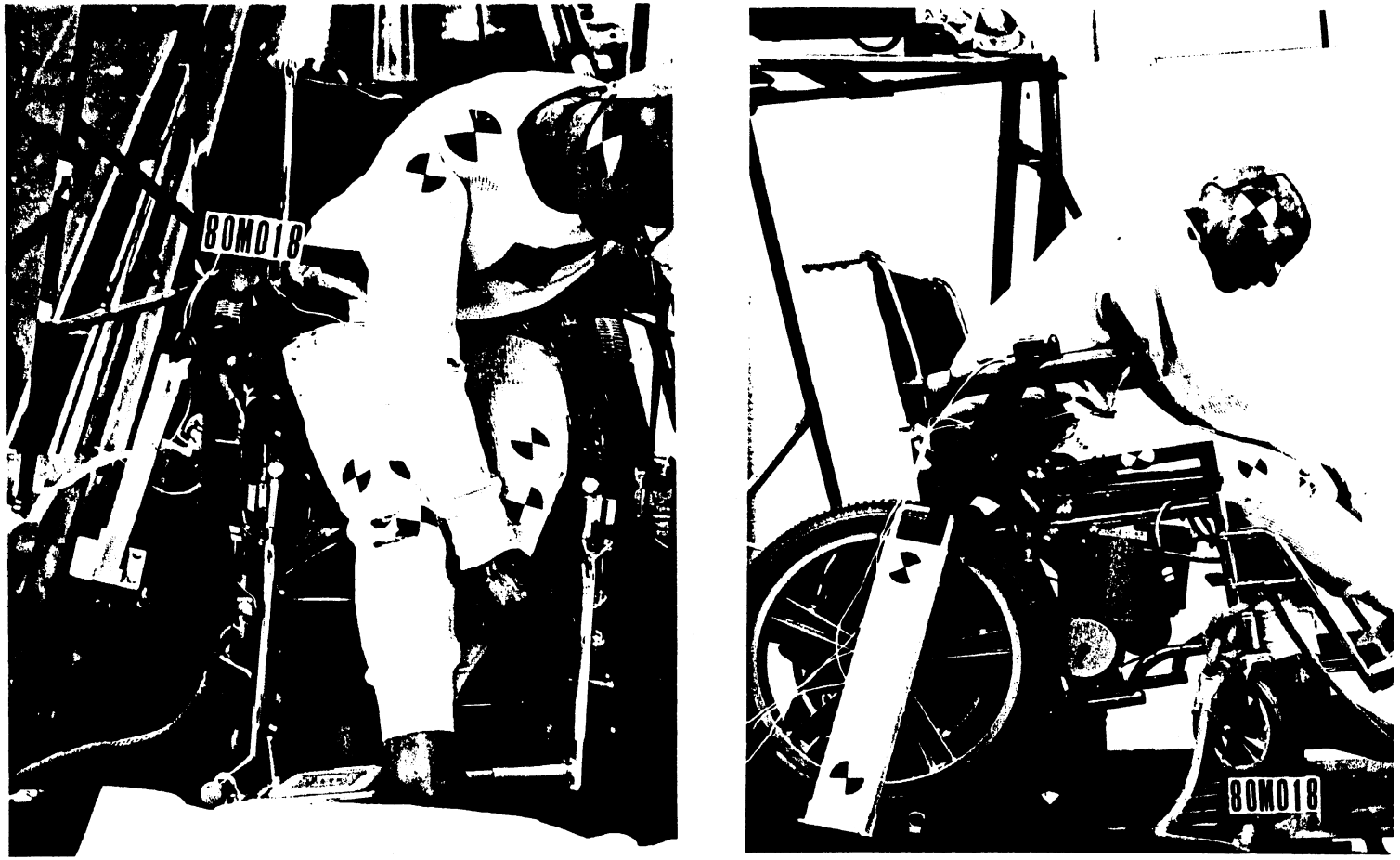
Peak Belt Loads (lbs)

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

Setup

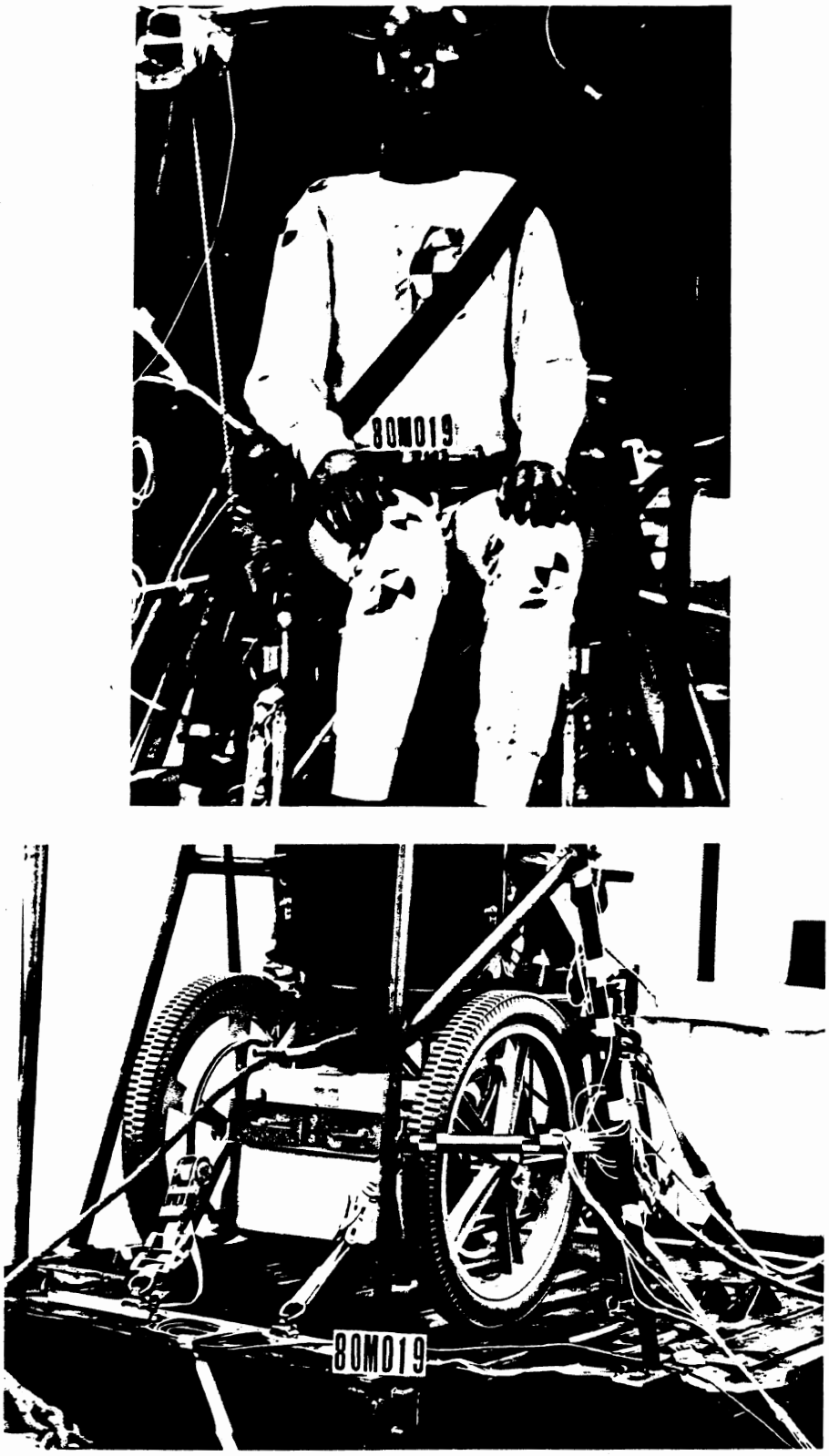
The wheelchair was restrained facing forward on the sled, using three Aeroquip straps anchored to Aeroquip "G" tracks bolted to the van sheet metal with hardened 1/4" flathead screws at 1-1/2" intervals. Two 1/8" thick by 2" wide steel plates running the length of the "G" tracks were placed under the 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

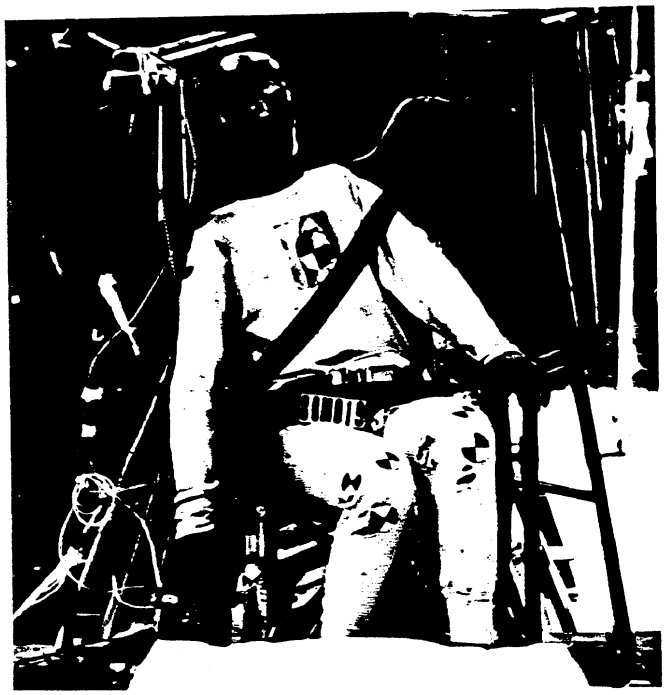
Both rear Aeroquip plugs pulled out of the "G" track simultaneously due to fracturing of metal collars on the plugs. The Bud passive belt system provided good occupant restraint, taking an extra load after the Aeroquip plugs released.

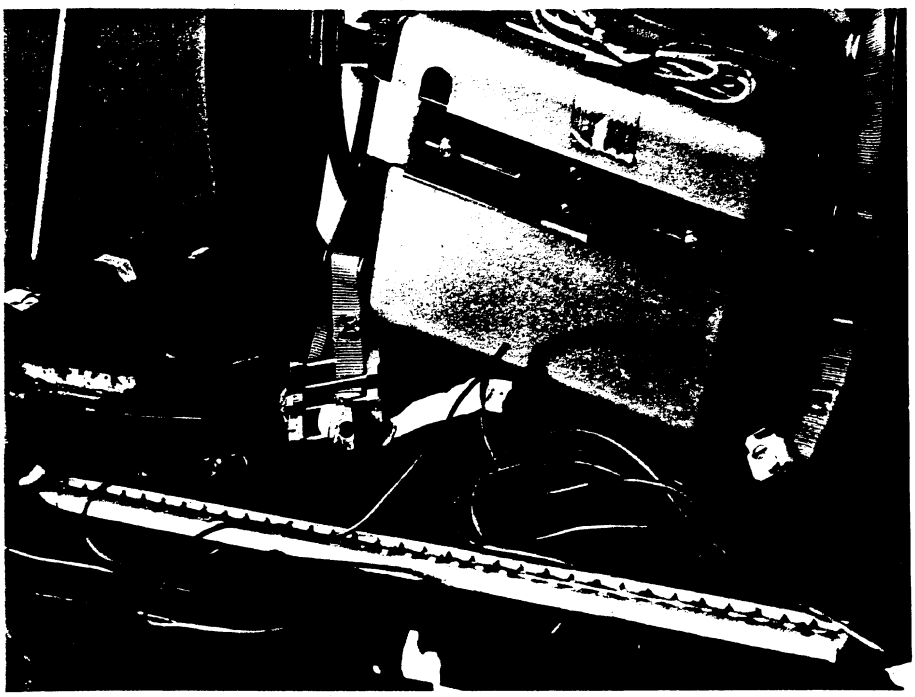
Peak Belt Loads (lbs)

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

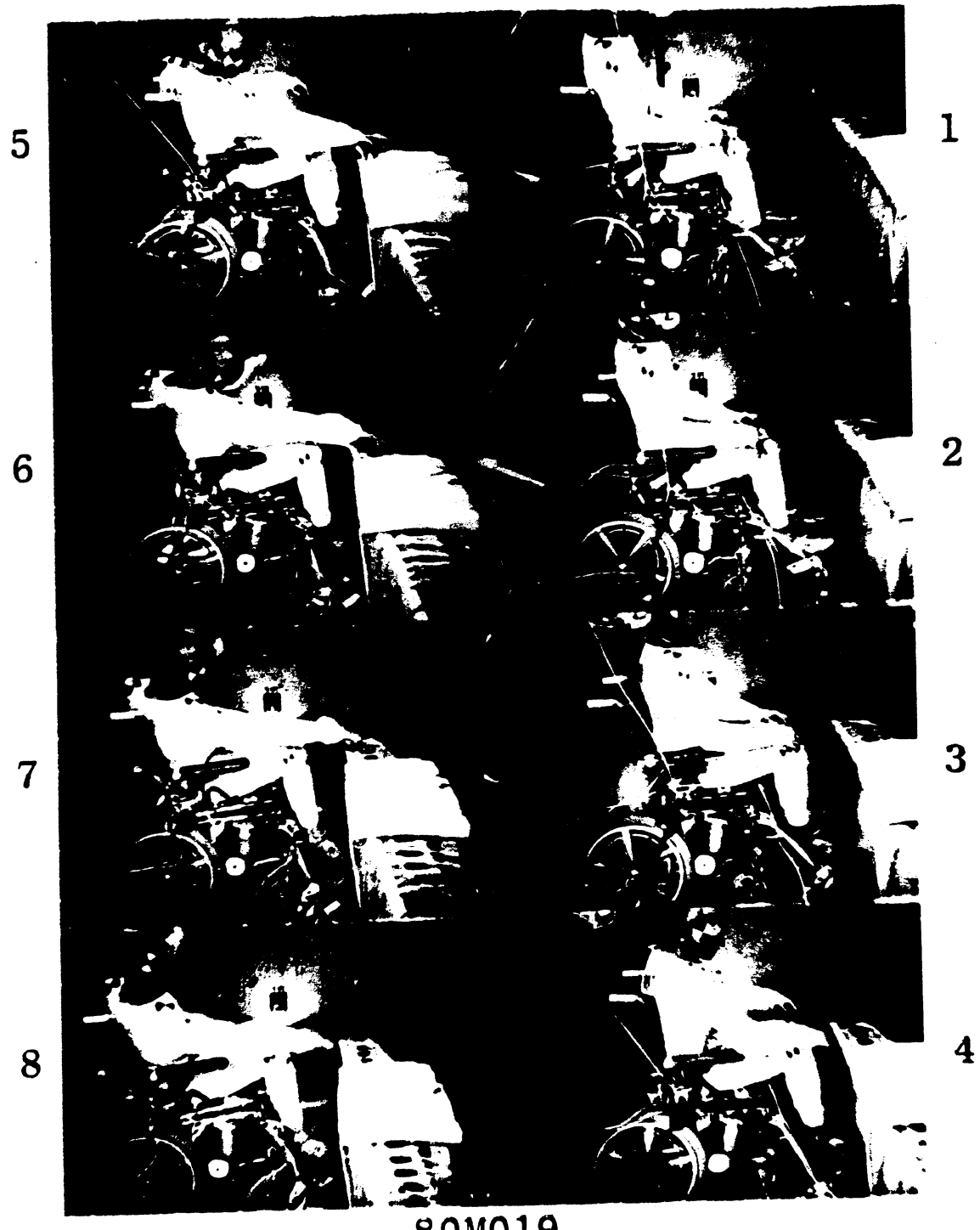


Set-Up Photos for Test 80M019





Post-Impact Photos for Test 80M019



Time Sequence Photo for Test 80M019

TEST NO.
80M020

Setup

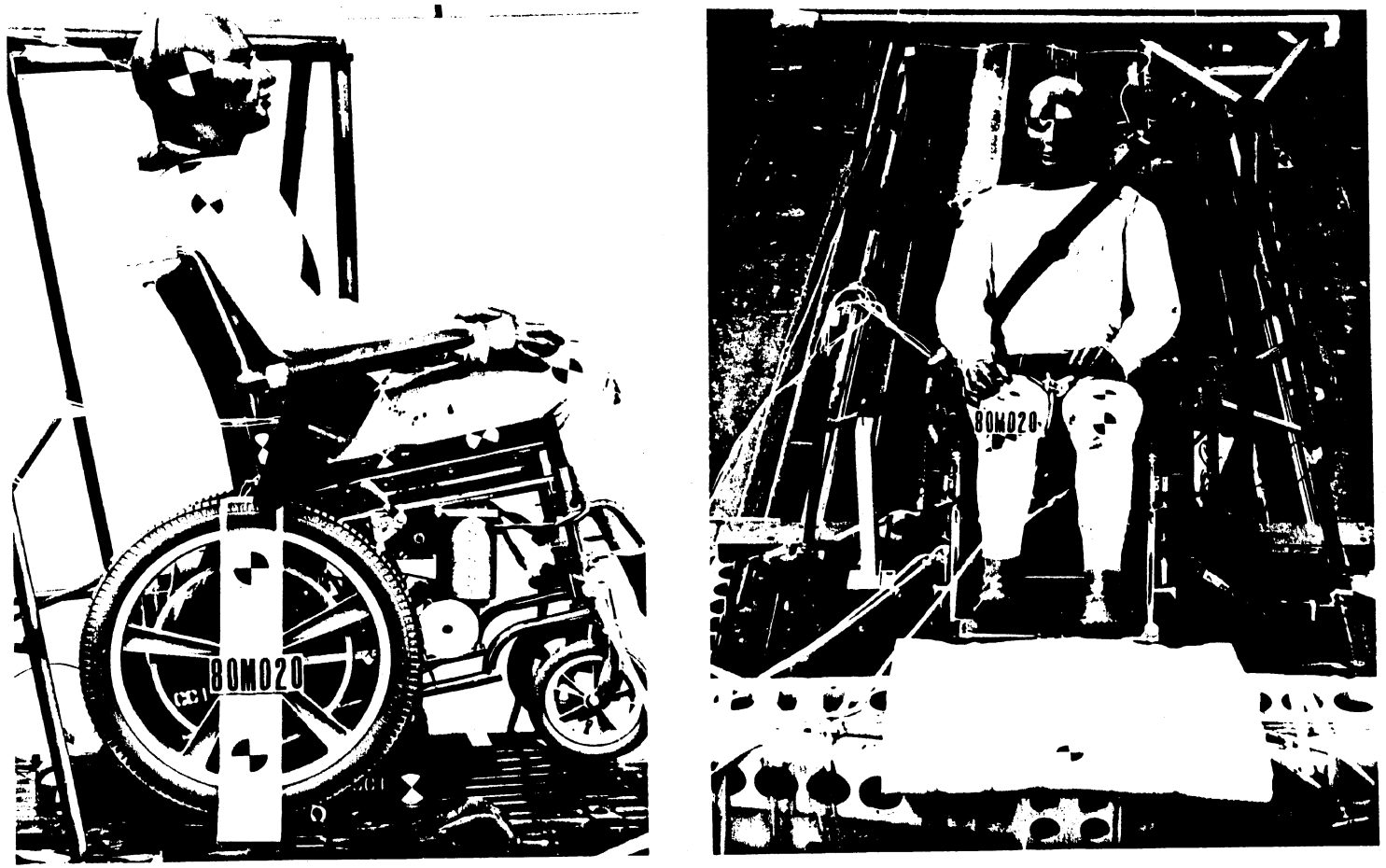
The wheelchair and dummy were restrained facing forward on the sled by the same tie-downs (CCI) and belt system (Falcon and lap) as used in test 80M018. The sheet metal was bolted to the sled more securely around the Falcon post, and an angle bracket was used to replace the left shoulder anchor fixture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

Results

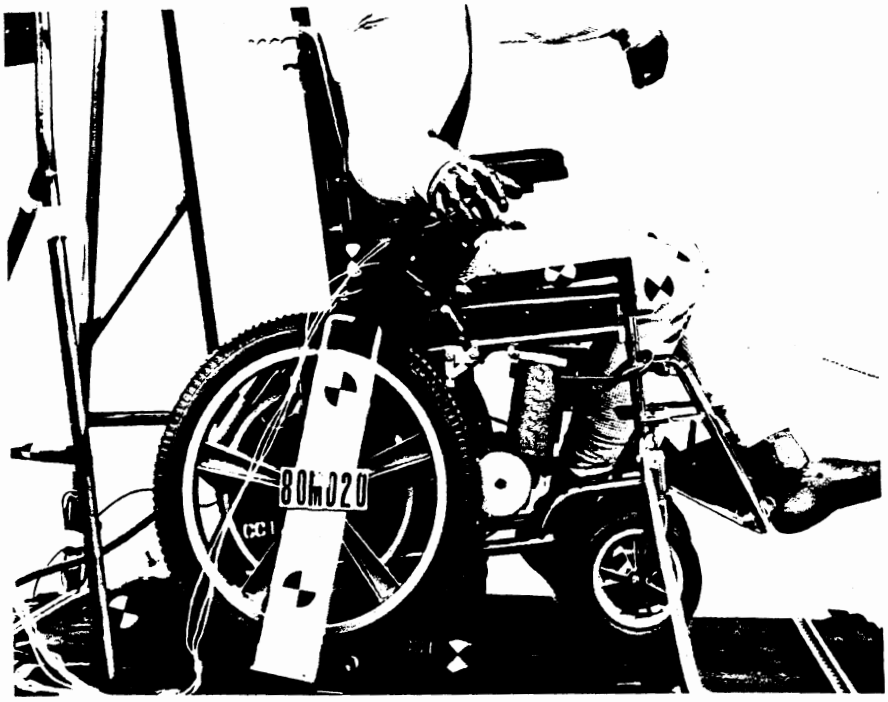
This system provided excellent wheelchair and dummy restraint. The post leaned over slightly due to deformation of the sheet metal, but the upper torso restraint was still quite effective.

Peak Belt Loads (lbs)

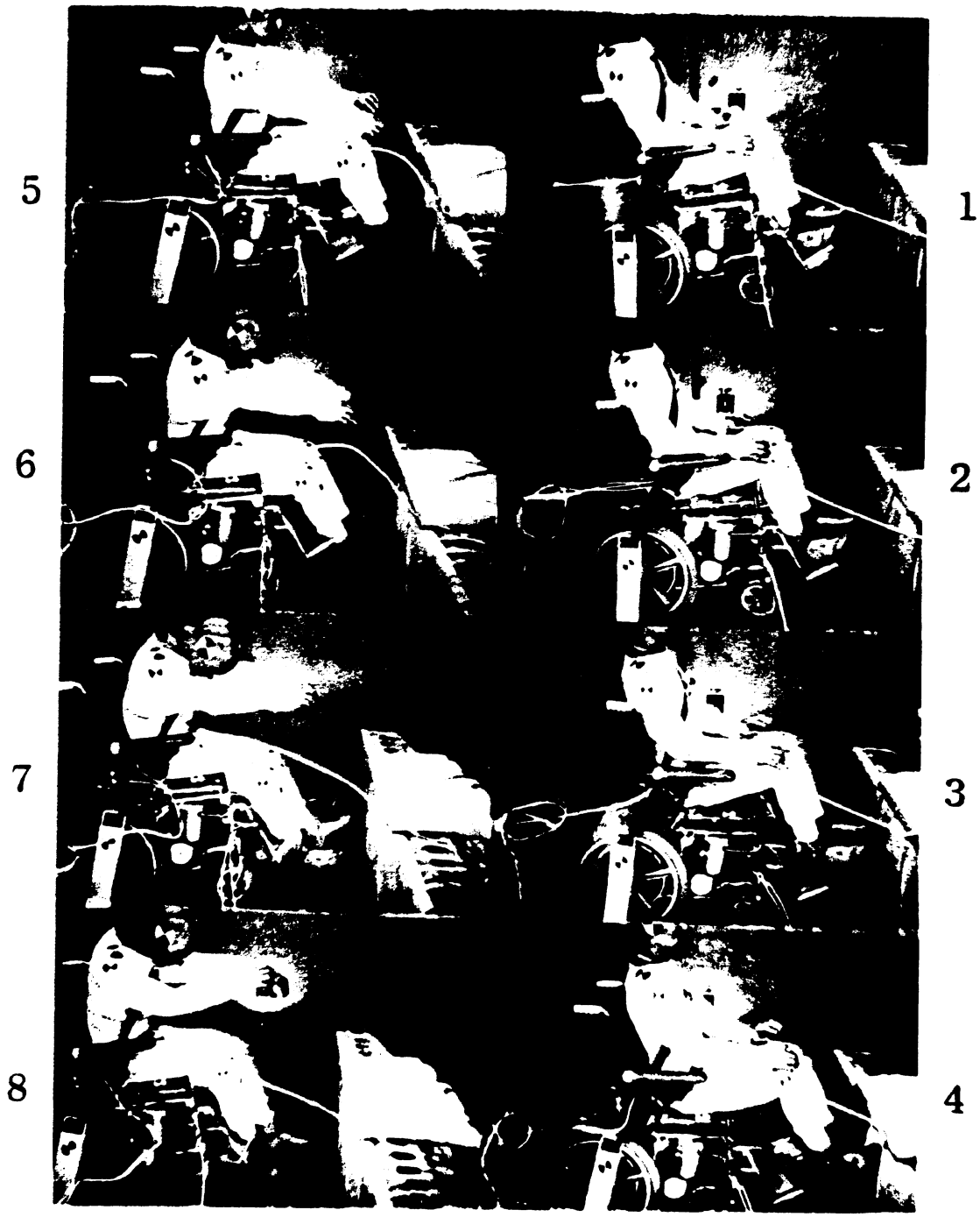
Shoulder	- 1600
Right lap	- 900
Left lap	- 1300
Passive lap	- 640



Set-Up Photos for Test 80M020



Post-Impact Photo for Test 80M020



Time Sequence Photo for Test 80M020

TEST NO.
80M021

Setup

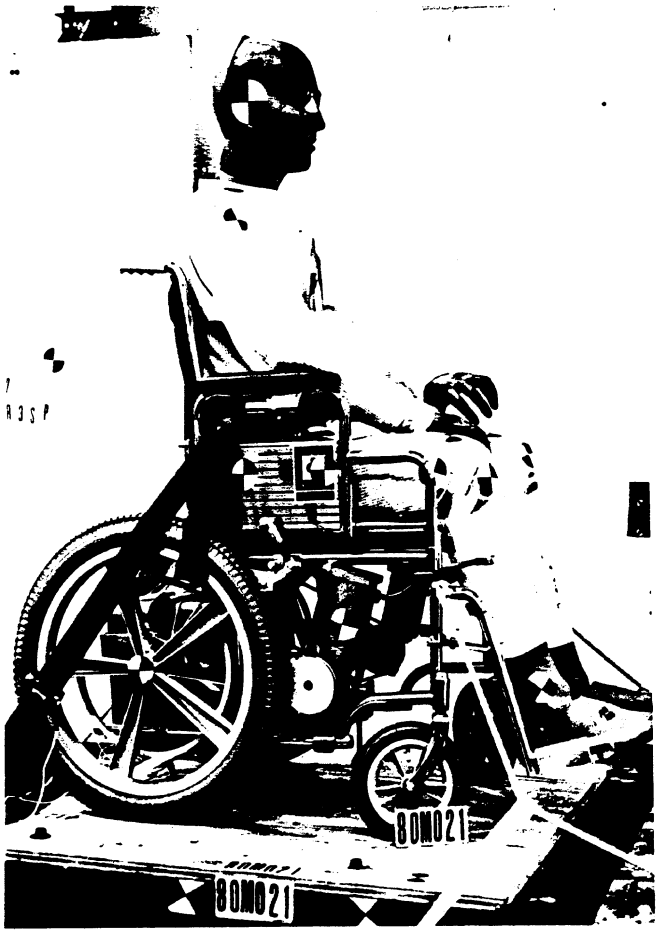
The wheelchair was restrained facing forward on the sled by a lap belt anchored to the floor, using lift ring assemblies and a T-bar also fastened to the floor by a hook bolt and lift ring assembly. The setup is the same as that for test 80M007 (minus the velcro chest belt) but all hardware was supplied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

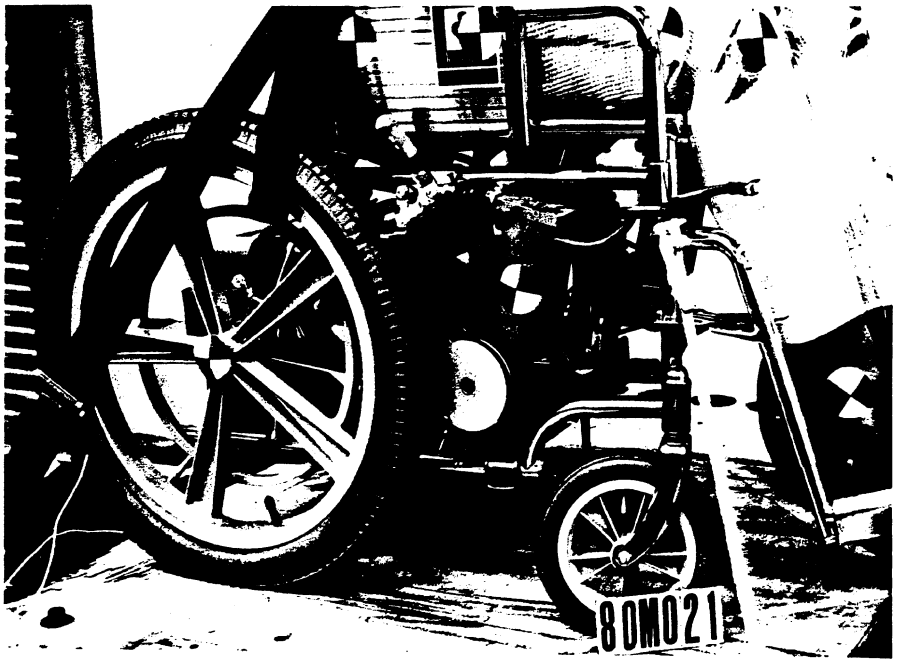
Results

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.

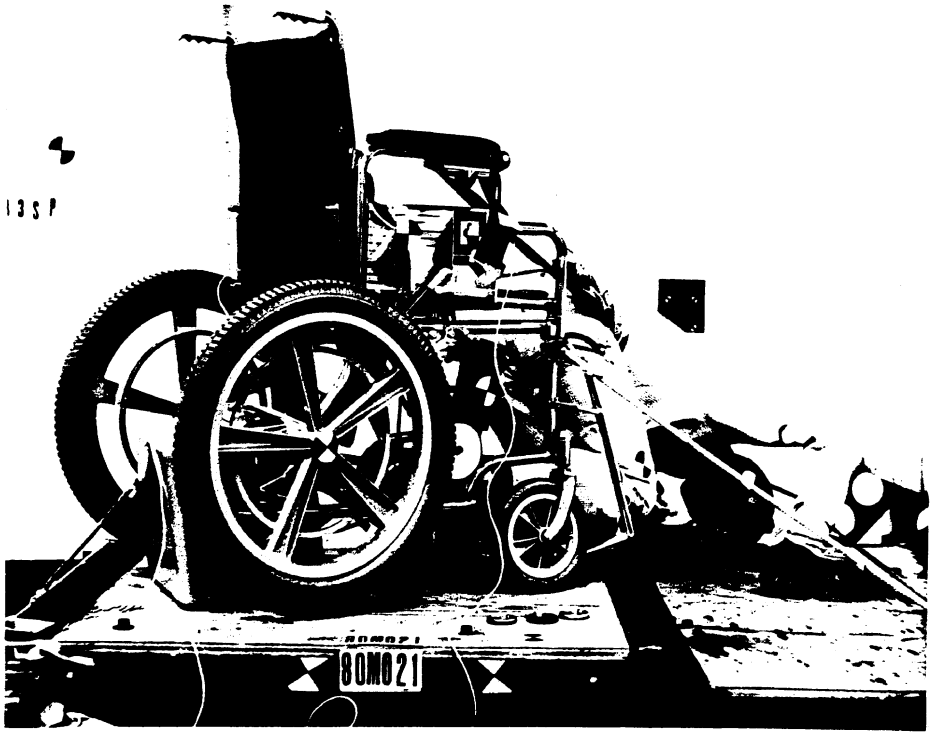
Peak Belt Loads (lbs)

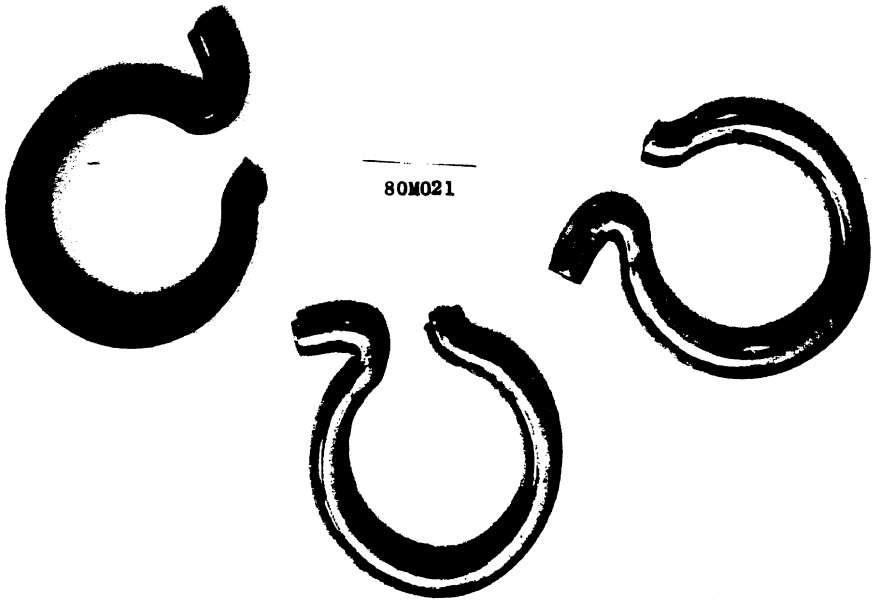
Left lap belt - 1000
Right lap belt - 1350





Set-Up Photos for Test 80M021





Post-Impact Photos for Test 80M021

Time Sequence Photo for Test 80M021

TEST NO.
80M022

Setup

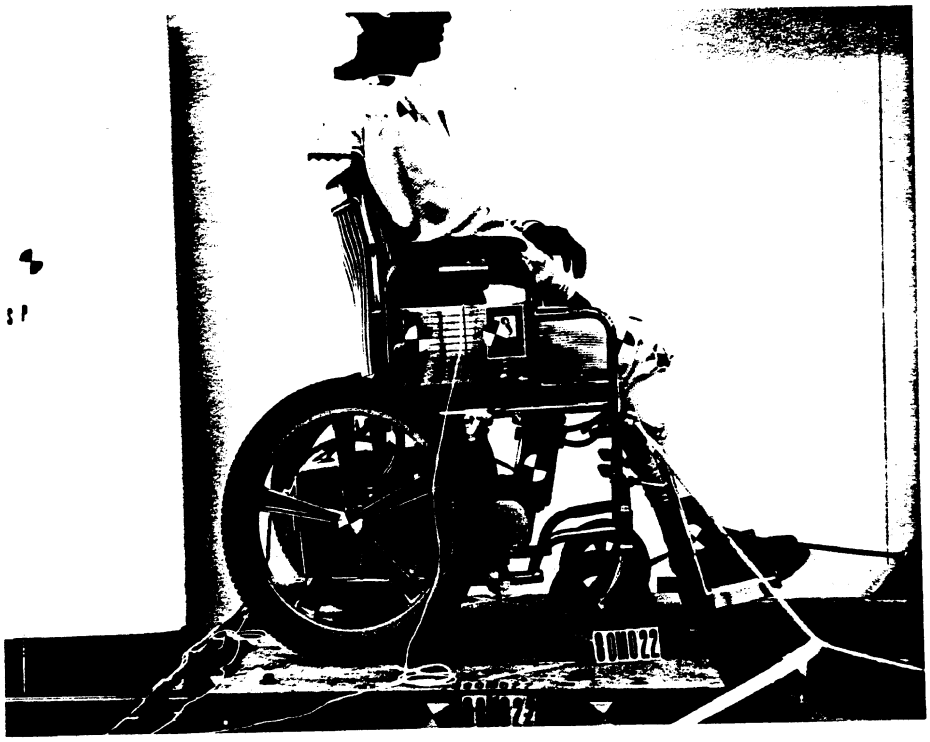
The wheelchair was restrained facing forward on the sled by a T-bar assembly from Target Industries. A heavy-duty eye bolt replaced the lift ring assembly, and the hook end of the hook bolt was welded closed around the eye bolt. The dummy was secured to the wheelchair by a lap belt attached to the back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

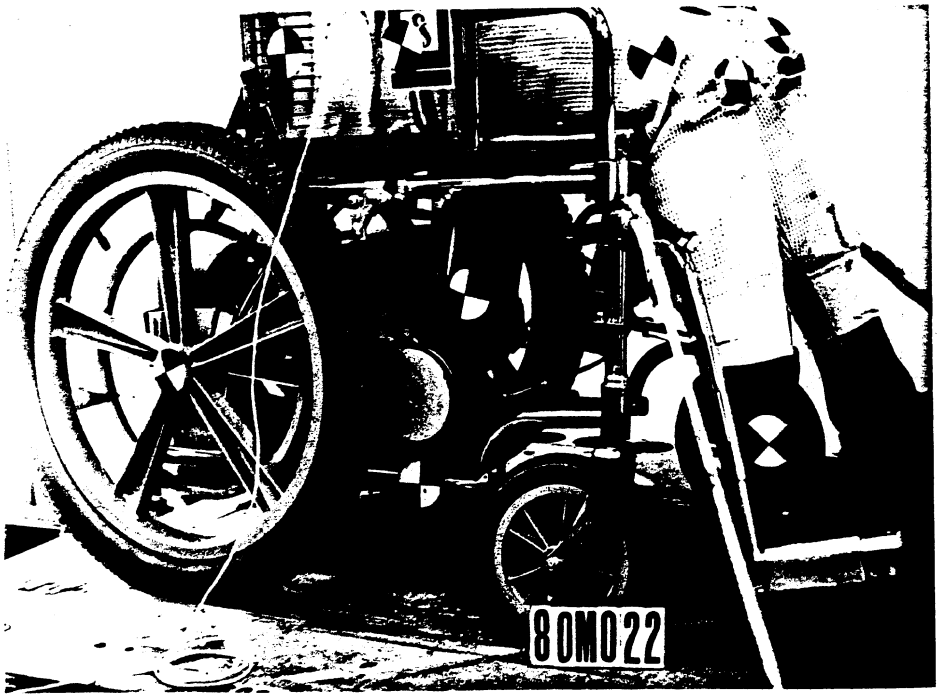
Results

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.

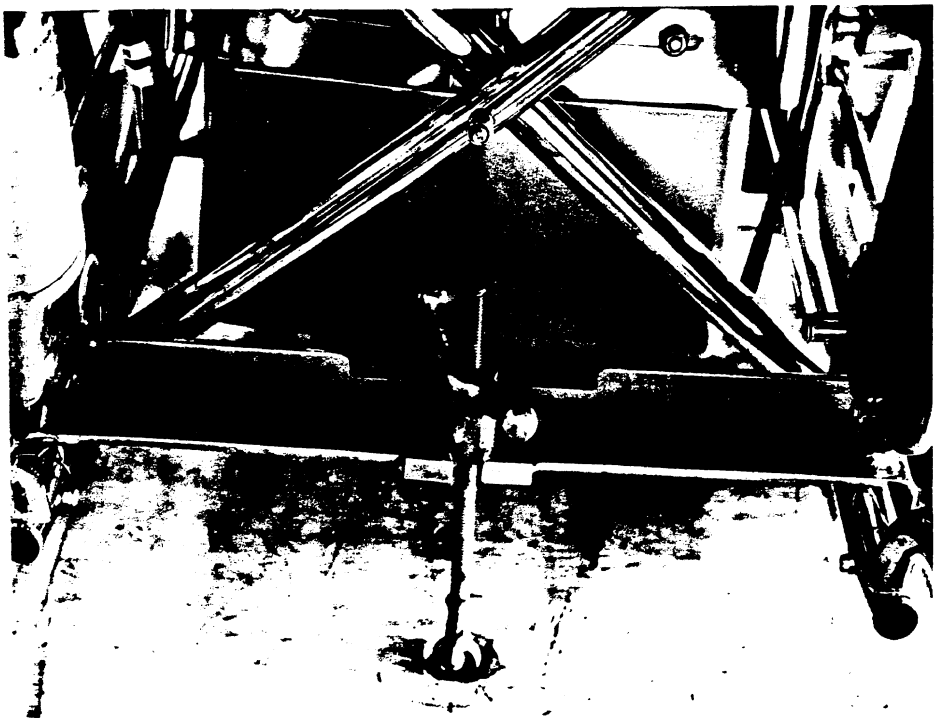
Peak Belt Loads (lbs)

Left lap - 150
Right lap - 125

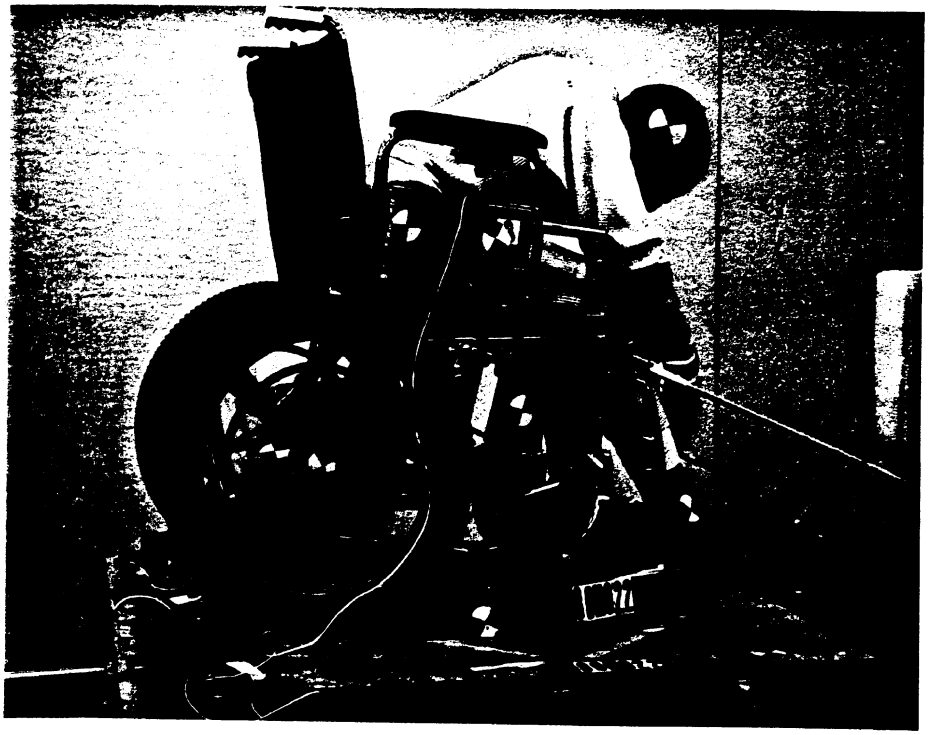




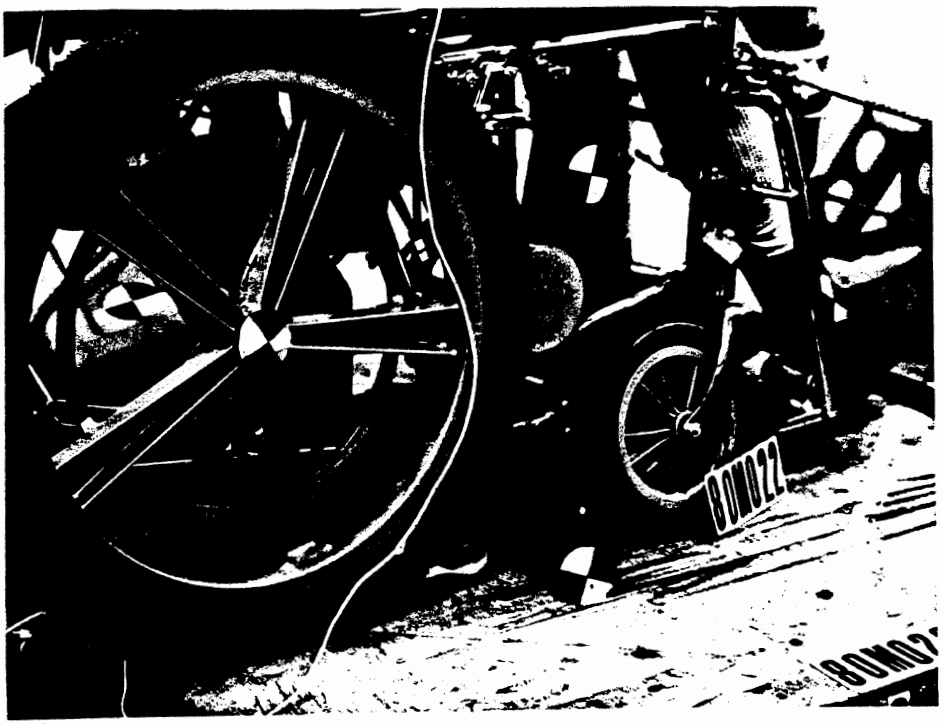
Set-Up Photos for Test 80M022

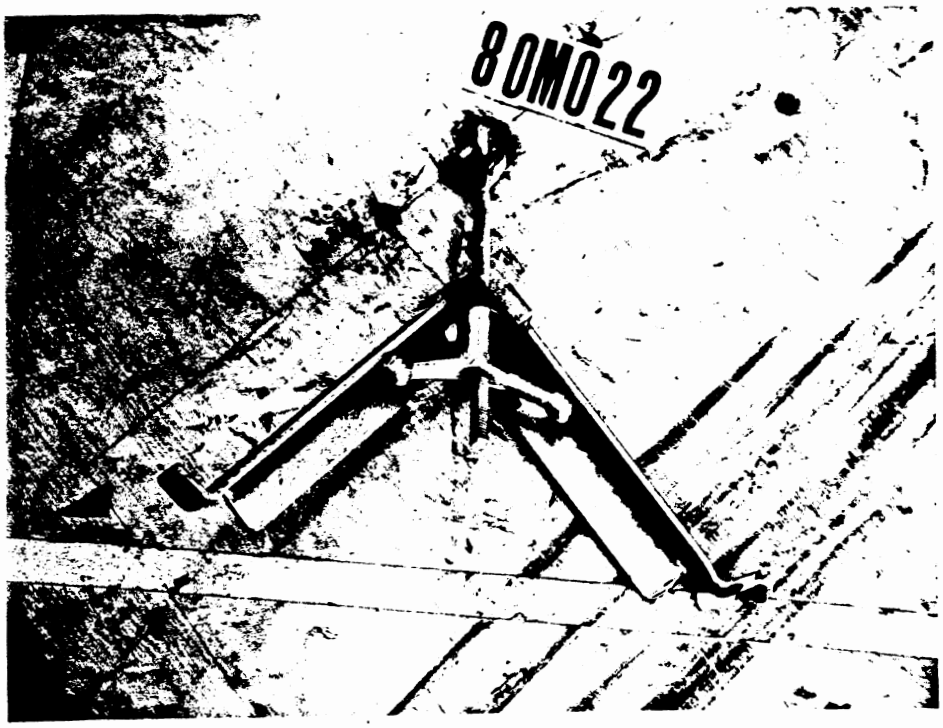


Set-Up Photo for Test 80M022

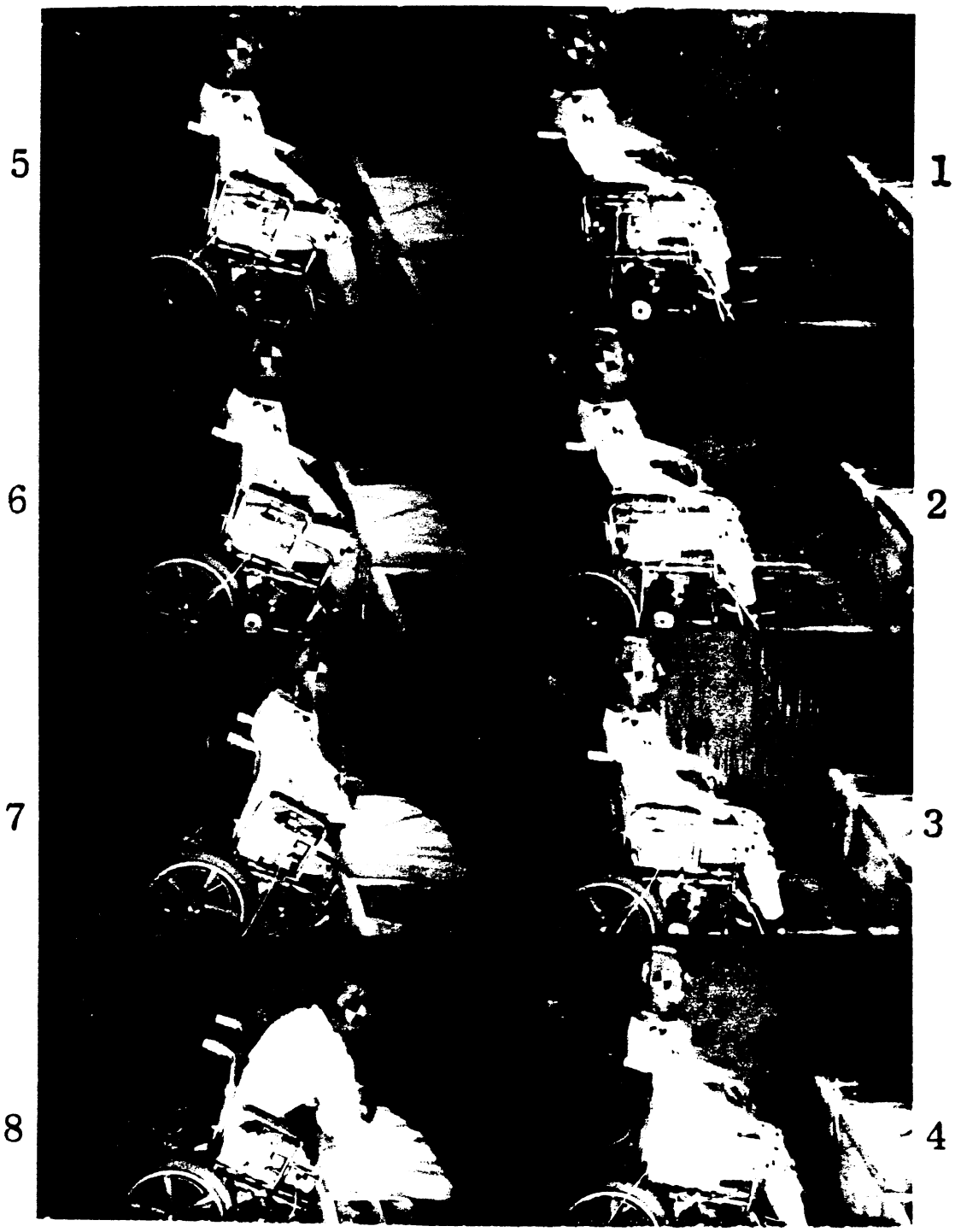


Post-Impact Photo for Test 80M022





Post-Impact Photos for Test 80M022



80M022

Time Sequence Photo for Test 80M022

TEST NO.
80M023

Setup

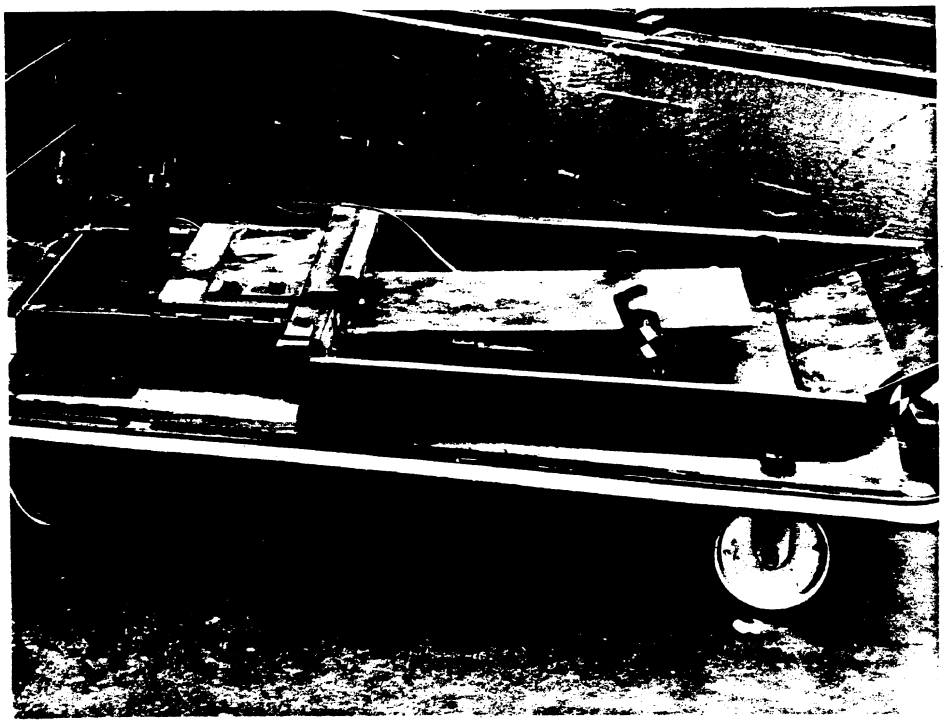
The wheelchair was restrained facing forward on the sled by a Creative Control Inc. tie-down system designed for use with the Bud power pan system. The chair is lowered into position, using the power pan actuator. When the desired position is reached, a second actuator activates the CCI system, which grabs and lifts the front steel bar through the open center of the adjustable floor pan. As the front end lifts up, the rear bar is seated in the rear retaining bracket, which is bolted to the vehicle floor. The dummy was restrained by a lap belt anchored to the CCI triangle and by the Bud 3-point passive restraint system placed over the chair arms.

Results

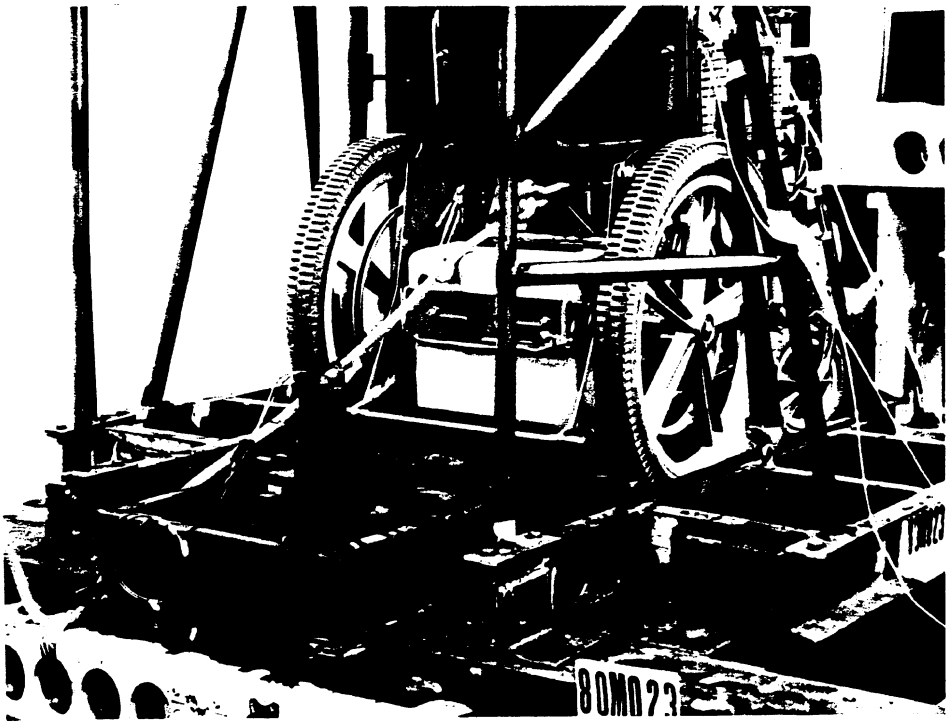
The tie-down and occupant restraint systems provided excellent restraint for the wheelchair and dummy, respectively. The lap portion of the Bud passive belt would have placed forces on the abdomen of an occupant, however. The wheelchair sustained little or no damage.

Peak Belt Loads (lbs)

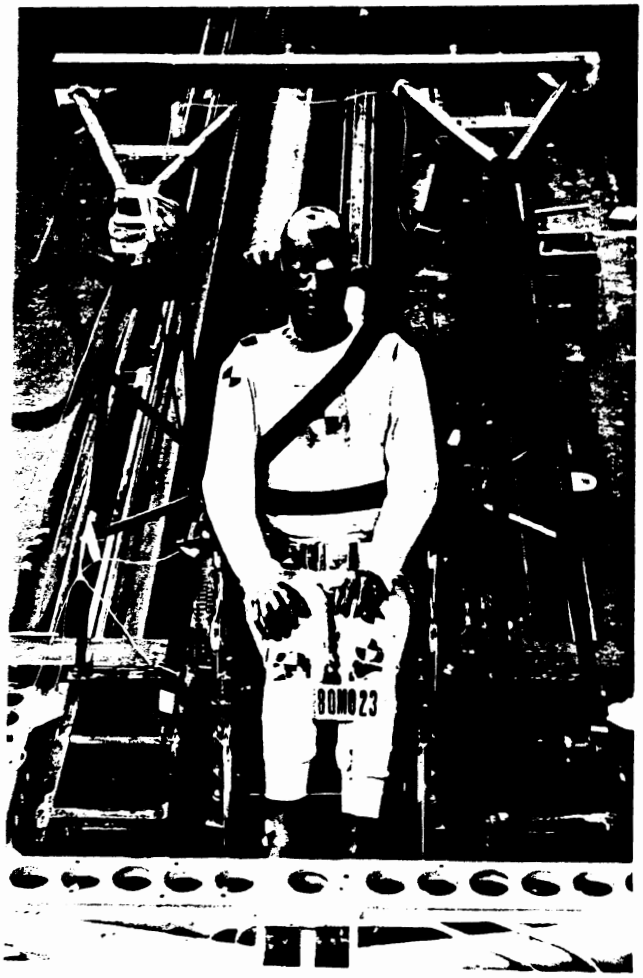
Floor	- 900
Passive shoulder	- 1300



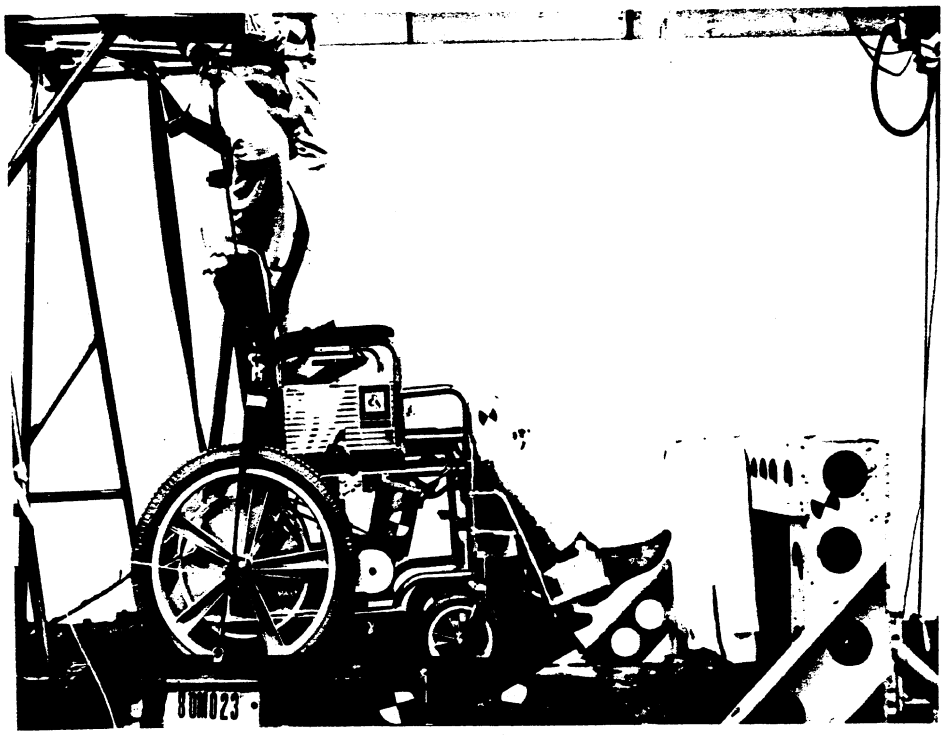
Power Pan With CCI Retrofit Securement System

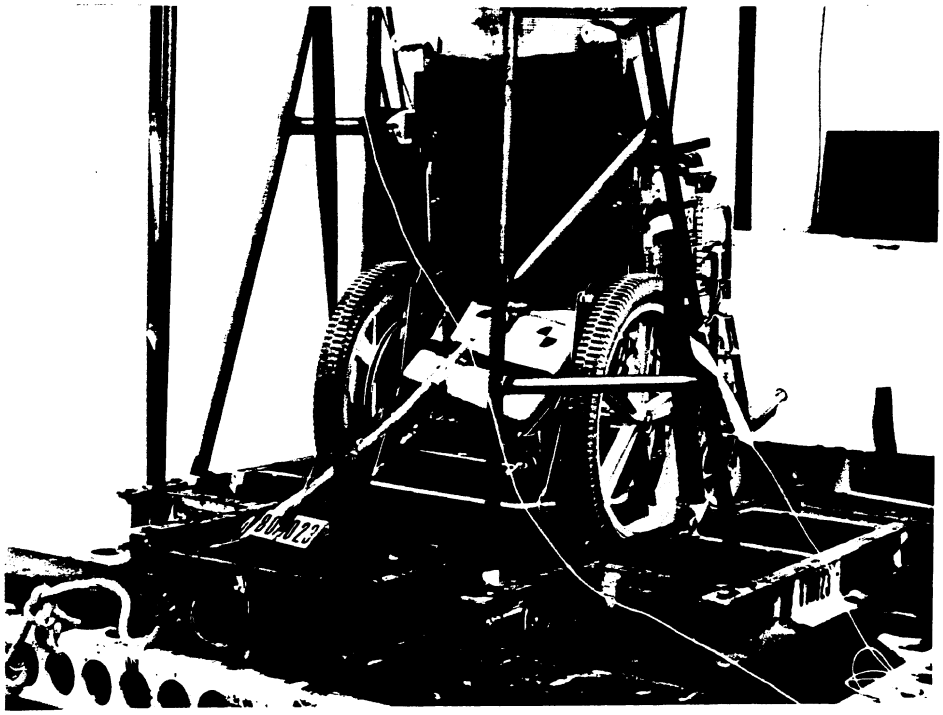


Set-up Photo for Test 80M023

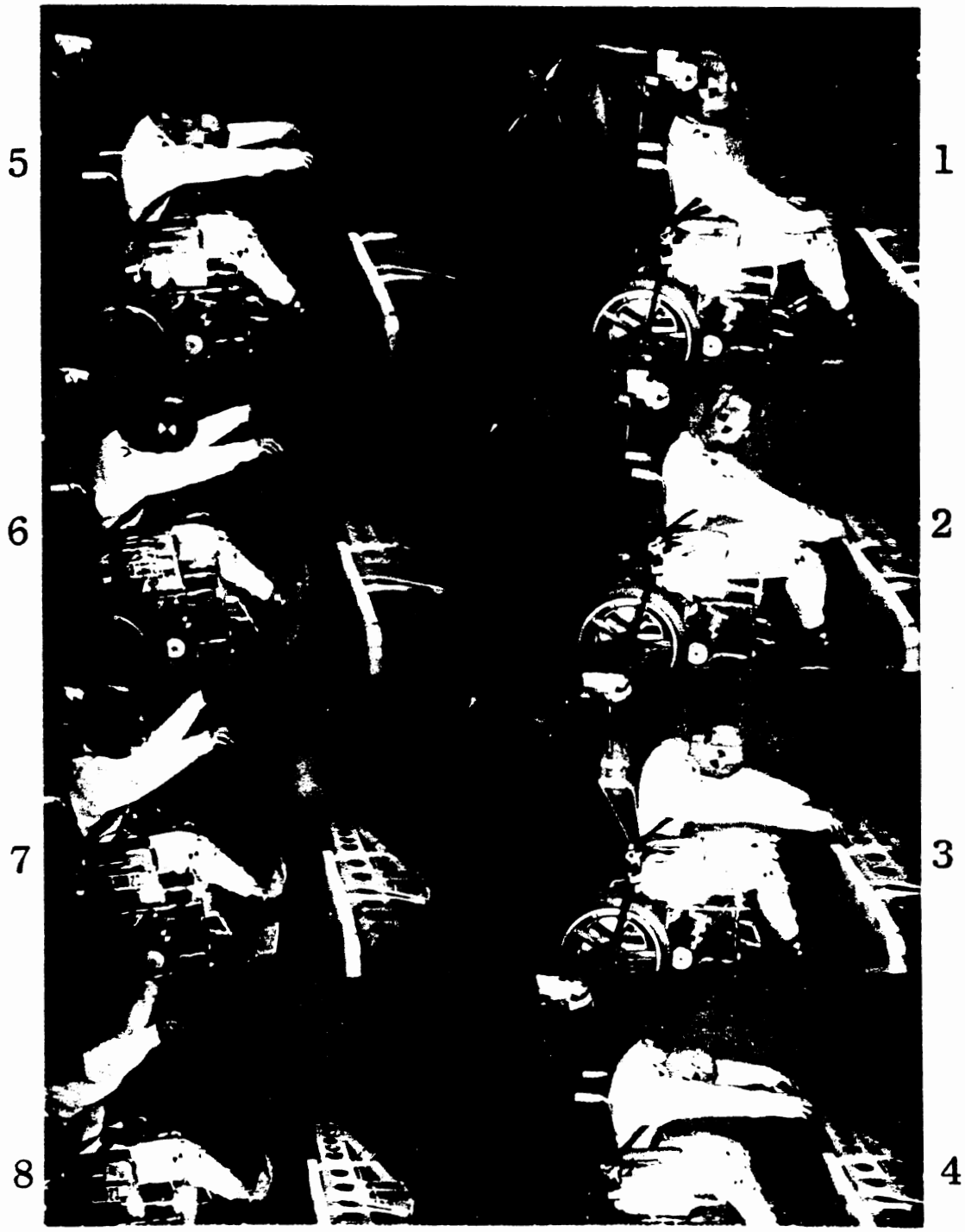


Set-up Photo for Test 80M023





Post-Impact Photos of Test 80M023



80M023

Time Sequence Photo of Test 80M023

TEST NO.
80M024

Setup

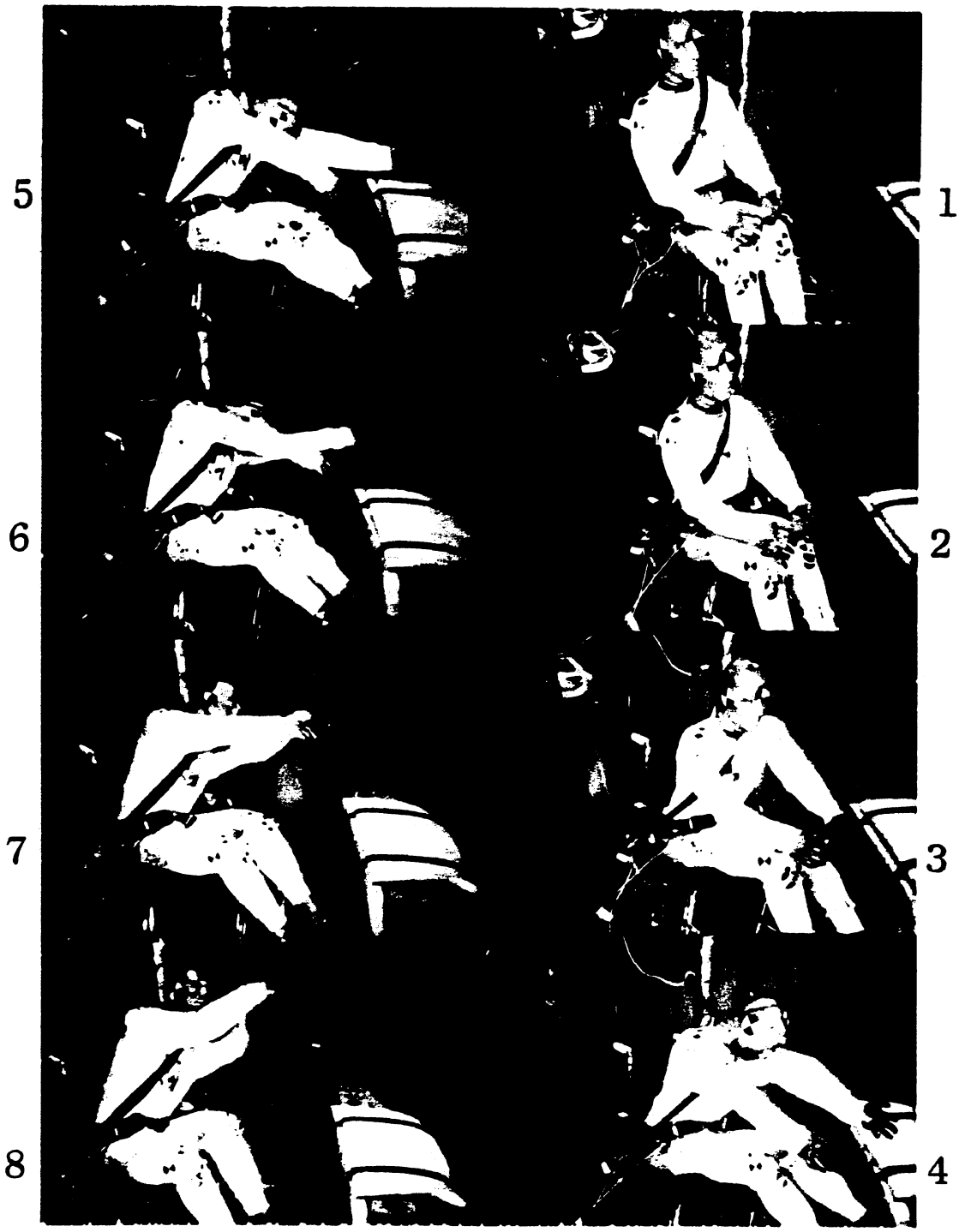
This test setup was identical to that of test 80M023 except that (1) the chair and power pan system were oriented at a 45 degree angle to the impact direction; and (2) the lap portion of the passive belt was placed under the arm rests of the chair so as to be over the pelvic bone region.

Results

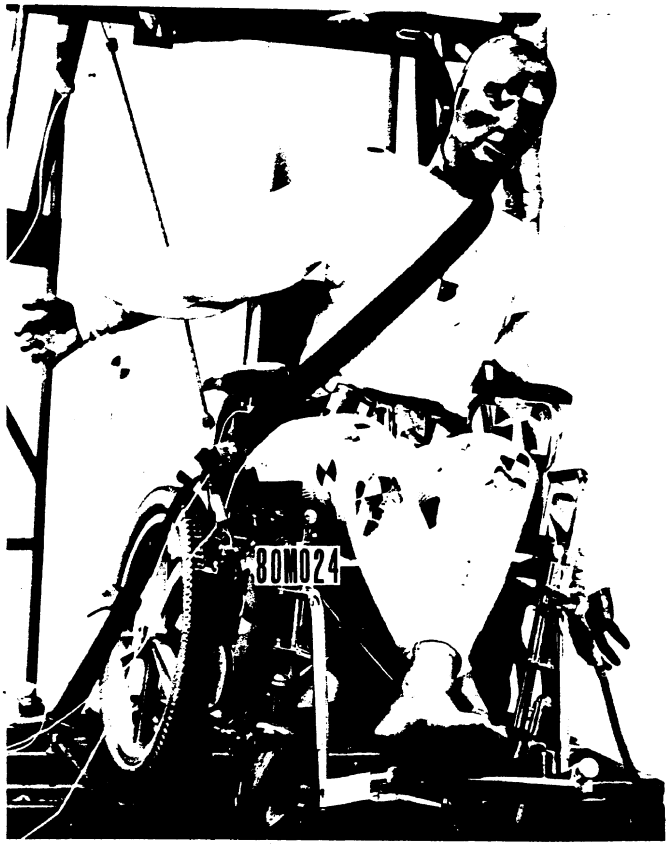
The CCI power pan retrofit tie-down system provided excellent wheelchair securement, and the chair sustained only minor damage due to the asymmetric forces. The dummy was well restrained, but the shoulder belt pressed into the dummy's neck due to the angle of impact.

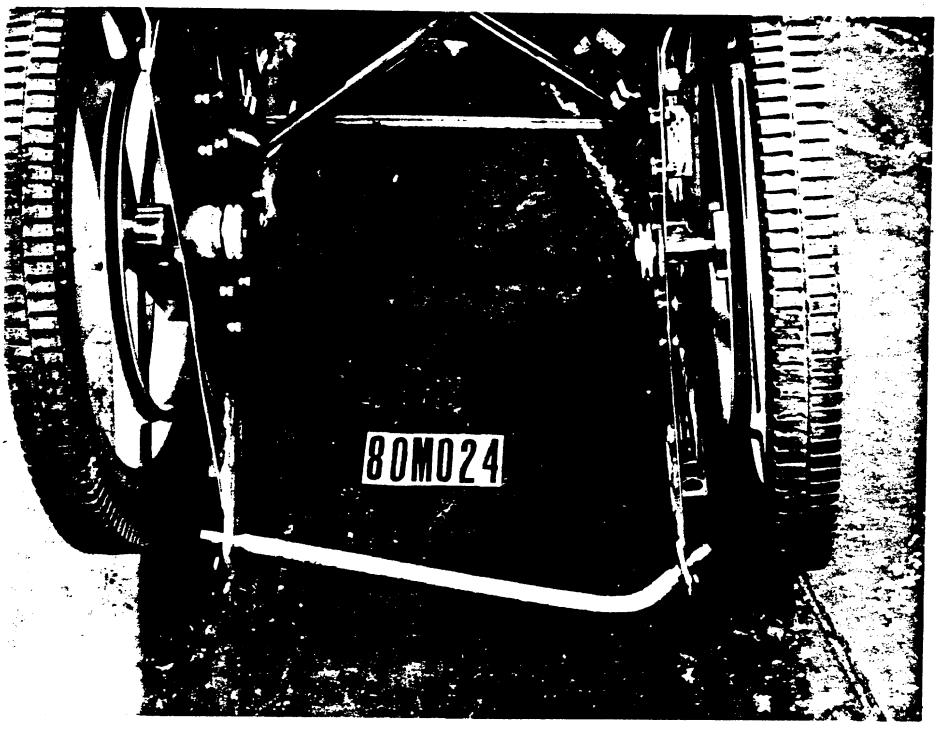
Peak Belt Loads (lbs)

Right lap (chair)	- 1050
Floor	- 1075
Passive shoulder	- 1300
Passive lap	- 200

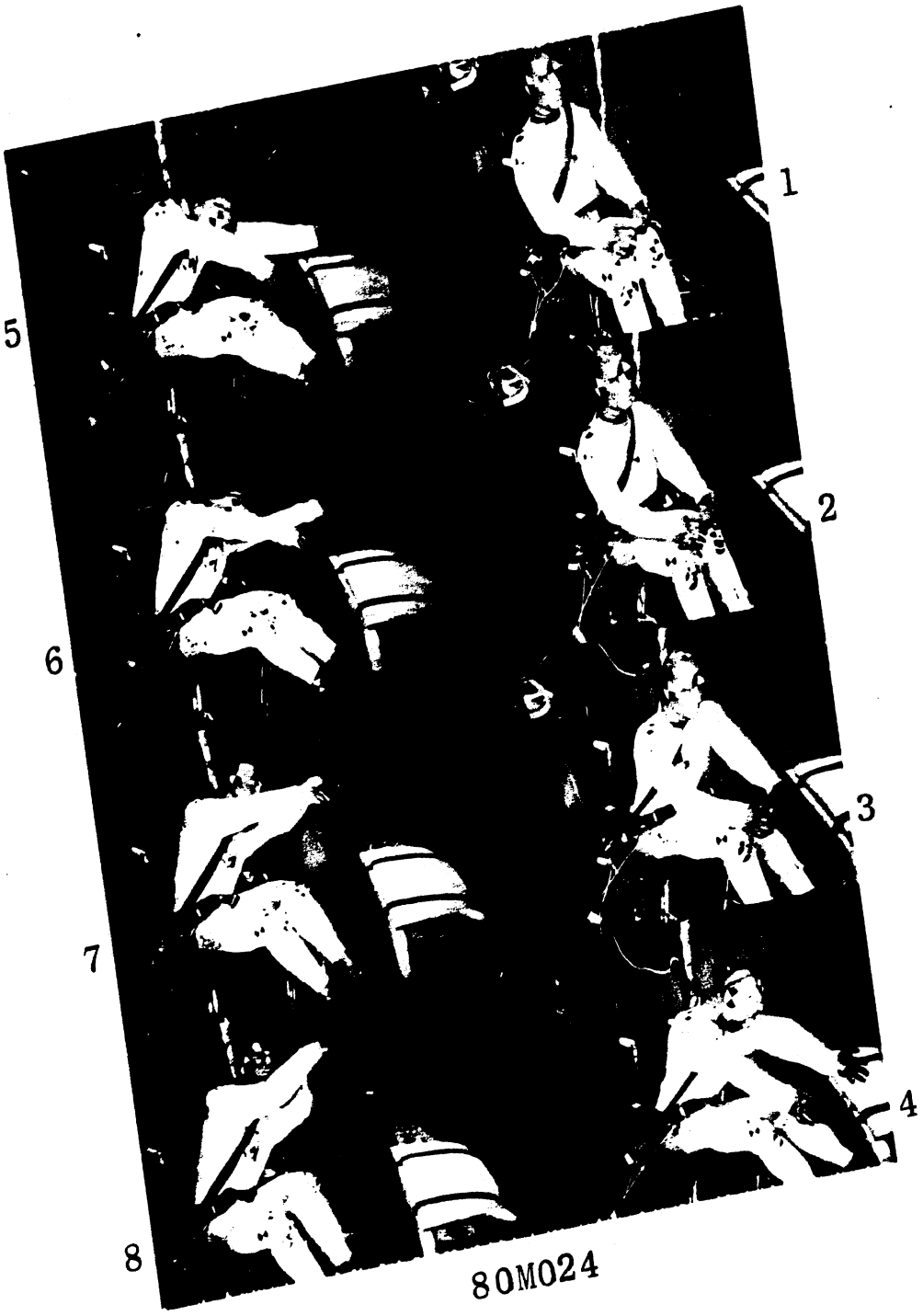


Time Sequence Photo of Test 80M024





Post-Impact Photos for Test 80M024



Time Sequence Photo of Test 80M024

TEST NO.
80M025

Setup

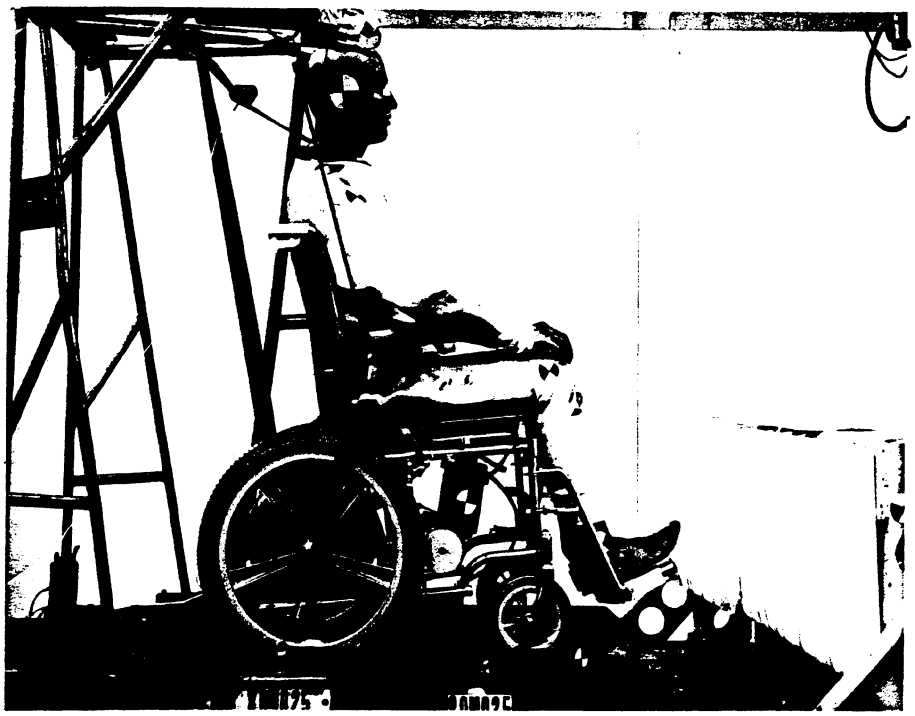
The wheelchair was secured by the CCI power pan retrofit tie-down system. The CCI triangular plates were modified to allow the wheelchair fore-aft position and tilt to be varied by providing extra sets of holes for the front and rear retaining bars. The dummy was restrained by a lap belt anchored to the CCI triangles and the Bud 3-point passive restraint system. Bud chair arms were used to allow the lap portion of the passive belt to rest over the pelvic area.

Results

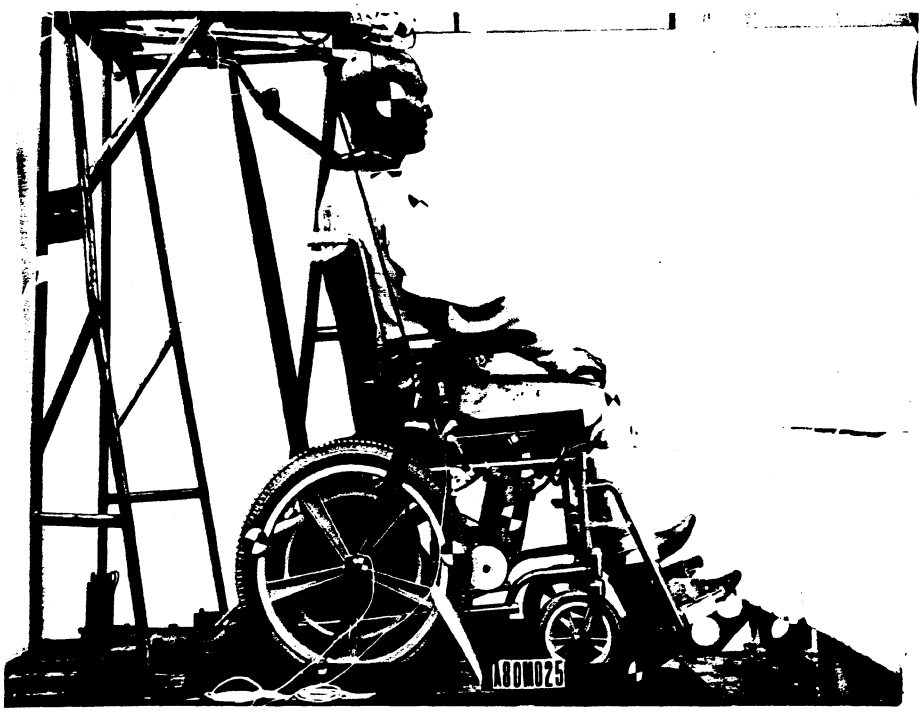
The wheelchair tie-down and belt systems provided excellent restraint for the wheelchair and dummy, respectively. The wheelchair sustained little or no damage.

Peak Belt Loads (lbs)

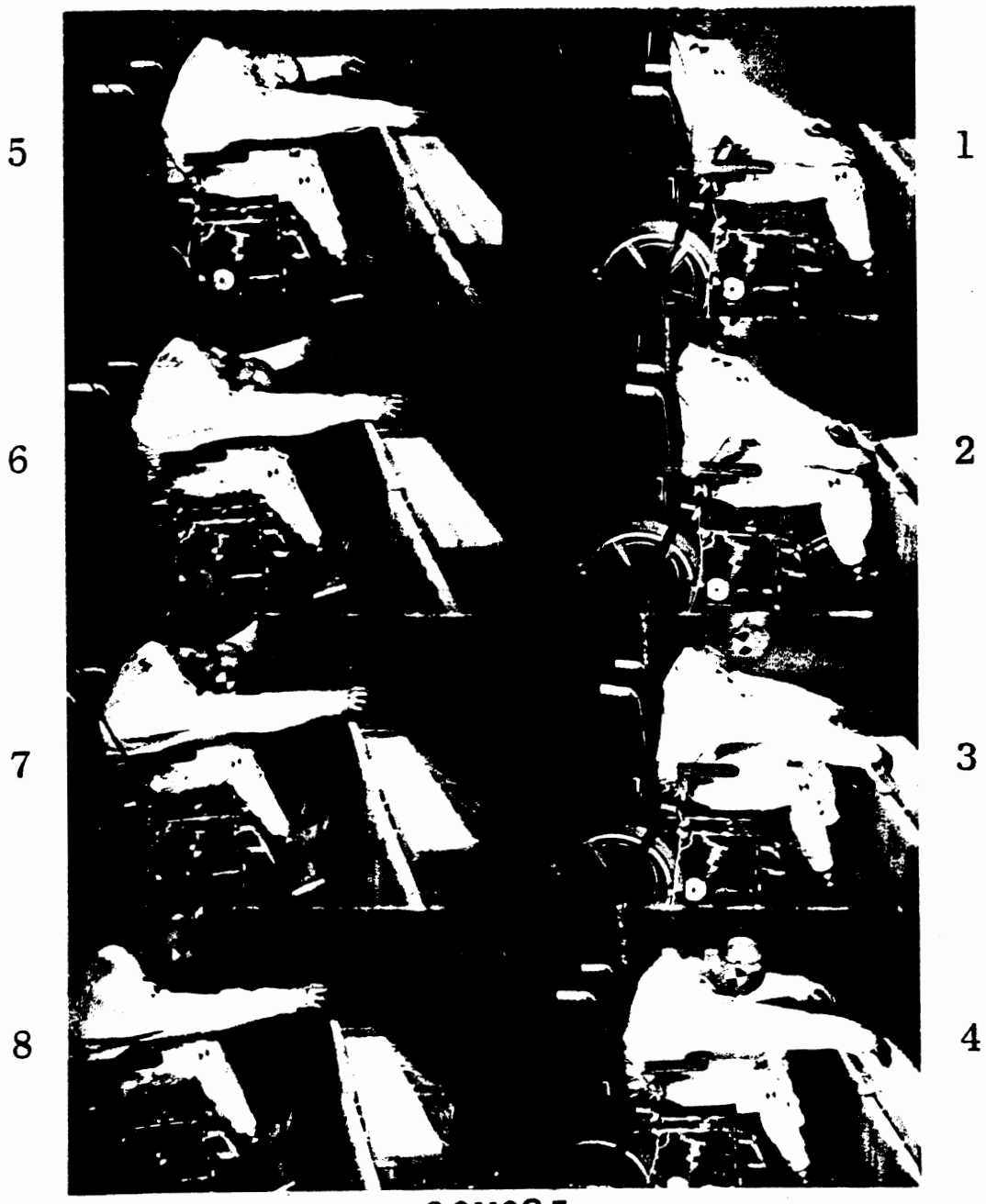
Right lap (chair)	- 1175
Floor	- 1075
Shoulder	- 1200



Set-up Photo for Test 80M025



Post-Impact Photo for Test 80M025



Time Sequence Photo for Test 80M025

TEST NO.
80M026

Setup

This test setup was identical to 80M025, except that the chair-anchored lap belt was removed so that only the Bud 3-point passive belt was restraining the dummy.

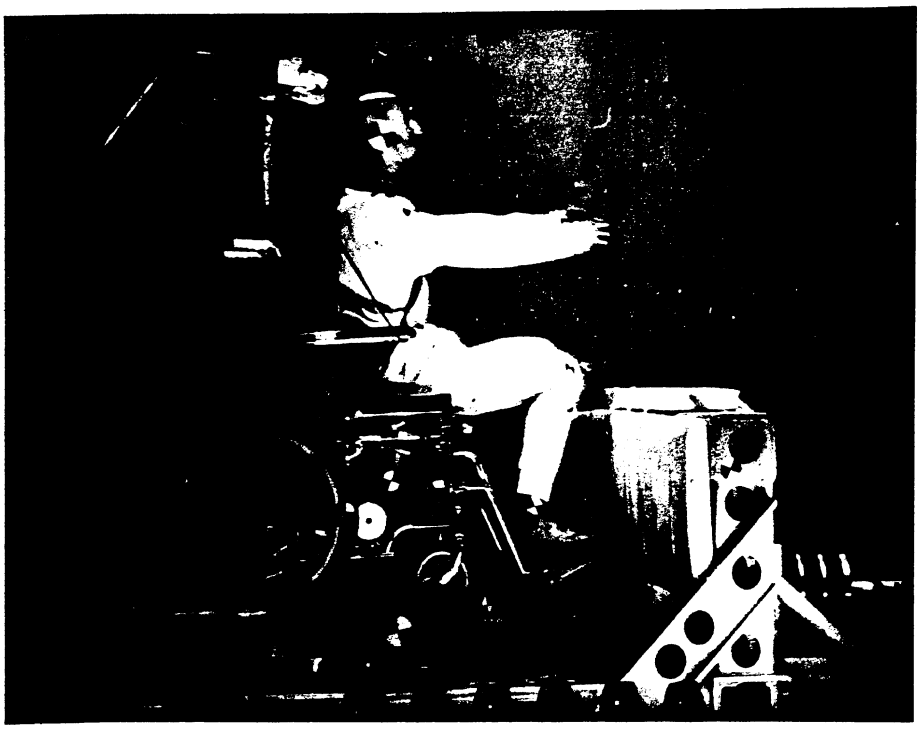
Results

The wheelchair was secured well by the CCI tie-down system, but a knot in the floor belt broke loose at the metal ring, allowing considerable forward translation of the dummy. The chair sustained little or no damage.

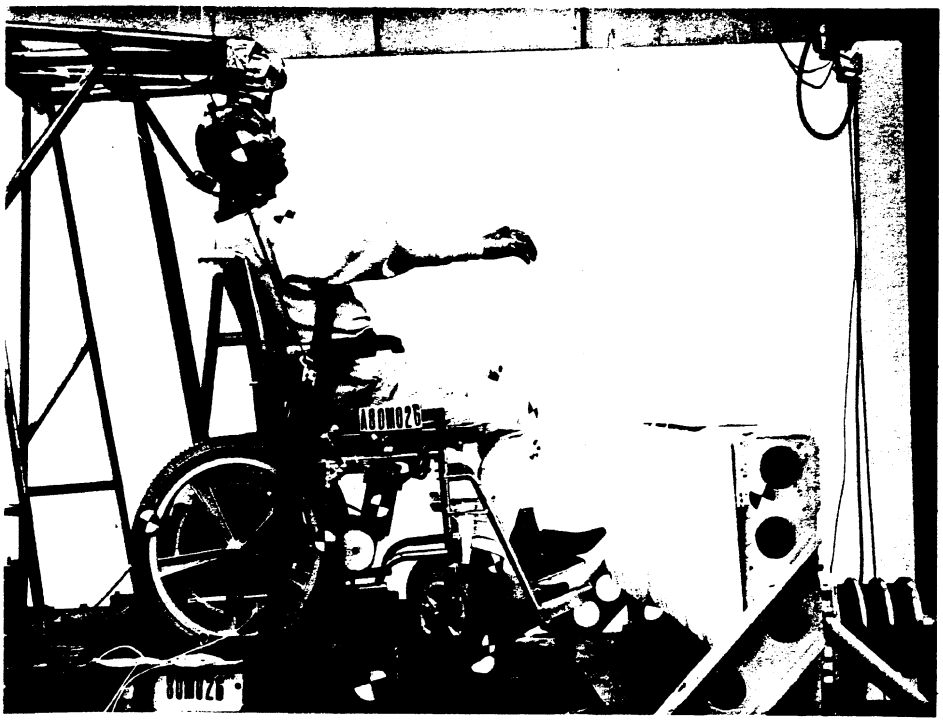
Peak Belt Loads (lbs)

Floor	-	1650
Shoulder	-	1200

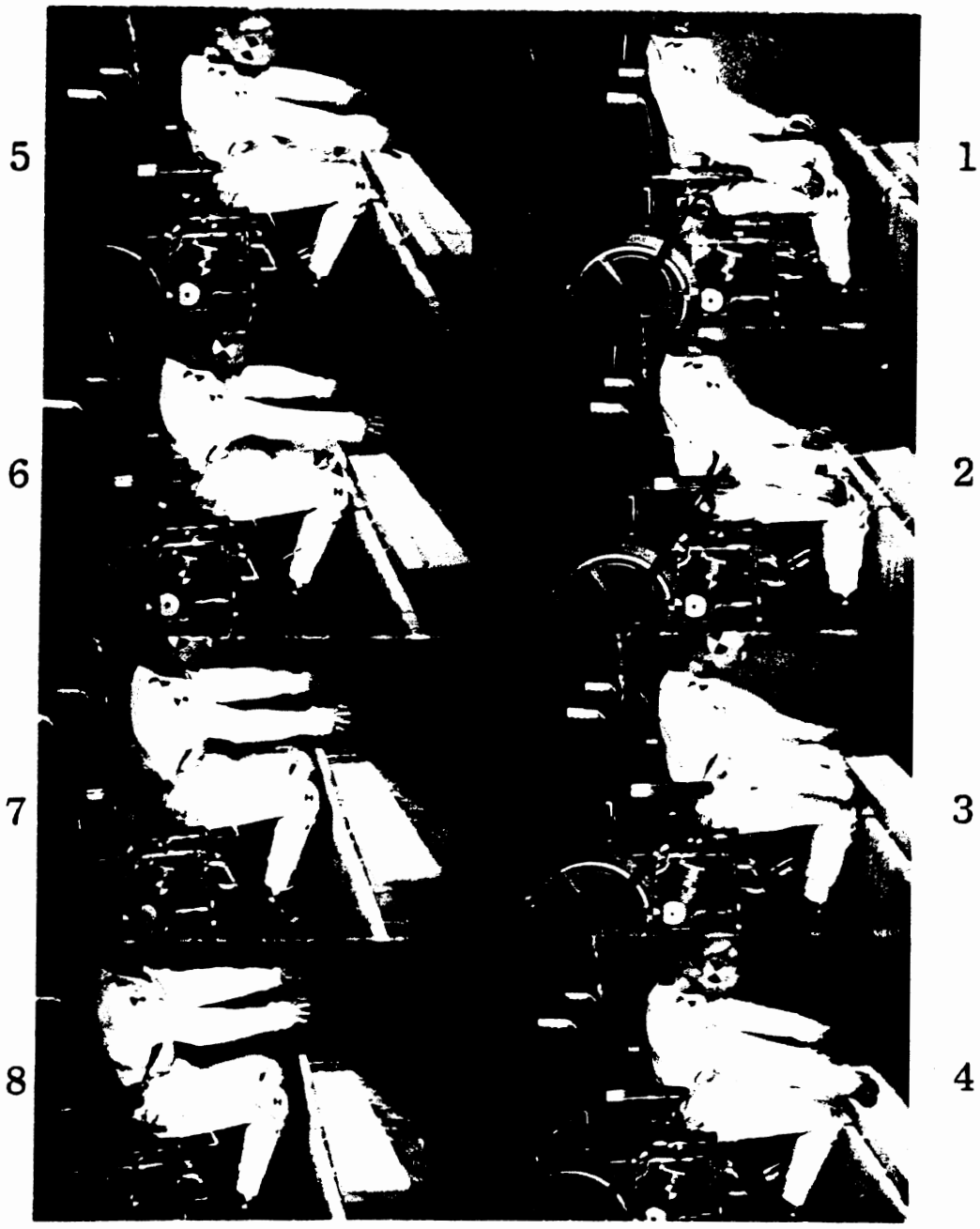
Set-up Photo for Test 80M026



Action Photo of Test 80M026



Post Impact Photo of Test 80M026



Time Sequence Photo of Test 80M026

TEST NO.
80M027

Setup

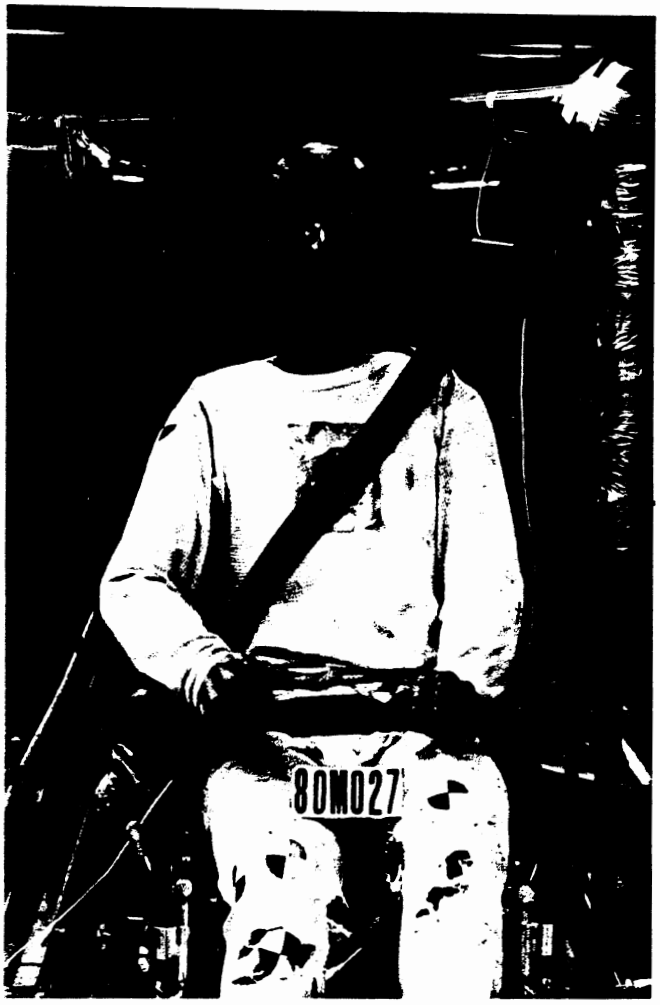
This test was a repeat of 80M26. The floor belt was replaced and secured to the metal ring by a new knot and tape.

Results

The CCI tie-down provided excellent securement for the wheelchair. The dummy was also effectively restrained, although the forward translation of the dummy was greater than when a chair lap belt was used. This excursion could probably be reduced by anchoring the floor belt further back.

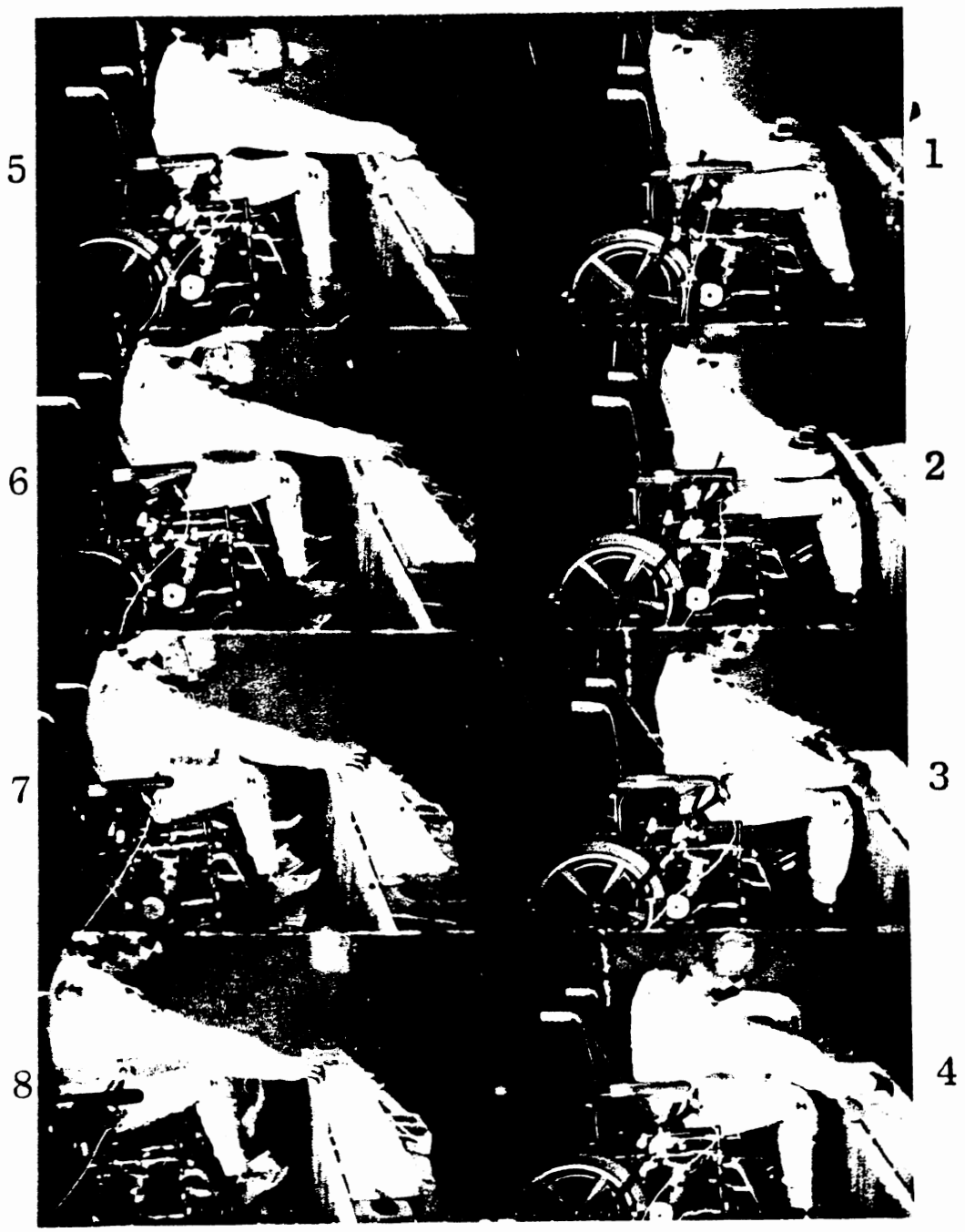
Peak Belt Loads (lbs)

Floor	- 1700
Right lap (chair)	- 1050
Shoulder	- 1450



Set-up Photo of Test 80M027

Post Impact Photo of Test 80M027



Time Sequence Photo of Test 80M027

TEST NO.
80M028

Setup

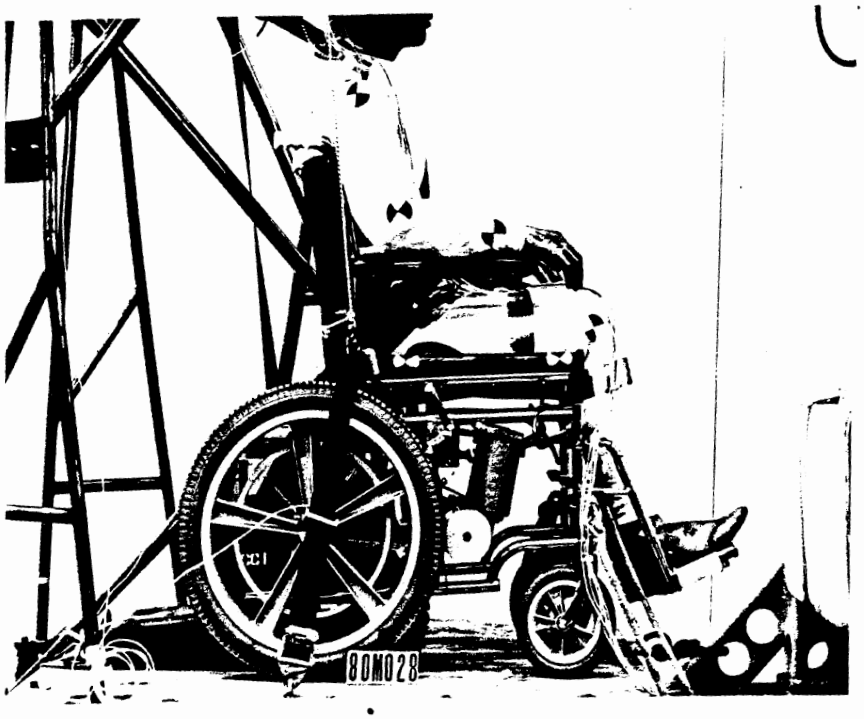
In this test a modified bolt-down CCI platform was used to secure the wheelchair. In this system the rear retaining bracket moves up as the front bar is lifted and secured, so that in the final locked position the wheelchair is not tilted, although it is still raised off the floor slightly. The dummy was secured by a chair lap belt and the Bud 3-point passive belt system in conjunction with the Bud chair arms.

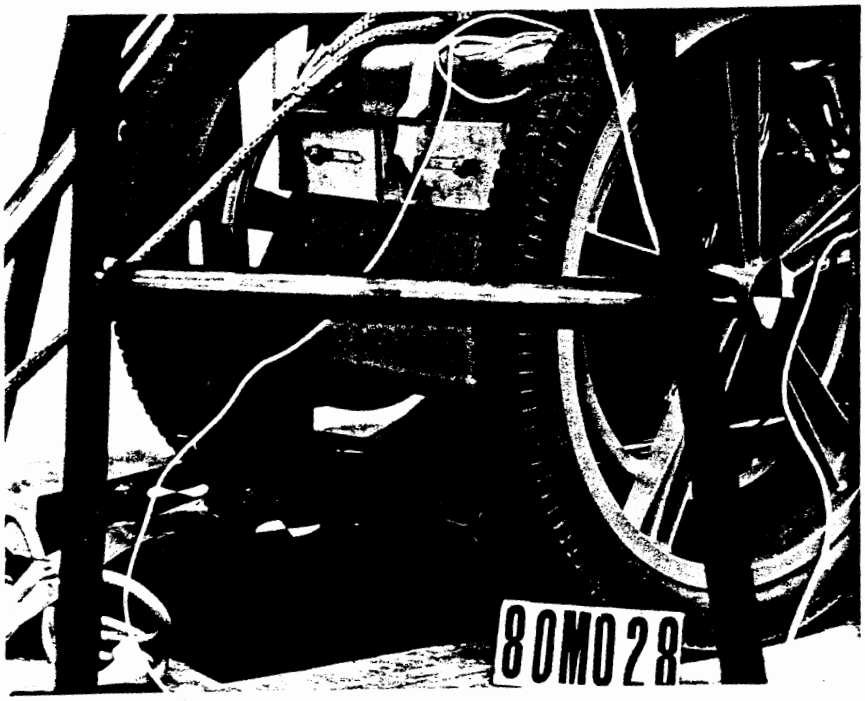
Results

The wheelchair and dummy were effectively restrained by the CCI tie-down and belt systems respectively. There was little or no damage to the wheelchair.

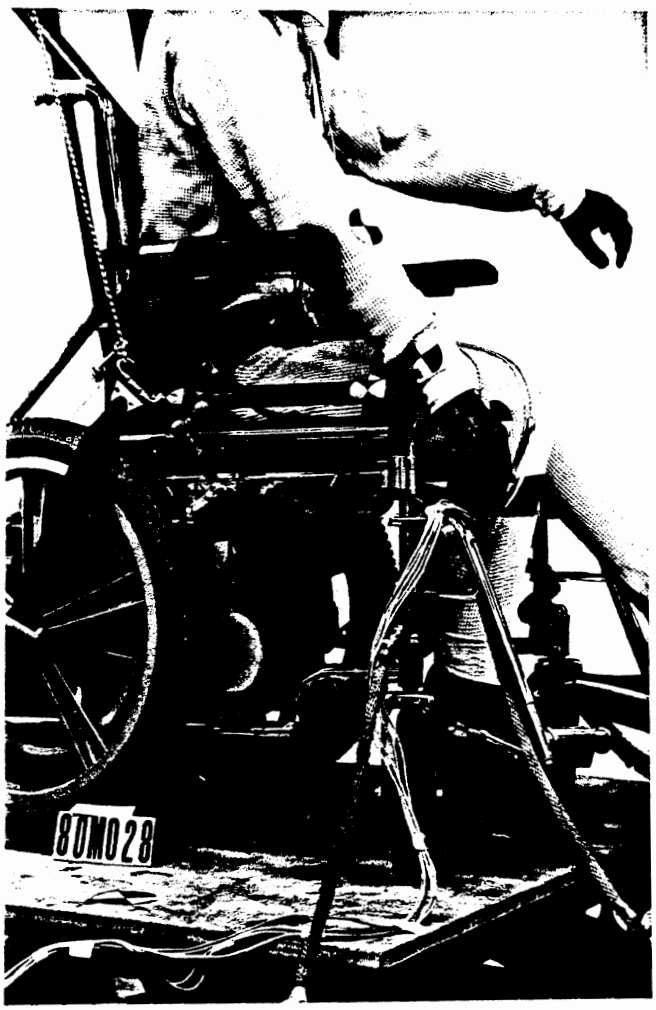
Peak Belt Loads (lbs)

Floor	- 1600
Right lap (chair)	- 1250
Shoulder	- 1350

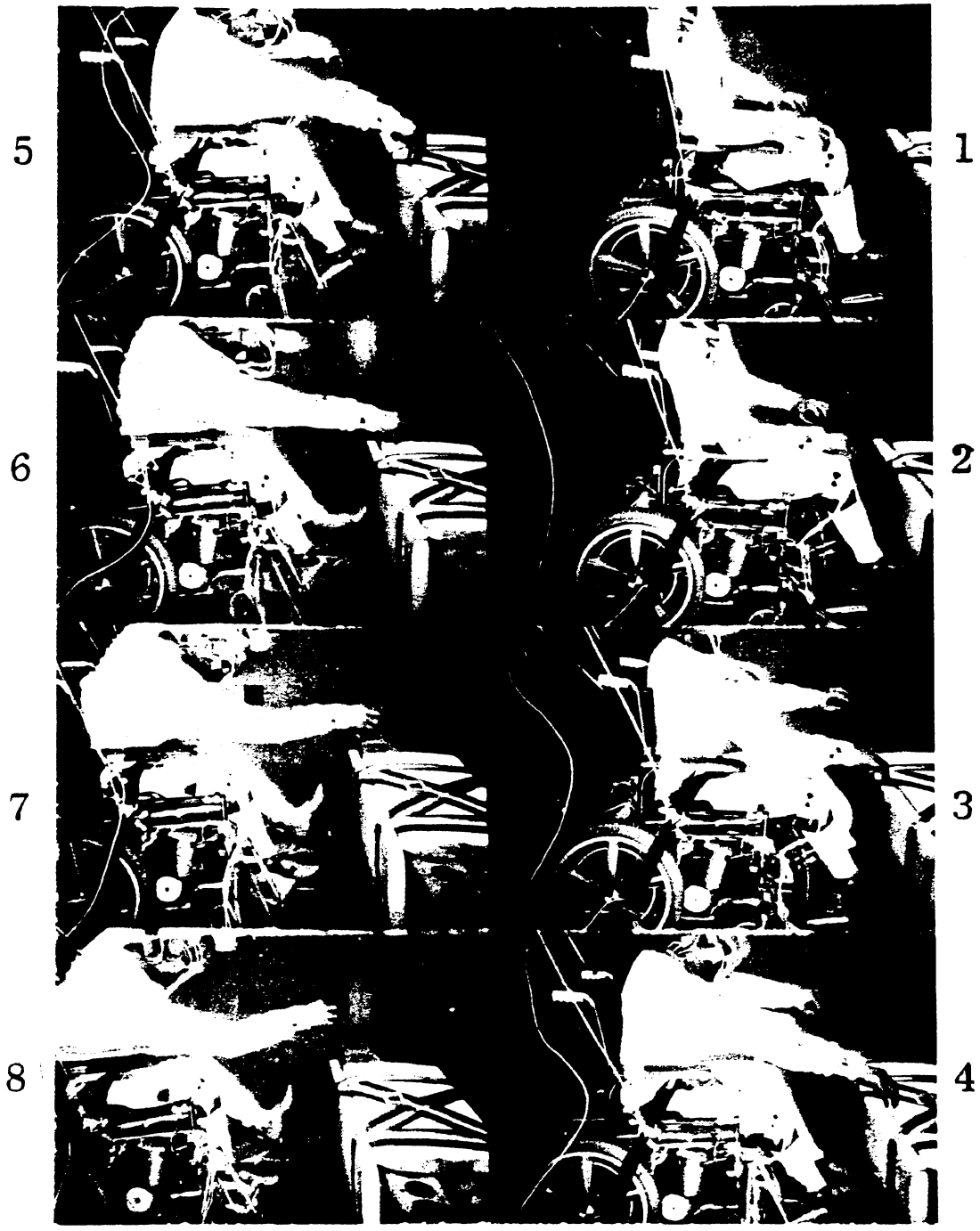




Set-up Photos of Test 80M028



Post Impact Photo of Test 80M028



Time Sequence Photo of Test 80M028

TEST NO.
80M029

Setup

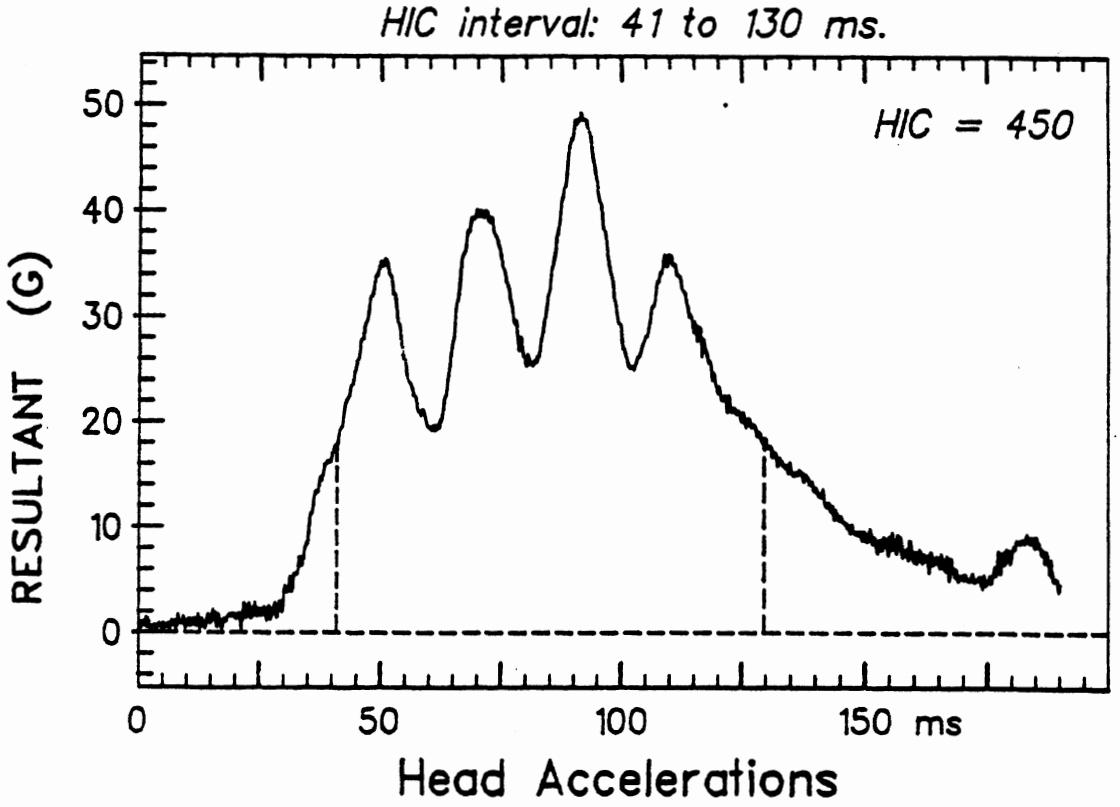
This test was identical to 80M028, except that a 30 mph, 20 G impact pulse was used instead of the 20 mph, 16-G pulse. Head and chest accelerometers were used in the dummy to measure head injury criteria (HIC) and chest resultant acceleration.

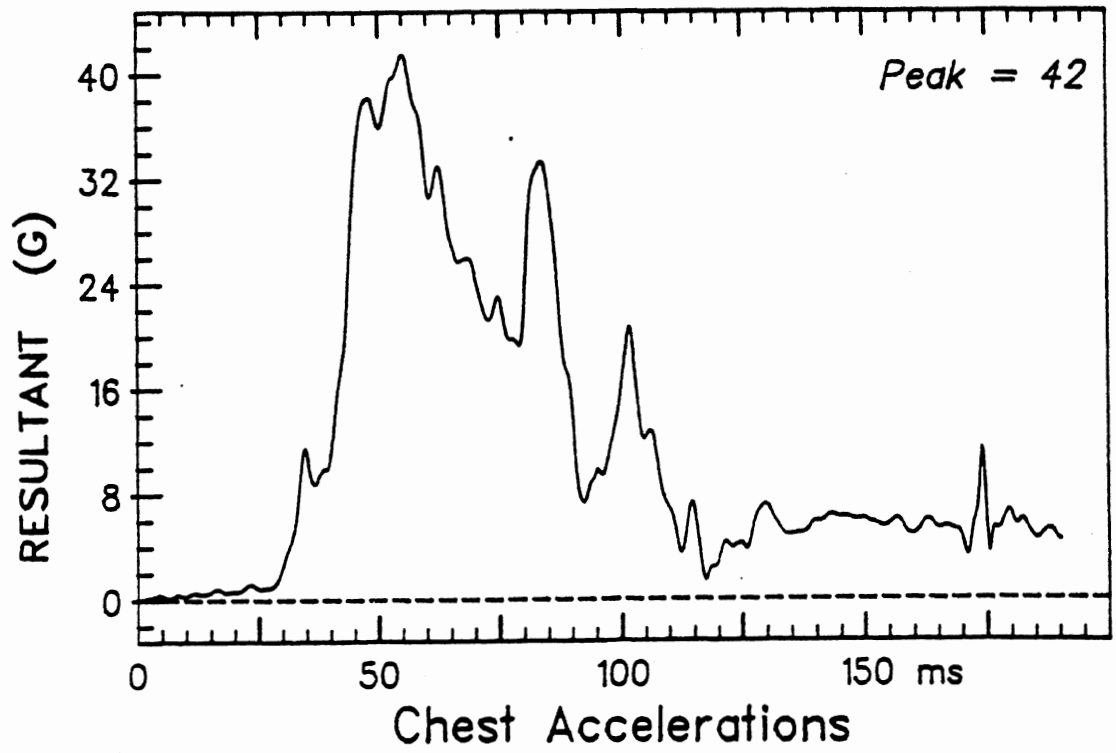
Results

The CCI tie-down and belt systems provided excellent restraint for the wheelchair and dummy, respectively. Head injury criteria was computed to be 450, peak head resultant acceleration (at head c.g.) was 49 G's, and peak chest resultant acceleration was 42 G's.

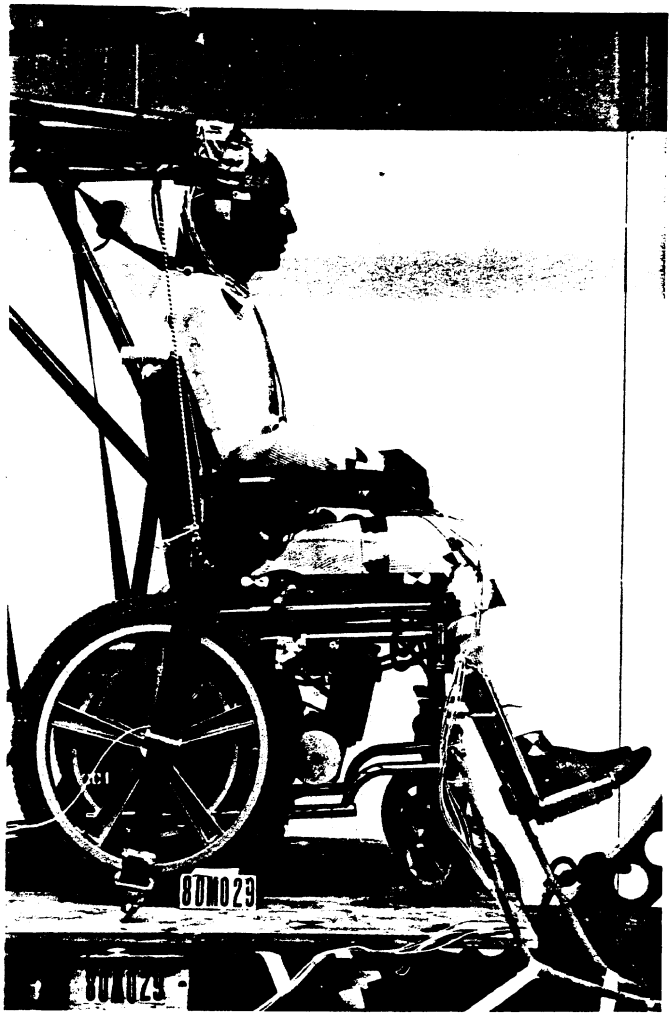
Peak Belt Loads (lbs)

Floor	- 1950
Right lap (chair)	- 1800
Shoulder	- 1750

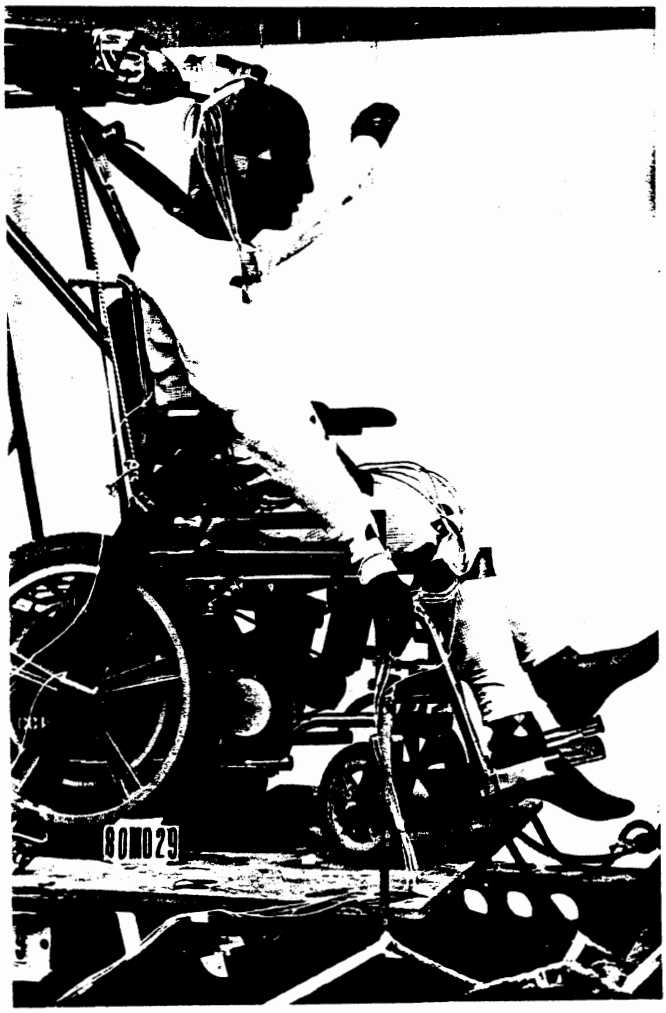




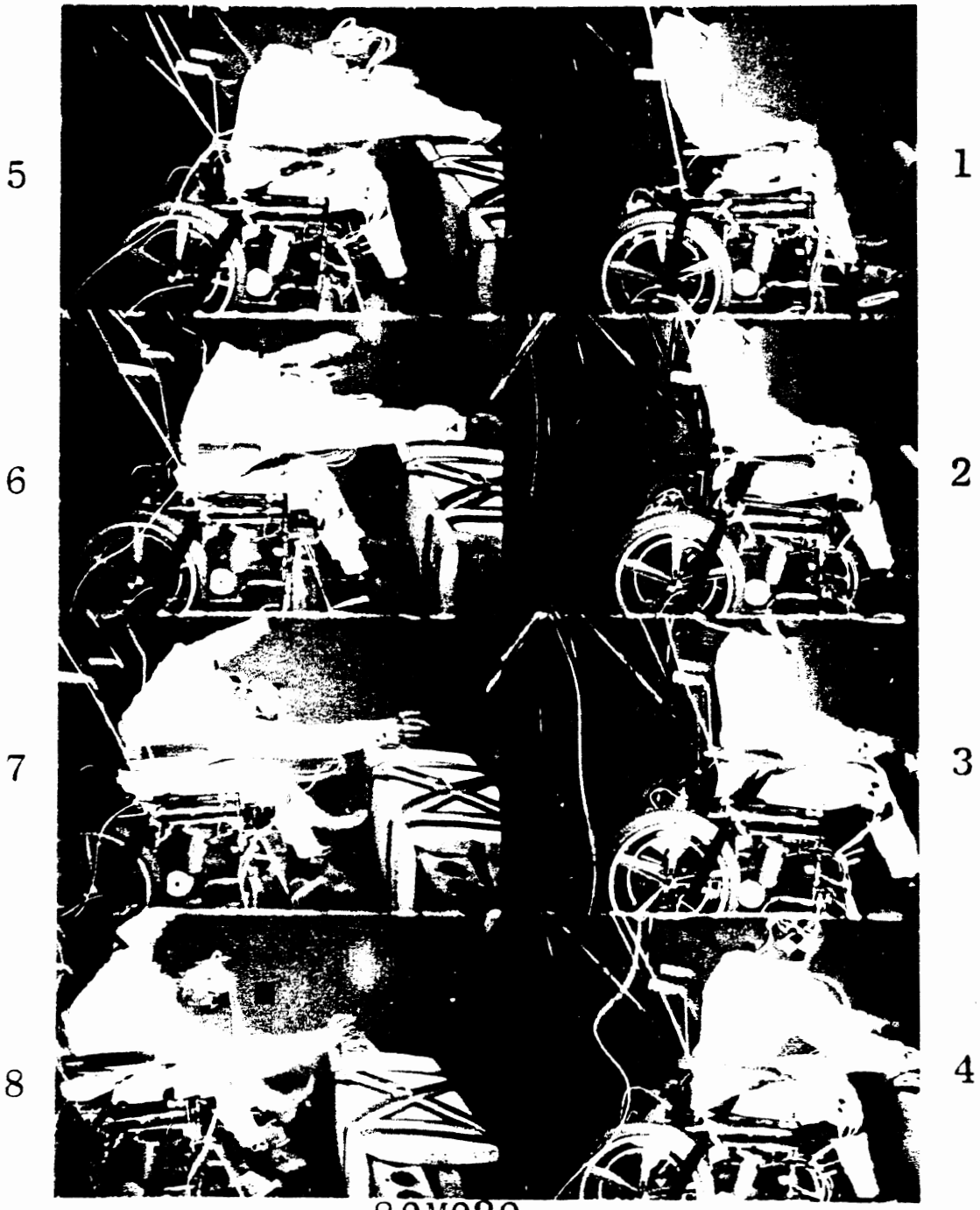
Head and Chest Resultant Accelerations for Test 80M029



Set-up Photo for Test 80M029



Post-Impact Photo for Test 80M029



Time Sequence Photo for Test 80M029

TEST NO.
81M030

Setup

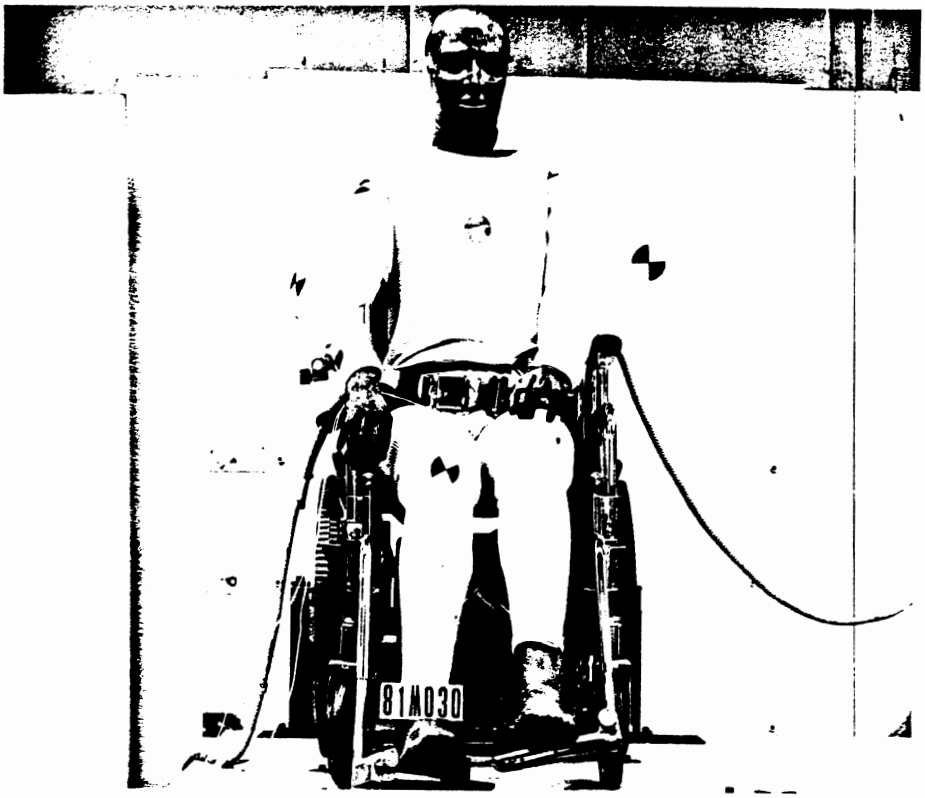
The wheelchair was secured facing sideways on the sled with the Bud Industries single chair rim-pin stanchion. The sleeve brackets that hold the rim pins were bolted to the bar to prevent sliding on impact. The dummy was restrained by a lap belt anchored to the rim-pin brackets.

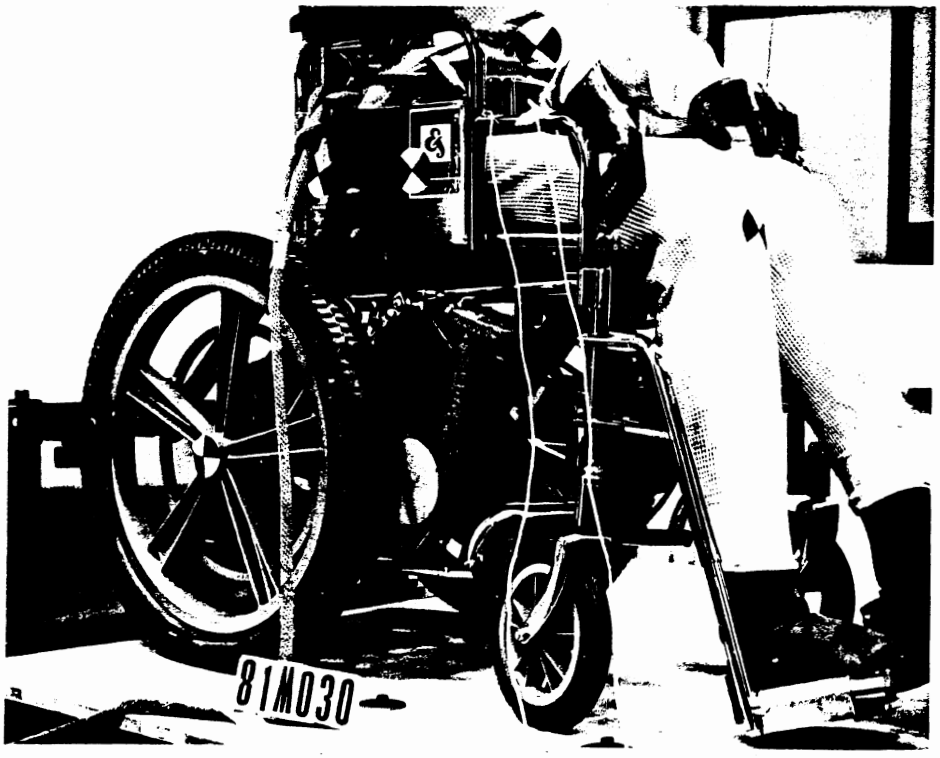
Results

The chair and dummy torqued and twisted sideways toward the front of the sled. The right magnesium rim of the chair broke apart and the chair sustained significant damage. The dummy's left side impacted into the left chair arm, causing significant bending of the chair frame.

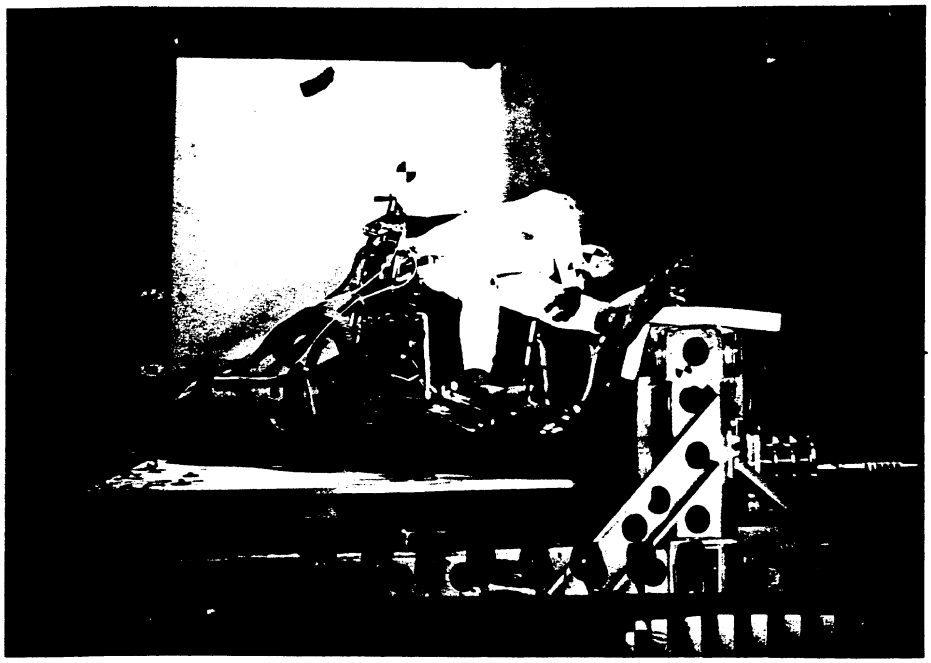
Peak Belt Loads (lbs)

Left Lap	- 750
Right lap	- 1150

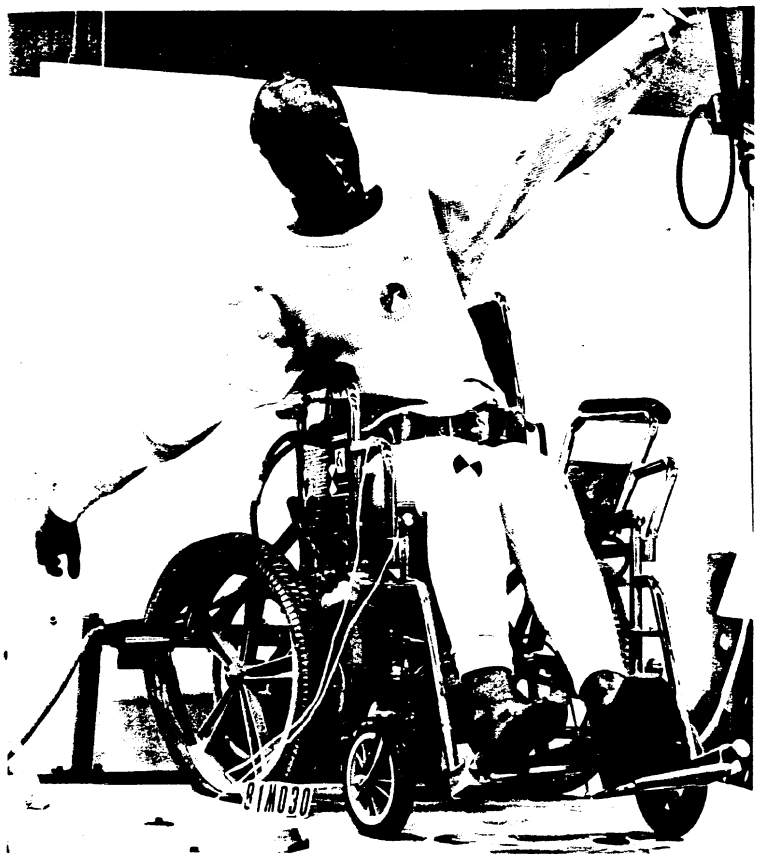




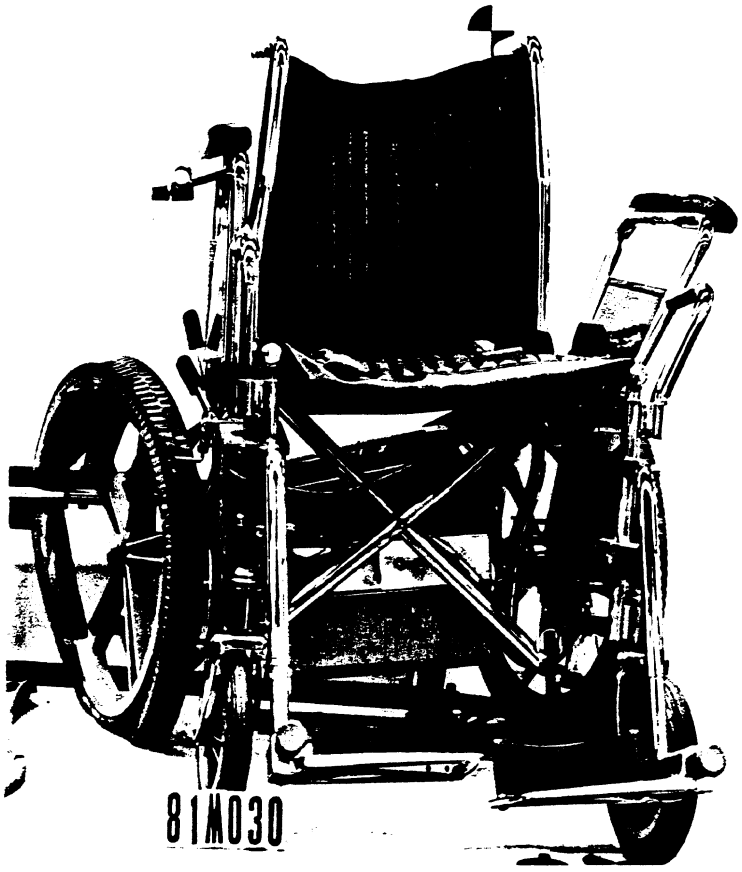
Set-up Photos for Test 80M030

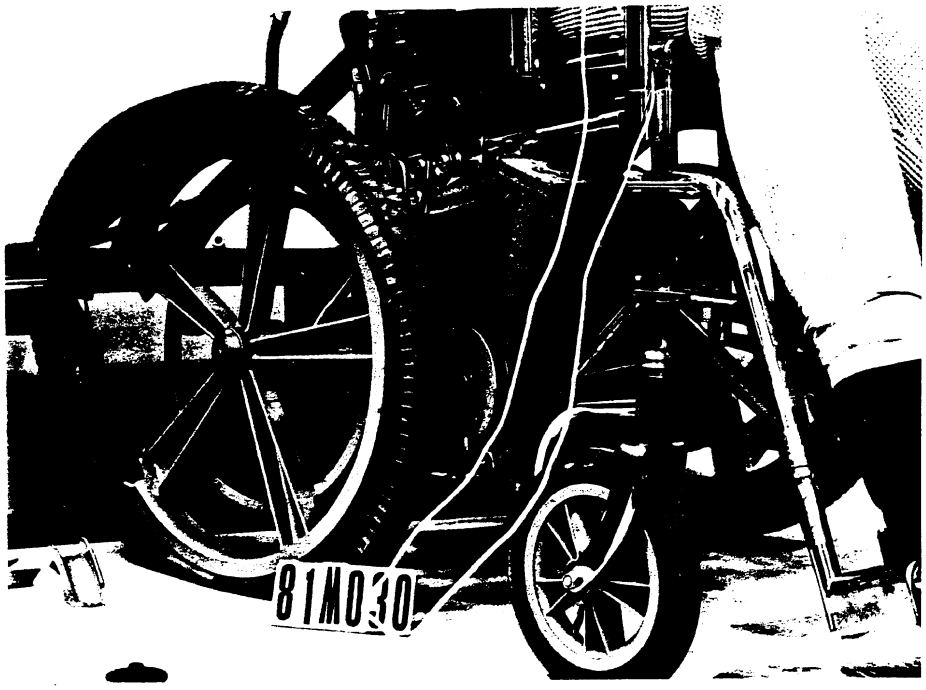


Action Photo of Test 81M030

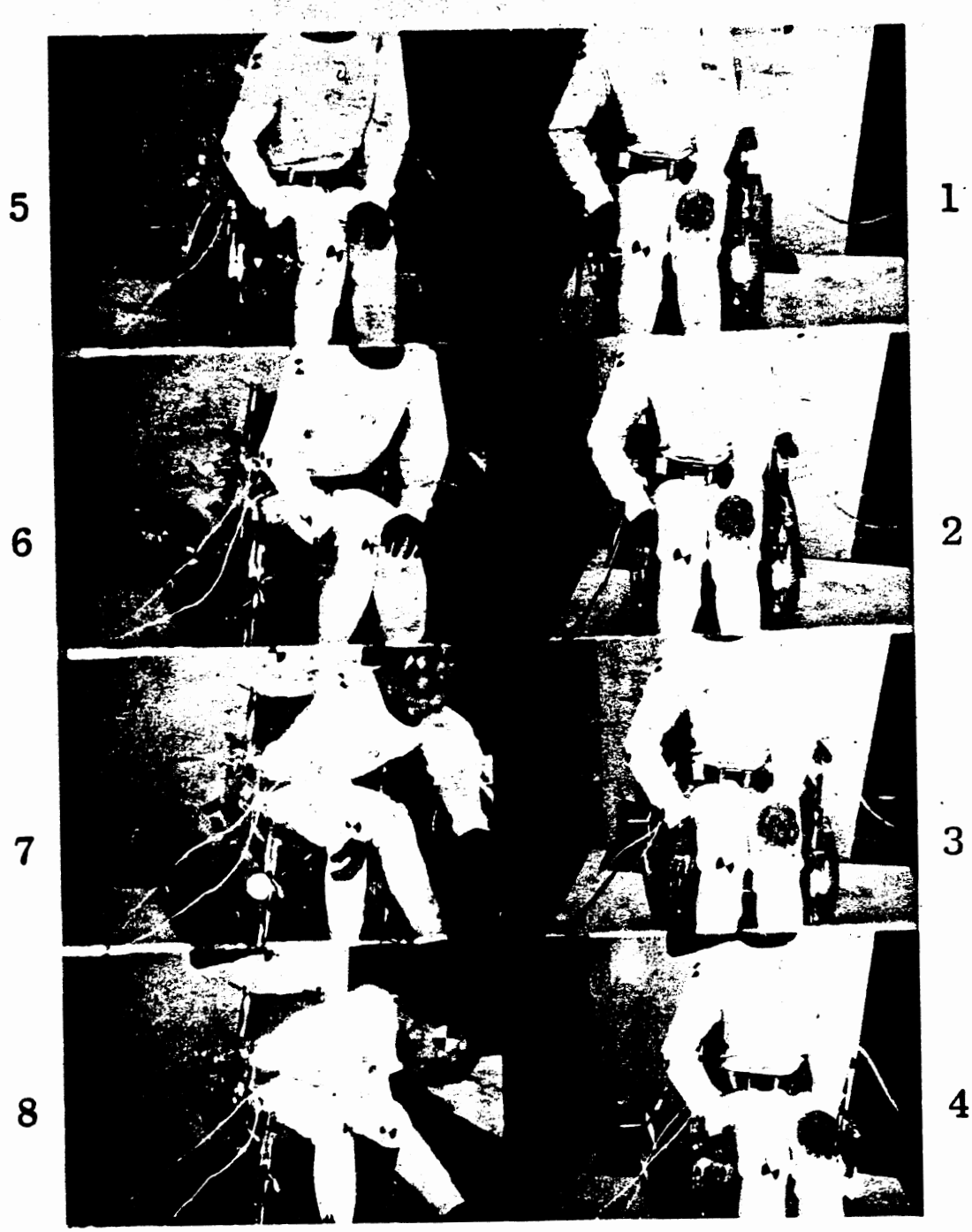


Post-Impact Photo of Test 81M030





Post Impact Photos of Test 81M030



Time Sequence Photo of Test 81M030

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 the wheelchair tie-down system hardware in current use by clients of the Massachusetts Rehabilitation Commission is generally inadequate to restrain the wheelchair in even a moderate frontal crash, and therefore these clients are currently traveling 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 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 formed from a piece of standard rod. Replacement of these ring assemblies by heavy duty eye bolts or some other strengthened hardware is essential for effective wheelchair restraint.

The adjustable T-bars provided by Bud Industries and the T-bar from 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

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.[2]

Because of hardware failures none of the tests conducted in this study have successfully investigated the concepts of the T-bar-and/or-lap-belt-to-floor procedures for wheelchair securement. However, some points and observations can be made.

The use of a lap belt to the floor as a restraint for the wheelchair and occupant together 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. Those 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 provides restraint only 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

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[2]It should not be inferred that products from specific industries which failed in any of these tests are inferior to similar products of other manufacturers. The products selected for testing in this study were chosen primarily from considerations of proximity to the sponsor. It is likely that other similar products produced elsewhere would have performed similarly to the products used in this study, but judgment of performance can be made only by subjecting each product to a dynamic test.

also questionable. Not only is the T-bar difficult to get in position and torqued down, especially on a powered wheelchair, but it provides securement only through friction forces on the smooth steel tubing of the wheelchair frame. Positive securement will occur only 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 known, 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 may 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 needs to move only a couple of inches before it is completely free. When the wheelchair and press-down bar do interact, the bar simply rotates out of the way, even though the two mounting bolts on the power lock-down bracket are torqued securely. The addition of a bar across the power pan and against the castor tires adds little to the restraint provided by this device. The power lock-down device is a completely ineffective approach to providing

wheelchair securement for impact, or even for 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 that 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 fastened to the rear posts just above the seat upholstery support tubing. 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 would make this a more effective manual tie-down. The forward-facing Bud stanchion also provides a good means of securing a forward-facing chair on frontal impacts as long as the occupant's lap belt is secured to the stanchion rather than the

wheelchair. Results of tests 80M010 and 81M030 clearly indicate the problems of using this type of securement in the side-facing mode for the majority of moderate and severe vehicle impacts from the front or rear.

The most effective wheelchair restraint was provided by the Creative Controls, Inc. (CCI) automatic tie-down system, in which triangular steel plates are bolted to the wheelchair side frames, and steel bars between these plates provide the means for retaining 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.

Modified CCI tie-down systems used in tests 80M023 through 80M029 also provided effective wheelchir securement. The CCI system adapted for use in vans outfitted with the power pan and ineffective power lock-down provides a relatively simple approach to improving wheelchair securement for many drivers. The triangular plates with multiple locations for the retaining bars (test 80M025) enables the wheelchair position to be varied for different users as required in training vehicles, and the non-tilt bolt-down platform (test 80M028 and 80M029) allows for effective wheelchair securement without tilting the wheelchair. In test 80M029 this device secured the chair effectively in a 30 mph 20 G impact. When bolting the CCI platform to sheet metal such as a van floor, it is essential to use steel backing plates to distribute the loads.

With effective wheelchair securement provided by the CCI

system, both the Bud and Falcon three-point passive restraint belts were effective in providing occupant restraint when used in conjunction with a chair lap belt. Effective restraint was also provided by the three point belt, without a chair lap belt but proper location of the floor belt anchor point is more critical to good lower torso restraint. In all cases, the Bud cantilevered chair arms were extremely beneficial in allowing the lap portion of the three-point belt to rest on the pelvis region rather than on the abdomen above the chair arm rests. In test 80M029 a sled deceleration pulse of 30 mph at 20 G's produced a head injury criteria (HIC) of 450 and a peak chest acceleration of 42 G's, using the Bud three-point passive belt and chair lap belt. These values are within the accepted tolerance levels of 1000 for HIC and 60 G's for chest acceleration.

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 generally inadequate to restrain a powered wheelchair in any kind of 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 such as the power lock-down and T-bar that 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. Current procedures for securing side-facing wheelchairs in motor vehicles provide little protection on frontal impacts.

6. The Creative Controls, Inc. wheelchair tie-down system provided excellent wheelchair securement in all tests for which they were used, including a 45-degree impact and a 30 mph 20 G impact.

7. Aeroquip straps can provide good wheelchair securement for forward facing chairs in frontal impacts if securement is to the joints of the chair tubing, but the "G" track plugs need to be strengthened.

8. Three-point passive belt systems by Bud and Falcon offer good occupant restraint when the wheelchair is effectively secured by other means. The use of a chair lap belt with these systems improves lower torso restraint, and the cantilevered chair arms by Bud Industries provide for improved placement of the passive lap belt over the pelvic region rather than the abdomen.

9. Velcro fasteners are inadequate for occupant restraint systems but may be desirable for postural support belts placed over soft tissue.