# FLEXBEAM REDIRECTIONAL SYSTEM FOR THE MODULAR CRASH CUSHION

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Research Report Number 146-3

Studies of Field Adaptation
of Impact Attenuation Systems

Research Study Number 2-8-68-146

Sponsored By

THE TEXAS HIGHWAY DEPARTMENT

in cooperation with

The U.S. Department of Transportation
Federal Highway Administration

October 1970

TEXAS TRANSPORTATION INSTITUTE

Texas A&M University
College Station, Texas

ACKNOWLEDGEMENTS

This study was conducted under a cooperative program between the Texas Transportation Institute and the Texas Highway Department. It was sponsored jointly by the Texas Highway Department and the Federal Highway Administration. Liaison was maintained through Mr. John Nixon and Mr. Paul Tutt, contact representatives for the Texas Highway Department. The crash cushion designs reported here were developed jointly by Texas Highway Department and Texas Transportation Institute engineers.

The crash tests were carried out by personnel of the Highway Safety Research Center of Texas Transportation Institute under the direction of the principal investigator, Dr. T. J. Hirsch of the Structural Research Division of the Texas Transportation Institute.

The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the Federal Highway Administration.

ABSTRACT

The Modular Crash Cushion of empty modified 55-gallon oil drums which is now in field use has proven to be highly successful, especially in head-on collisions, however, it does have a potential danger zone near the back. When impacting in this danger zone, a vehicle can pocket and contact the rigid obstacle before losing a signficiant amount of energy. It is evident that, in this danger zone, redirection would normally be more desirable than complete arrestment.

A set of steel drums wrapped with a flexbeam of W-section guardrail has been added to the rear portion of the Modular Crash Cushion to prevent pocketing of impacting vehicles. Longitudinal cables on each side of the front portion of the crash cushion serve to redirect vehicles hitting the sides. Drawings of the revised structure incorporating these features show details for construction.

# SUMMARY

The Modular Crash Cushion, through testing and field experience, has proven to be an effective impact attenuator between automobiles and rigid obstacles. While the Modular Crash Cushion design which is now in field use has proven to be highly successful, especially in head-on collisions, it does have a potential danger zone near the back of the cushion. When impacting in this danger zone, a vehicle can pocket and contact the rigid obstacle before losing a significant amount of energy. It is evident that, in this danger zone, redirection would normally be more desirable than complete arrestment. A possible modification, intended to produce the needed redirectional capability in this danger zone, was evaluated by three vehicle crash tests.

The test results indicated that the inclusion of a W-section guardrail around a set of drums added to the rear portion of the crash cushion can provide redirectional capability for angular crashes near the rigid obstacle if adequately supported by fixed posts and rigid cable connections. However, for angular hits directly in front of the guardrail portion, the vehicle will "pocket" and then encounter the guardrail at a severe angle. This tends to cause the vehicle to both spin and rebound. Nevertheless, the decelerations produced in such a test are not considered excessive for properly restrained passengers.

It was evident from the tests that the longitudinal cables attached to the flexbeam form an integral part of the flexbeam redirection system. These cables must provide lateral stability in angled impacts while producing

negligible interference in head-on crashes. One (unsuccessful) test reported here demonstrated the need for strong and rigid cable connectors, and several fixed posts supporting the guardrail.

Drawings of a revised design incorporating these features are presented in the report. It would be desirable to evaluate this revised design with a full-scale crash test.

## IMPLEMENTATION STATEMENT

Preliminary tests of a flexbeam W-section guardrail around a set of drums added to the rear portion of the Modular Crash Cushion and longitudinal cables along each side of the front portion of the structure show feasibility for consideration in (1) eliminating pocketing of vehicles near rigid backup wall and in (2) attaining redirection after impact from side hits. Further evaluation with full-scale crash tests is desirable for more complete evaluation.

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# INTRODUCTION

The Modular Crash Cushion, through testing and field experience, has proven to be an effective impact attenuator between automobiles and rigid obstacles.[1,2*] The three crash tests reported herein were conducted on a modified Modular Crash Cushion using a W-section flexbeam as the basic redirection system.

While the Modular Crash Cushion design which is now in field use has proven to be highly successful, especially in head-on collisions, it does have a potential danger zone near the back of the cushion. When impacting in this danger zone, a vehicle can pocket and contact the rigid obstacle before losing a significant amount of energy. It is evident that, in this danger zone, redirection would normally be more desirable than complete arrestment. A possible modification, intended to produce the needed redirectional capability in this danger zone, was made on the crash cushions tested in this program.

This program is a continuation of previous Modular Crash Cushion design and testing performed under this contract.[3] Other redirectional systems have been tested under another contract.[4]

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*Superscript numerals refer to the corresponding number in the Selected References.

## DETAILS OF TESTS

### GENERAL

In an effort to provide a redirectional capability for angular impacts near the rigid obstacle, yet maintain the "soft" characteristics for head-on collisions, a W-section guardrail was placed around the modules as shown in Figures 1, 1A and 2. In the three crash tests conducted, the vehicles impacted the cushion at an angle of 20 degrees to the cushion center line. The vehicle used in the first test impacted the guardrail portion about 10 feet in front of the rigid wall. For the second test, an impact point was chosen to determine the effects of pocketing and hitting the curved portion of the guardrail at a severe angle. The point of impact for the third test was at the same position on the guardrail as in the first test. These impact points are indicated on Figures 1 and 1A.

The instrumentation in each test consisted of high-speed cameras and electromechanical accelerometers. The high-speed cameras, operating at 500 frames-per-second, recorded the events of each crash, and provided a means of obtaining time-displacement data.

The vehicle used in the first test was equipped with two longitudinal accelerometers, one on each longitudinal frame member behind the driver's seat. In the second and third tests, two transverse accelerometers were added, one near each longitudinal accelerometer. An anthropometric dummy was secured in the driver's seat with a lap belt attached to a load cell to obtain the seat belt force. In the first two tests, the signals from these devices were transmitted by shielded cable to stationary recorders. For the third test, data transmission was by telemetry. In addition, a mechanical Impact-O-Graph was mounted in the vehicle's trunk to provide a secondary source of acceleration information. Data from tape switches activated by the approaching vehicles provided a means of checking the initial speeds obtained from high-speed photography.

In the list of data accompanying the individual test descriptions, the initial speeds were obtained from the high-speed films, while the average and maximum decelerations were obtained from accelerometers mounted on the vehicle frame. (The values given are the average of the accelerometer pairs.) The Times in Contact are from the films, and show good agreement with the Times in Contact determined from the accelerometer traces. The film and accelerometer data, as well as seat-belt force traces, are shown in the Appendix.

Sequential and still photographs accompany each individual test description.

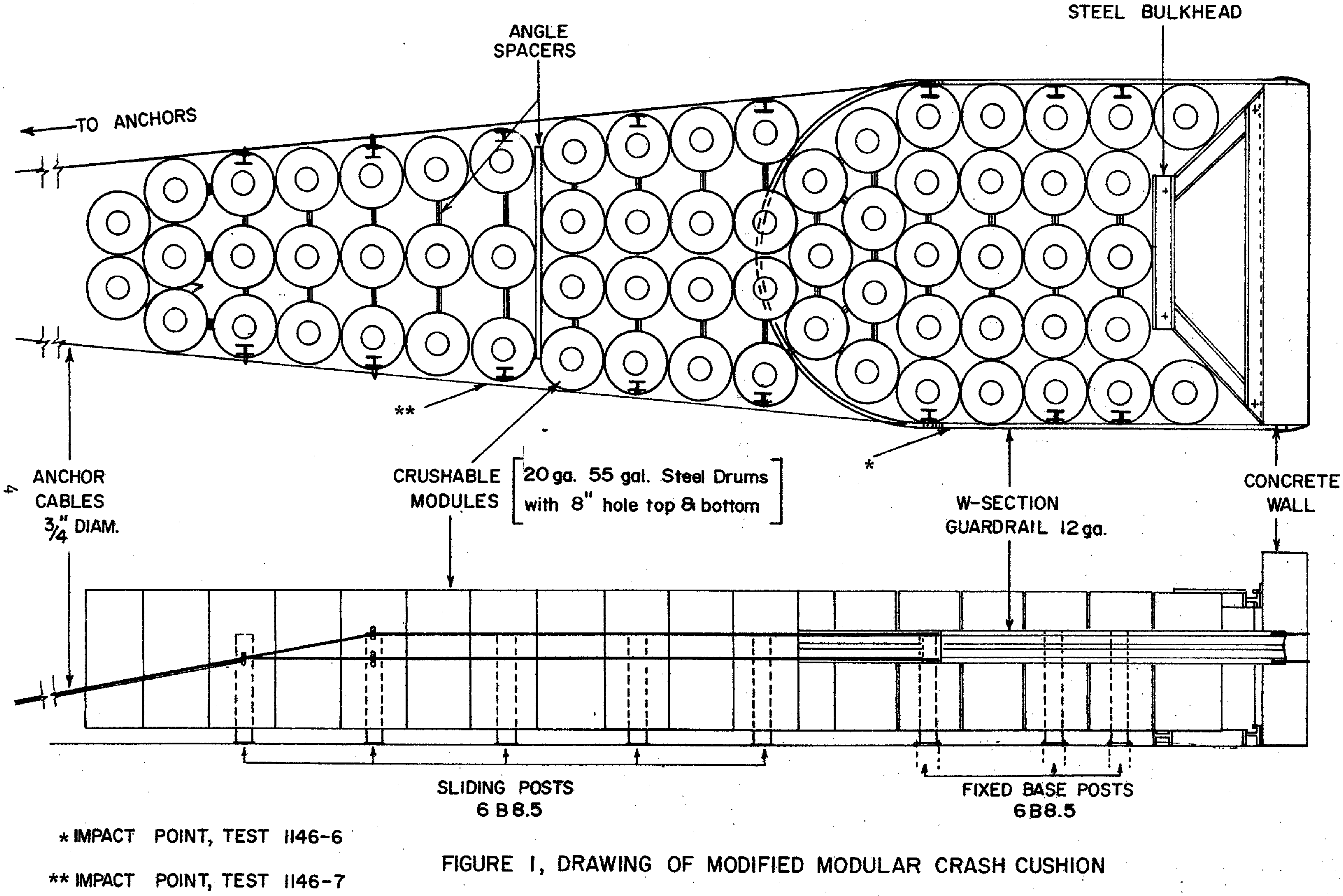



FIGURE 1, DRAWING OF MODIFIED MODULAR CRASH CUSHION

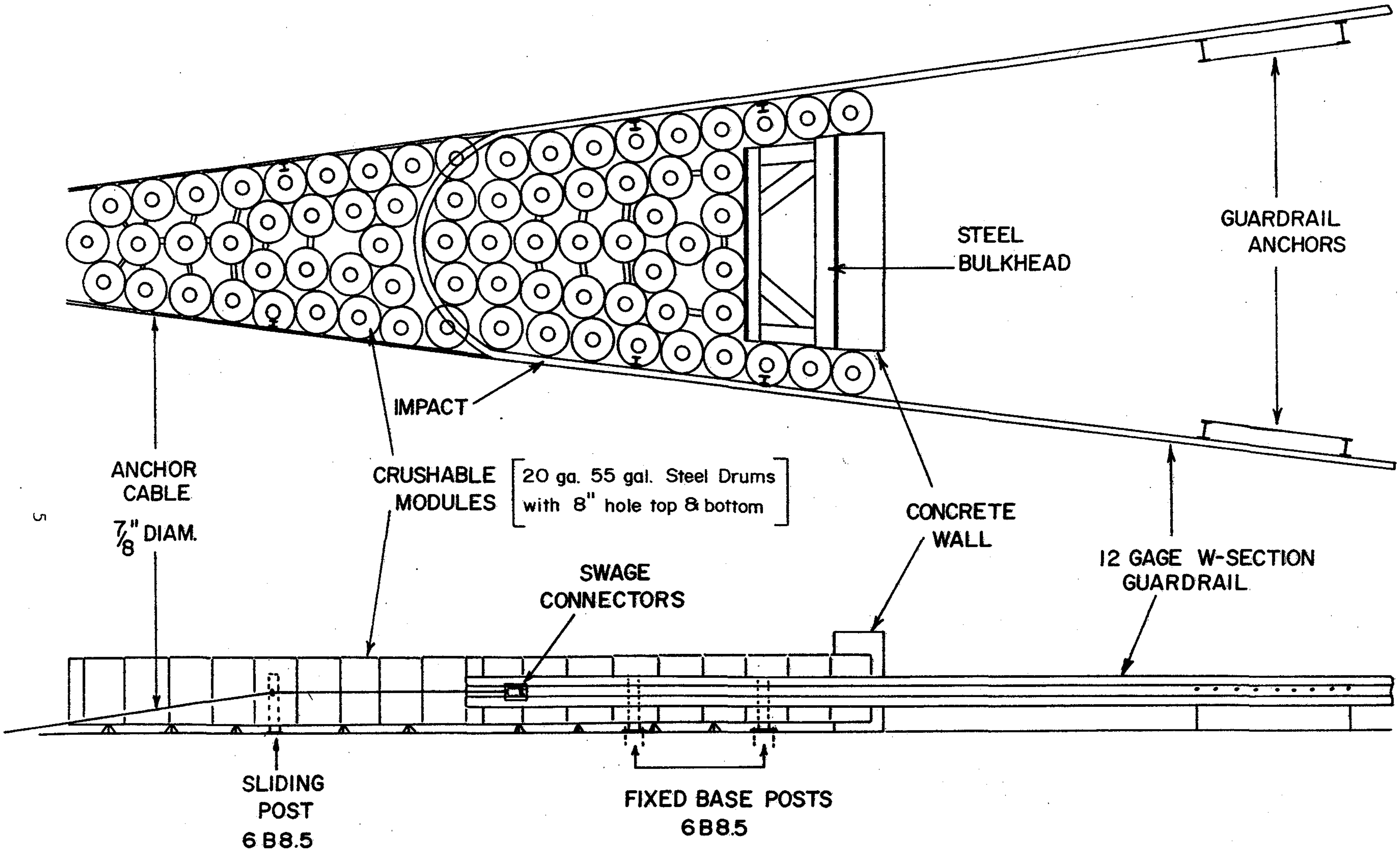
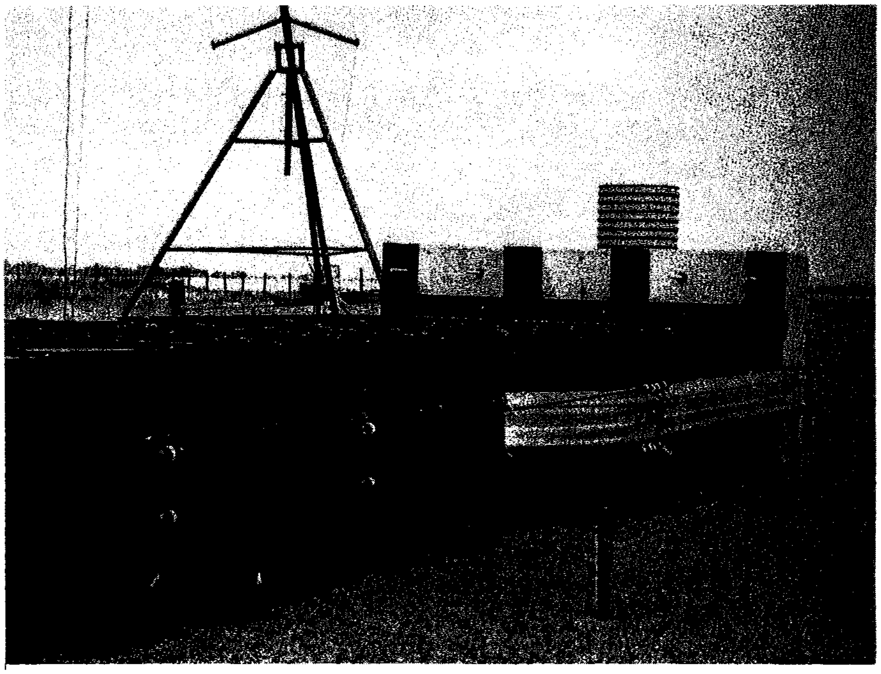



FIGURE 1A, MODULAR CRASH CUSHION CONFIGURATION - TEST 1146-8



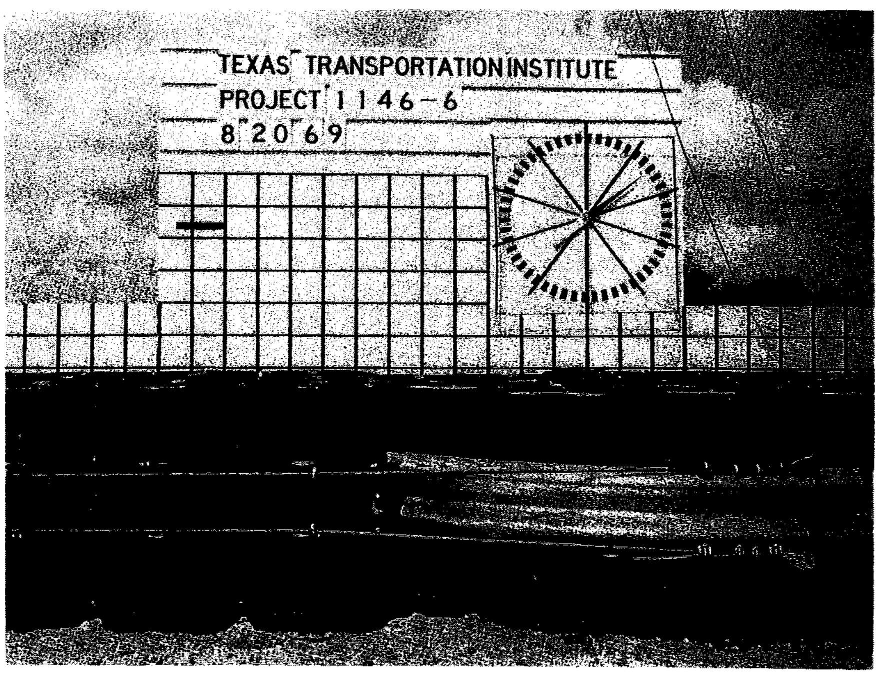



Figure 2, Barrier Before Test 1146-6.

TEST 1146-6

Impact at $20^{o}$ with cushion center line. Impact point on W-section guardrail 9.6 feet in front of the rigid wall. See Figure 1.

Vehicle Weight = 3550 lbs

Initial Speed = 58.2 mph or 85.4 ft/sec

Average Decelerations:

Longitudinal = 6.2 g's

Transverse = ---*

Maximum Decelerations:

Longitudinal = 12.4 g's

Transverse = ---*

Time in Contact = 0.30 sec

In this test, a 1963 Plymouth sedan (Figure 3) impacted the guardrail portion at the rear of the cushion and was redirected. The vehicle traveled about 150 feet before striking a large piece of concrete (which was not associated with the test) and coming to rest (see Figure 4).

There was only minor damage to the crash cushion (Figures 6 and 7). The vehicle sustained considerable damage to the left front end. The amount of damage due to the collision with the concrete block was undetermined. The broken windshield resulted from the vehicle's hood breaking free during the primary impact (Figures 4 and 5).

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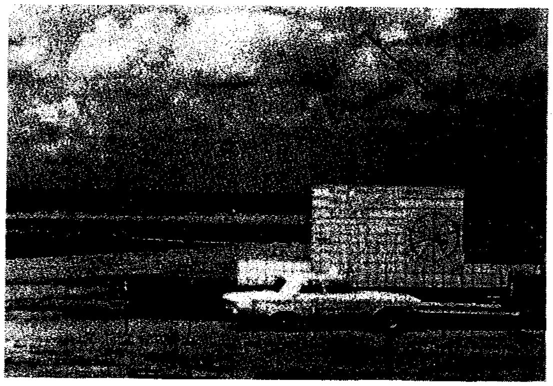
*There were no transverse accelerometers on the frame, but the Impact-O-Graph in the trunk showed a transverse maximum of 16.7 g's and an average of 2.0 g's over 0.48 seconds.

Figure 3, Vehicle Before Test 1146-6.

Figure 4, Vehicle After Test 1146-6.
(Note barrier in background
visible above roof of vehicle.)



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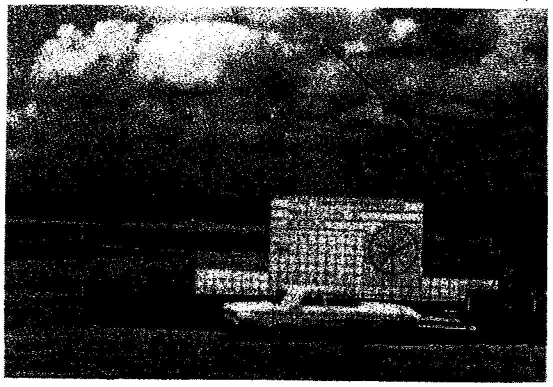

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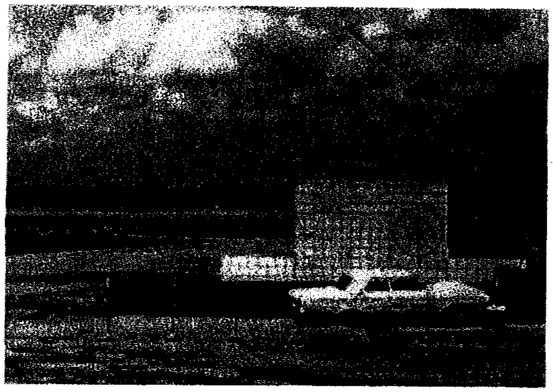

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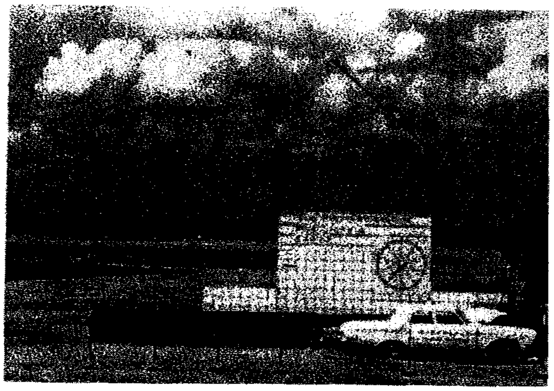

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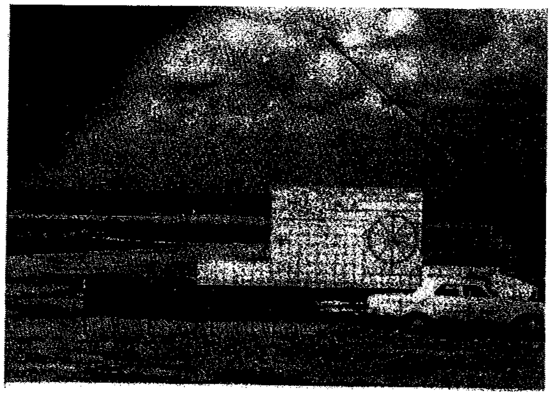

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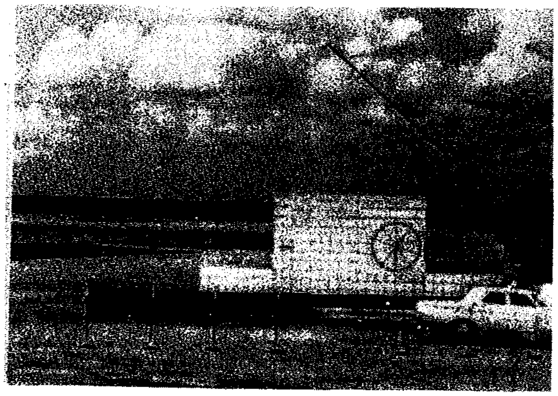

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Figure 5, Sequential Photographs of Test 1146-6.

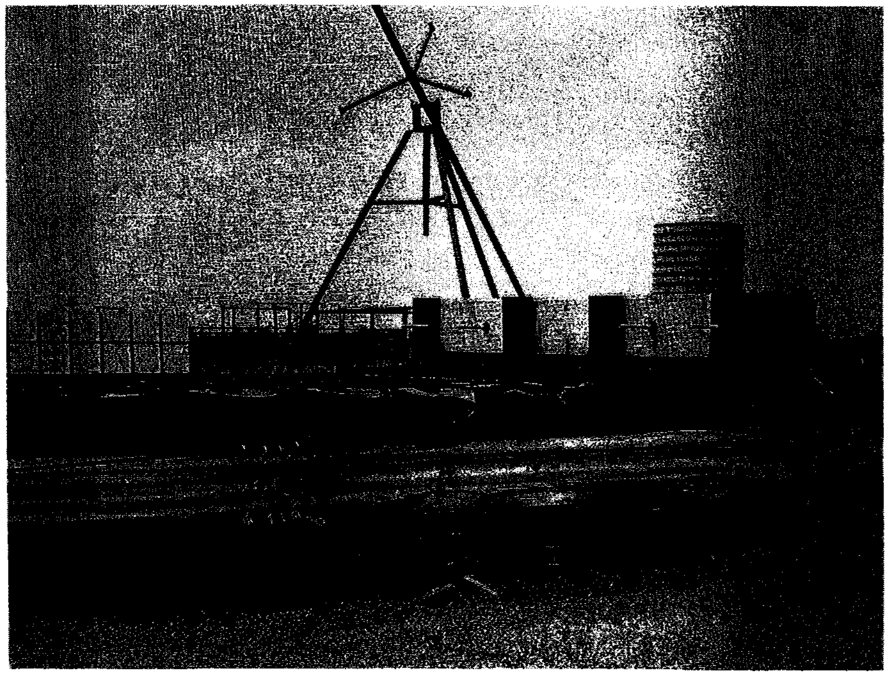


Figure 6, Barrier After Test 1146-6.

Figure 7, Top view of Barrier After Test 1146-6.

TEST 1146-7

Impact at 20° with center line of cushion in front of W-section guardrail, 23 feet from the rigid wall. See Figure 1.

Vehicle Weight = 3630 lbs

Initial Speed = 51.2 mph or 75.1 ft/sec

Average Decelerations:

Longitudinal = 8.0 g's

Transverse = 1.4 g's

Maximum Decelerations:

Longitudinal = 14.1 g's

Transverse = 3.7 g's

Time in Contact = 0.38 sec

Again, a 1963 Plymouth sedan (Figure 8) was used. The crash cushion was restored to its original condition prior to the test (Figures 9 and 12). In this test, the vehicle was directed into the modules in front of the curved portion of the guardrail to determine the severity of the secondary collision with the rail.

The vehicle traveled about 9.5 feet from the point of initial contact with the modules to the point of initial contact with the guardrail. As the left front end of the vehicle was intercepted by the curved portion of the rail (Figures 13 and 14), the accompanying deceleration caused the vehicle to rotate about 35° and come to a stop. Some rebounding was observed (Figure 11). Again, the left front end was severely damaged, but the passenger compartment was not penetrated.

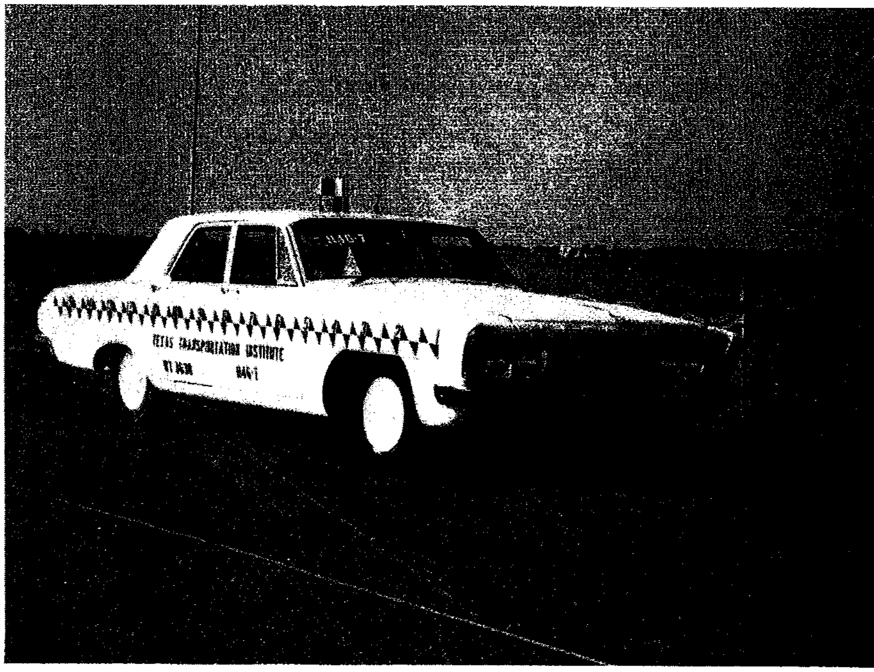
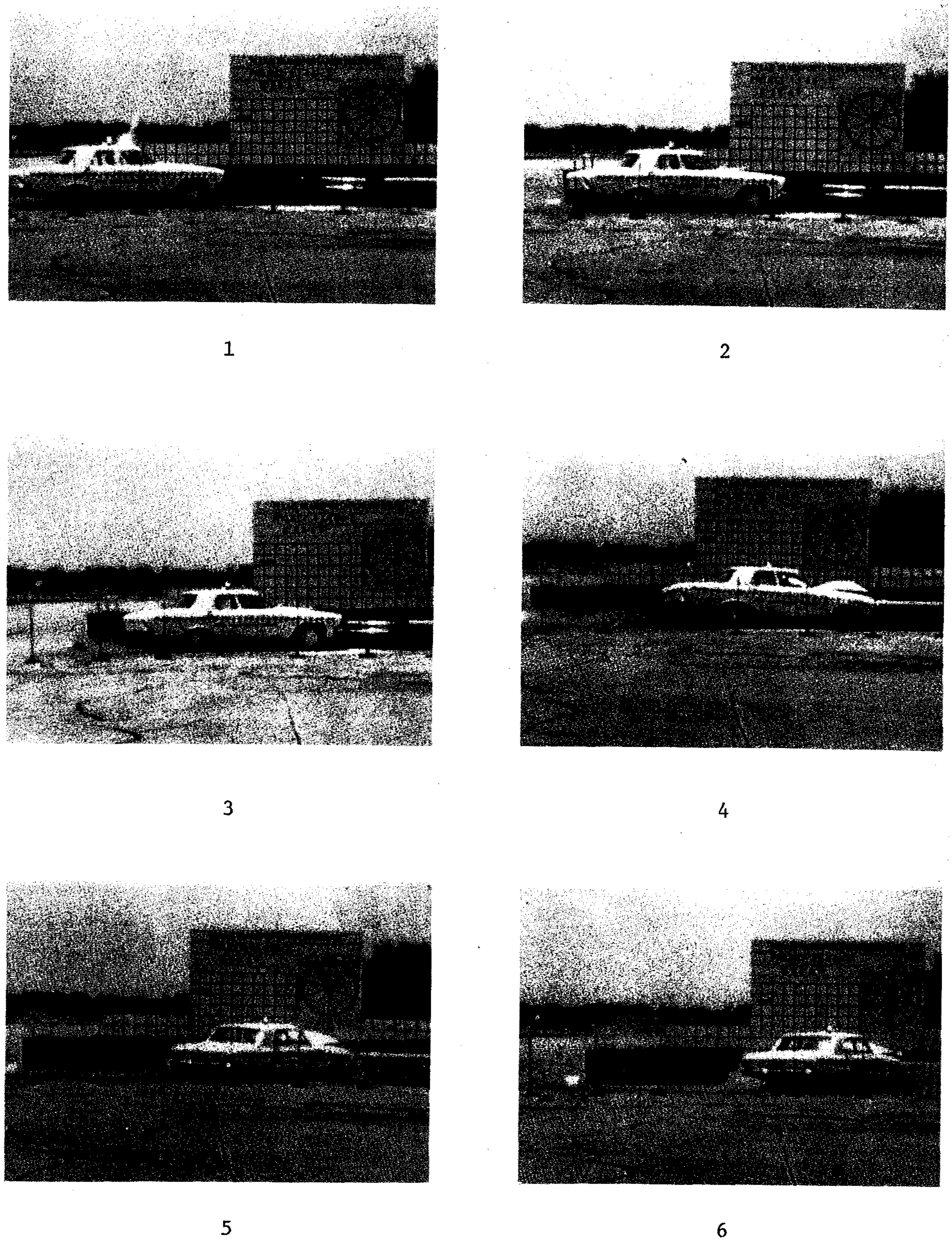


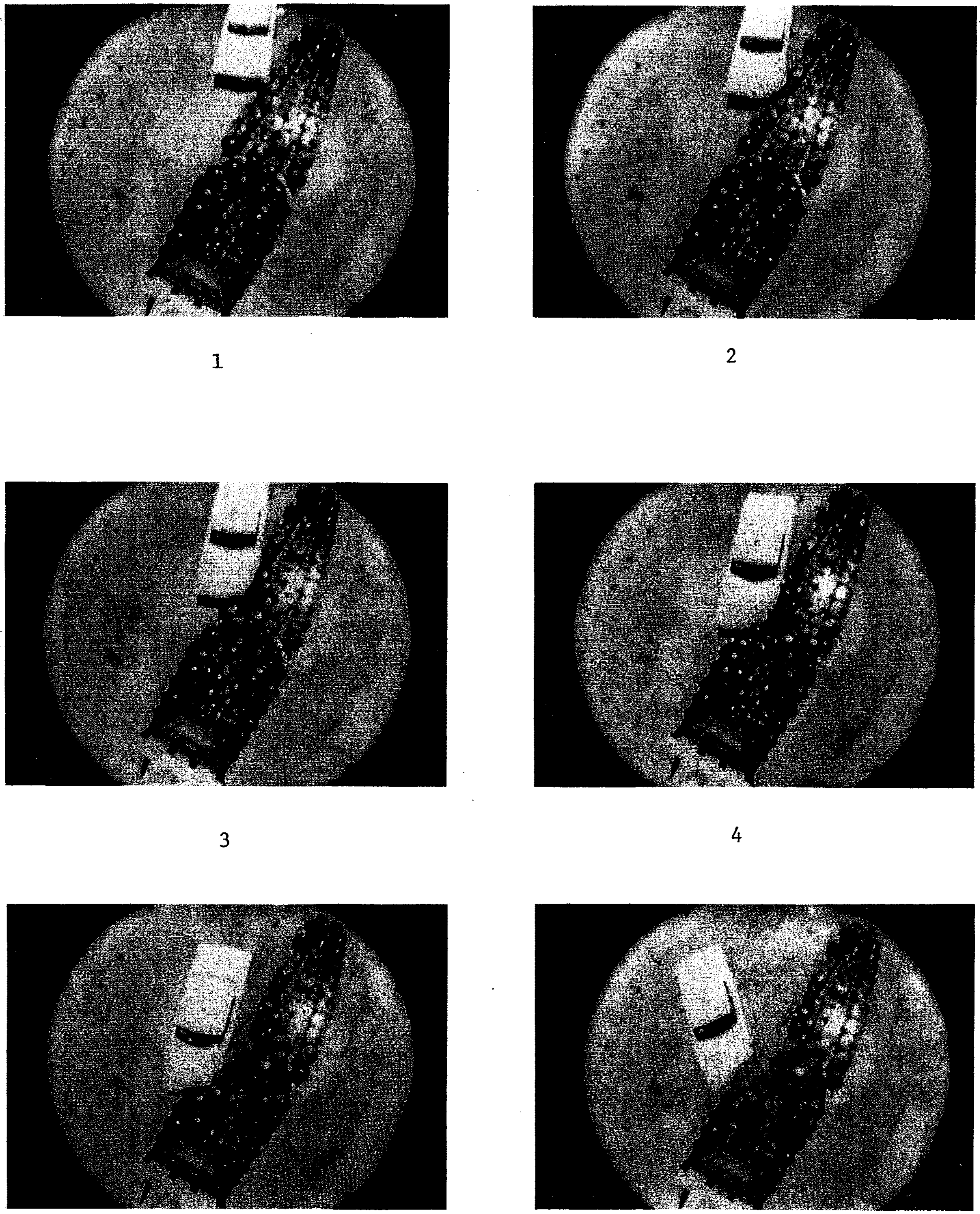
Figure 8, Vehicle Before Test 1146-7.

Figure 9, Repaired Barrier Before Test 1146-7.



1 2 3 4 5 6

Figure 10, Sequential Photographs of Test 1146-7.



1 2 3 4 5 6

Figure 11, Overhead View of Test 1146-7.

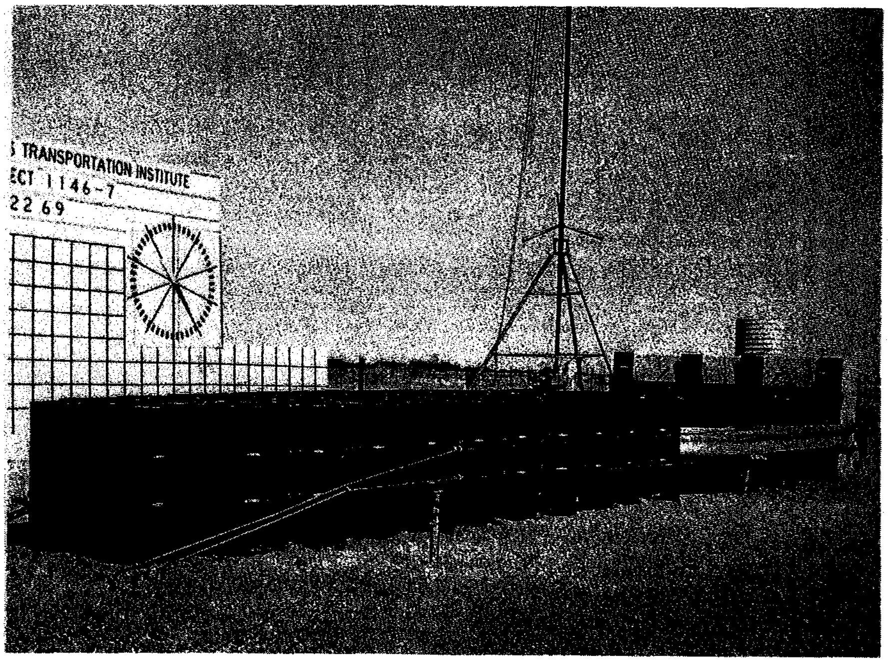



Figure 12, Barrier Before Test 1146-7.

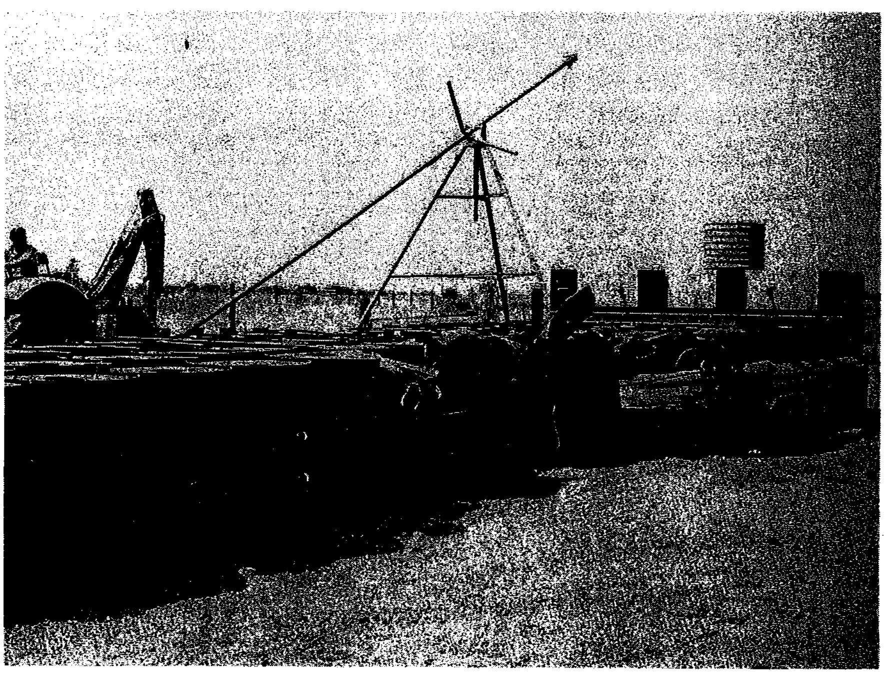


Figure 13, Barrier After Test 1146-7.

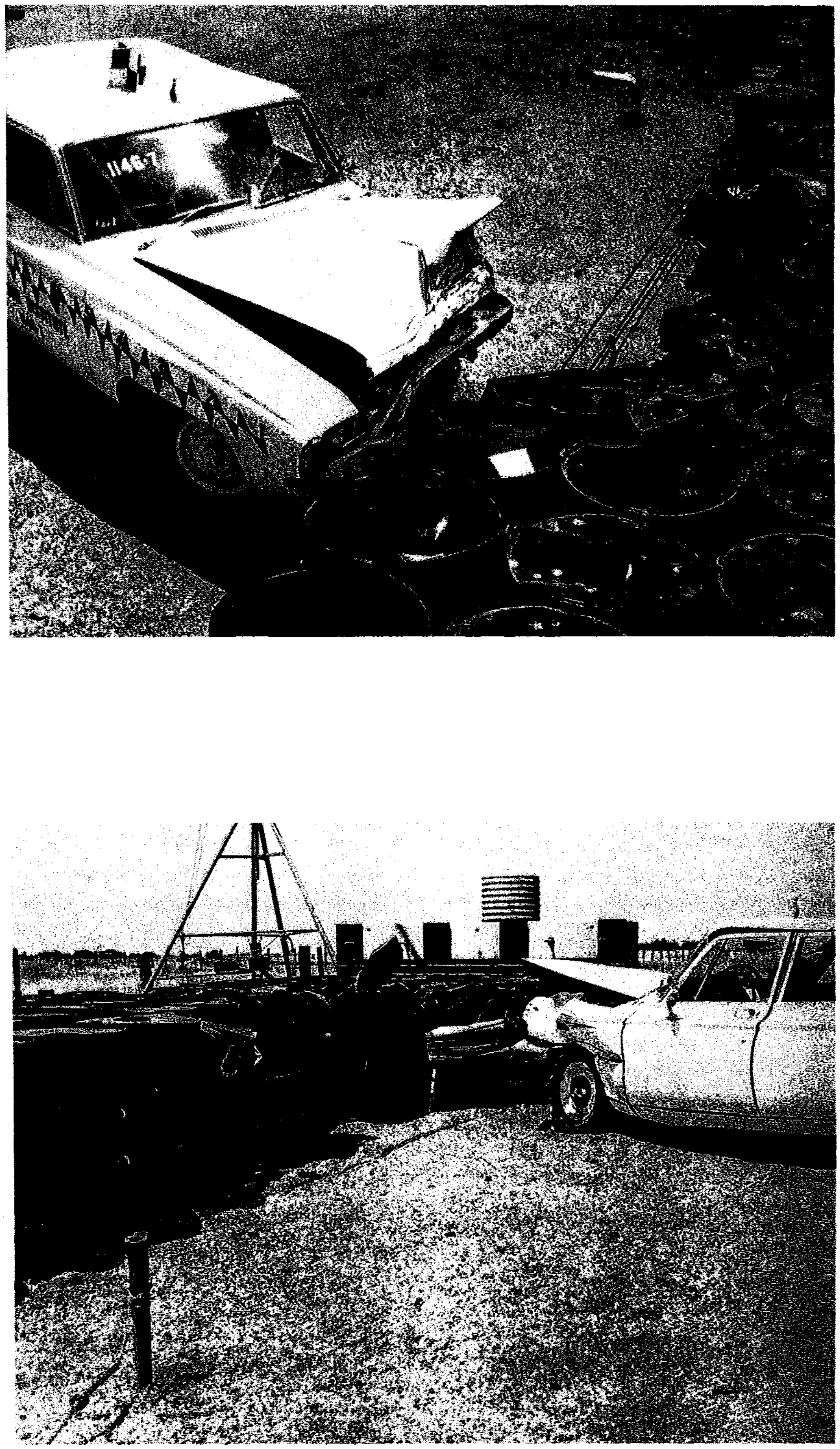



Figure 14, Vehicle and Barrier After Test 1146-7.

TEST 1146-8

Impact at $20^{\circ}$ with center line of cushion on W-section guardrail, 15.5 feet in front of the rigid wall. See Figure 1A.

Vehicle Weight = 4540 lbs

Initial Speed - 54.1 mph or 79.3 ft/sec

Average Decelerations:

Longitudinal - 8.8 g's

Transverse = 1.2 g's

Maximum Decelerations:

Longitudinal = 22.4 g's

Transverse = 11.4 g's

Time in Contact = 0.29 sec

Several modifications were made to the cushion before this test was run. These included extending the W-section guardrail 22 feet beyond the rigid wall, adding more drums to the system and enclosing more drums with the W-section guardrail, relocating and removing some of the 6 B 8.5 support posts, and using a single 7/8" diameter anchor cable (with swage connectors) on each side. A 1963 Oldsmobile impacted the guardrail section at the same point as in Test 1146-6. The vehicle did not redirect as intended and contacted the steel bulkhead after 0.148 sec, causing a high peak deceleration. The vehicle then rebounded slightly, rotated, and came to a stop as shown in Figure 20. The guardrail was damaged beyond repair, and some of the I-beams were ripped from their plates. Damage to the front end of the vehicle was severe as shown in Figure 16.

Figure 18 and Figure 20 indicate that the main support cable and guardrail yielded and produced slack during impact and allowed the vehicle to pocket and rotate. Examination of the swage cable connections indicated the cable slipped about 3/4" on each end. In addition, the 12-gage guardrail section appeared to have yielded in tension and its bolted connections slipped slightly. Added together, the stretch and slip in the cable, guardrail, and connections generated enough slack to allow the cable and guardrail to sag laterally several feet, which caused the vehicle to pocket instead of redirecting as intended.

In this test, there was only one 6 B 8.5 fixed post at the impact point to support the guardrail. In the previous (successful) test, there were three fixed posts near the impact point to support the guardrail.

Figure 15, Vehicle Before Test 1146-8.

Figure 16, Vehicle After Test 1146-8.

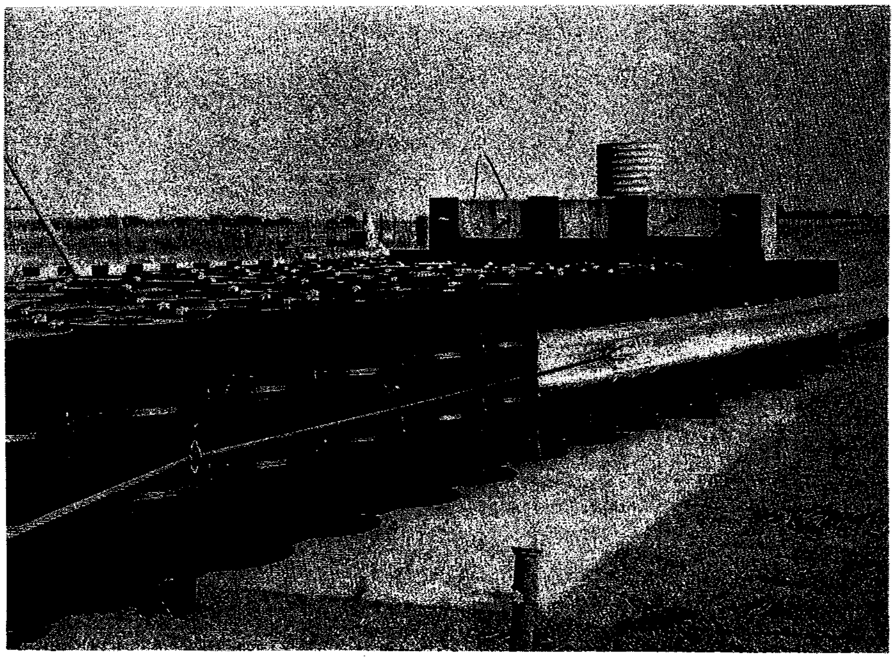


Figure 17, Barrier Before Test 1146-8.

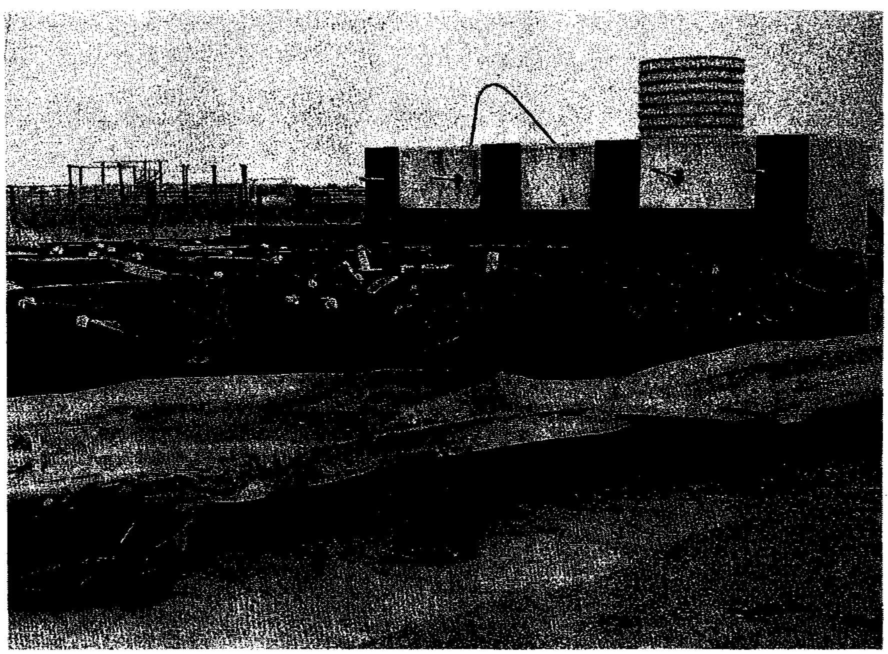


Figure 18, Barrier After Test 1146-8.

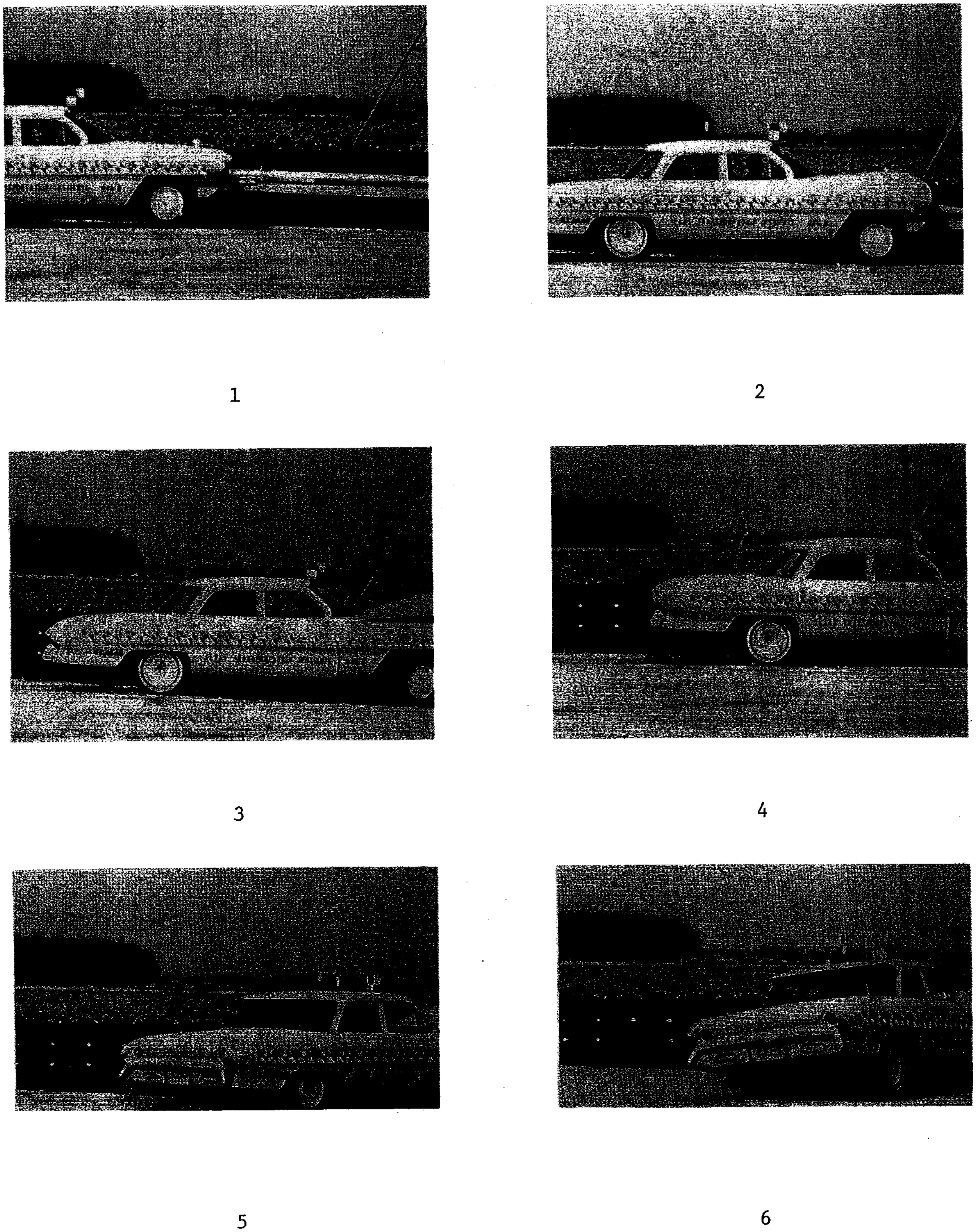
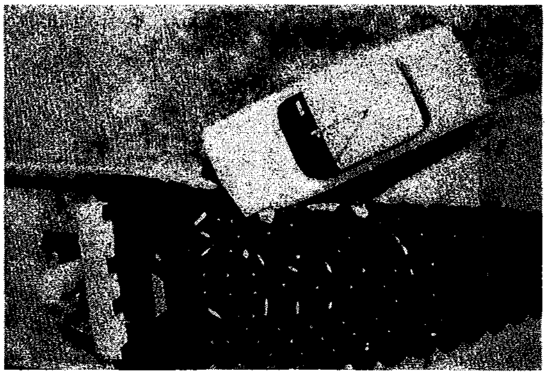



Figure 19, Sequential Photographs of Test 1146-8.



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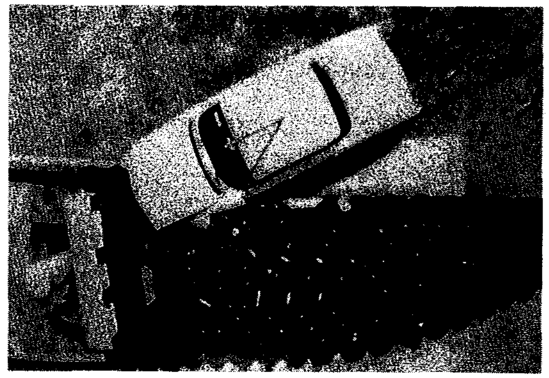

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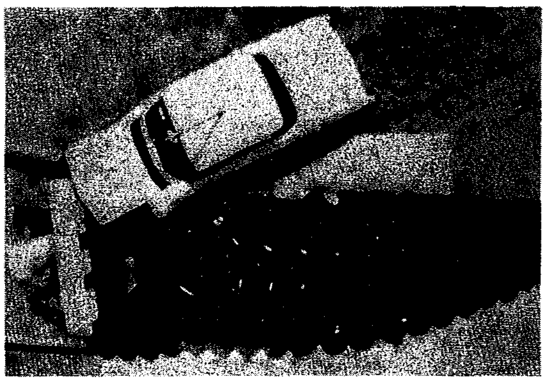

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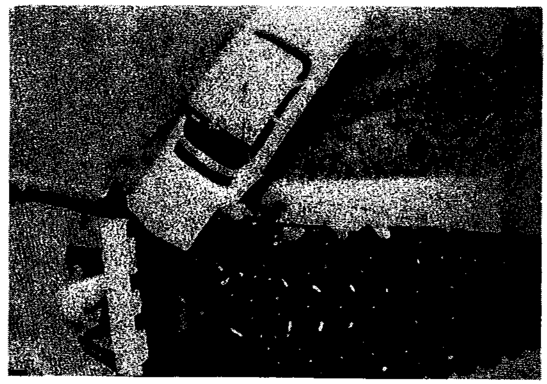

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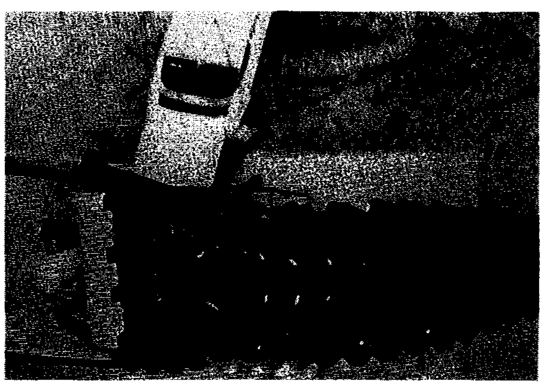

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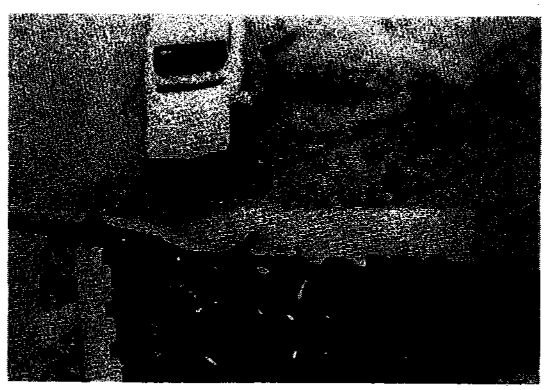

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Figure 20, Overhead View of Test 1146-8.

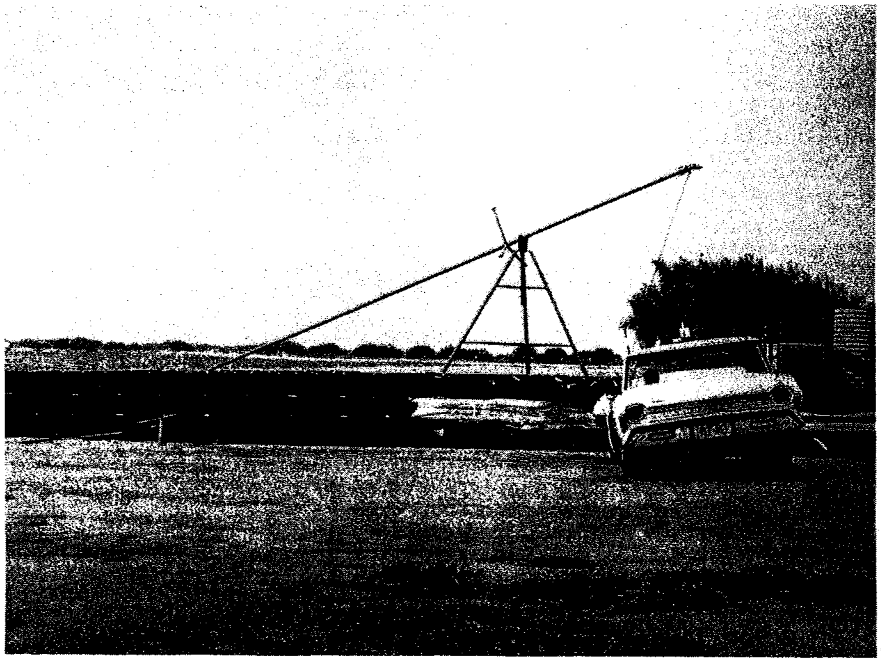

Figure 21, Impact Area After Test 1146-8.

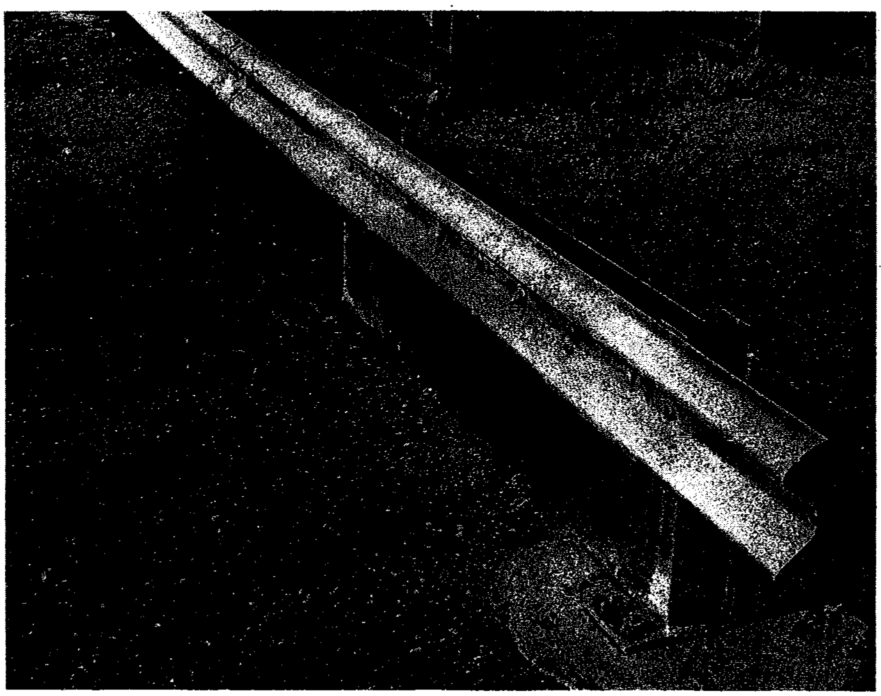

Figure 22, Guardrail Anchorage Behind Rigid Wall.

## CONCLUSIONS

The inclusion of a W-section guardrail around additional drums installed at the rear portion of the crash cushion can provide redirectional capability for angular crashes near the rigid obstacle if adequately supported by fixed posts and rigid cable connections. However, for angular hits directly in front of the guardrail portion, the vehicle is allowed to "pocket" and then encounter the guardrail at a severe angle. This tends to cause the vehicle to both spin and rebound. Nevertheless, the decelerations produced in such a test are not considered excessive for properly restrained passengers.

It is evident that the longitudinal cables attached to the flexbeam form an integral part of the redirection system. These cables must provide lateral stability in angled impacts while producing negligible interference in head-on crashes. The third test reported here demonstrated the need for strong and rigid cable connectors, and several fixed posts supporting the guardrail as use in test 1146-6.

Drawings of a revised design incorporating these features are shown in Figure 23. It would be desirable to evaluate this revised design with a full-scale crash test.

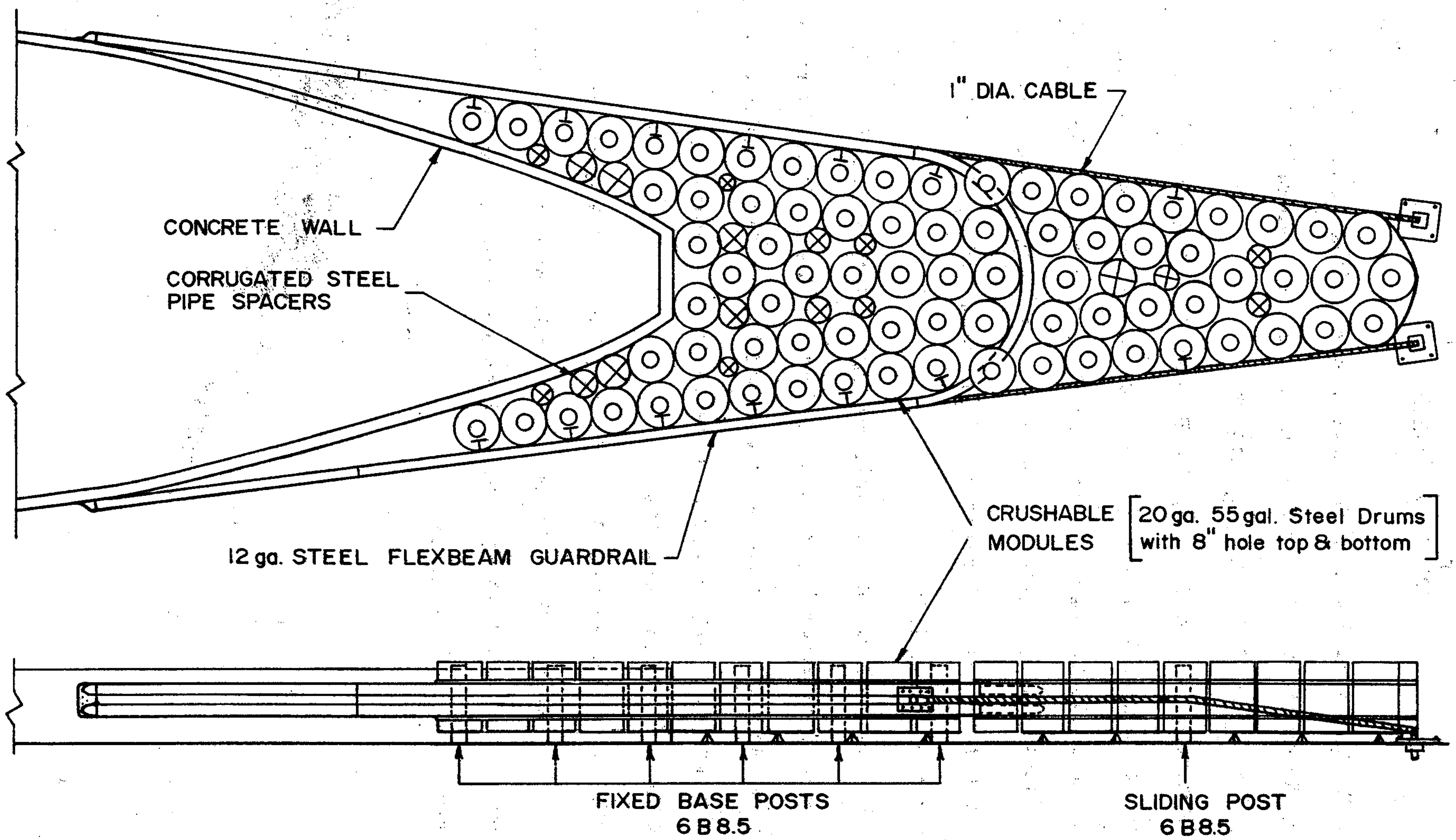


FIGURE 23, REVISED DESIGN OF FLEXBEAM REDIRECTION SYSTEM FOR THE MODULAR CRASH CUSHIONS

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2. White, Monroe C., Ivey, Don L., and Hirsch, T. J., *In-Service Experiences on Installations of Texas Modular Crash Cushions*, Research Report Number 146-2, Texas Transportation Institute, research study number 2-8-68-146 sponsored by the Texas Highway Department in cooperation with the U.S. Department of Transportation, Federal Highway Administration, July 1970.

3. Hirsch, T. J. and Ivey, D. L., *Vehicle Impact Attenuation by Modular Crash Cushion*, Research Report 146-1, Texas Transportation Institute, research study number 2-8-68-146 sponsored by The Texas Highway Department in cooperation with the U.S. Department of Transportation, Federal Highway Administration, June 1969.

4. Hirsch, T. J., Hayes, Gordon G., and Ivey, Don L., "Modular Crash Cushion," Technical Memorandum 505-1S, a supplement to 505-1, under review by the Federal Highway Administration and to be published by Texas Transportation Institute.

# A P P E N D I X

## Film and Accelerometer Data

TABLE A1

HIGH-SPEED FILM DATA

TEST 1146-6

| Time (milliseconds) | Displacement (feet) | Time (milliseconds) | Displacement (feet) |
|---|---|---|---|
| -61.1 | -5.2 | 151.2 | 11.3 |
| -50.9 | -4.4 | 161.3 | 11.9 |
| -40.7 | -3.5 | 171.4 | 12.4 |
| -30.5 | -2.6 | 181.4 | 13.0 |
| -20.4 | -1.7 | 191.5 | 13.4 |
| -10.2 | -0.9 | 201.6 | 13.8 |
| 0 Impact | 0 | 221.8 | 14.7 |
| 10.1 | 0.9 | 241.9 | 15.7 |
| 20.2 | 1.8 | 262.1 | 16.6 |
| 30.2 | 2.6 | 282.2 | 17.6 |
| 40.3 | 3.5 | 302.4 | 18.6 |
| 50.4 | 4.2 | 322.6 | 19.6 |
| 60.5 | 5.0 | 342.7 | 20.7 |
| 70.6 | 5.9 | 362.9 | 21.6 |
| 80.6 | 6.6 | 383.0 | 22.7 |
| 90.7 | 7.4 | 403.2 | 23.8 |
| 100.8 | 8.1 | 423.4 | 24.7 |
| 110.9 | 8.8 | 443.5 | 25.8 |
| 121.0 | 9.5 | 463.7 | 26.8 |
| 131.0 | 10.2 | | |
| 141.1 | 10.8 | | |

TABLE A2

HIGH-SPEED FILM DATA

TEST 1146-7

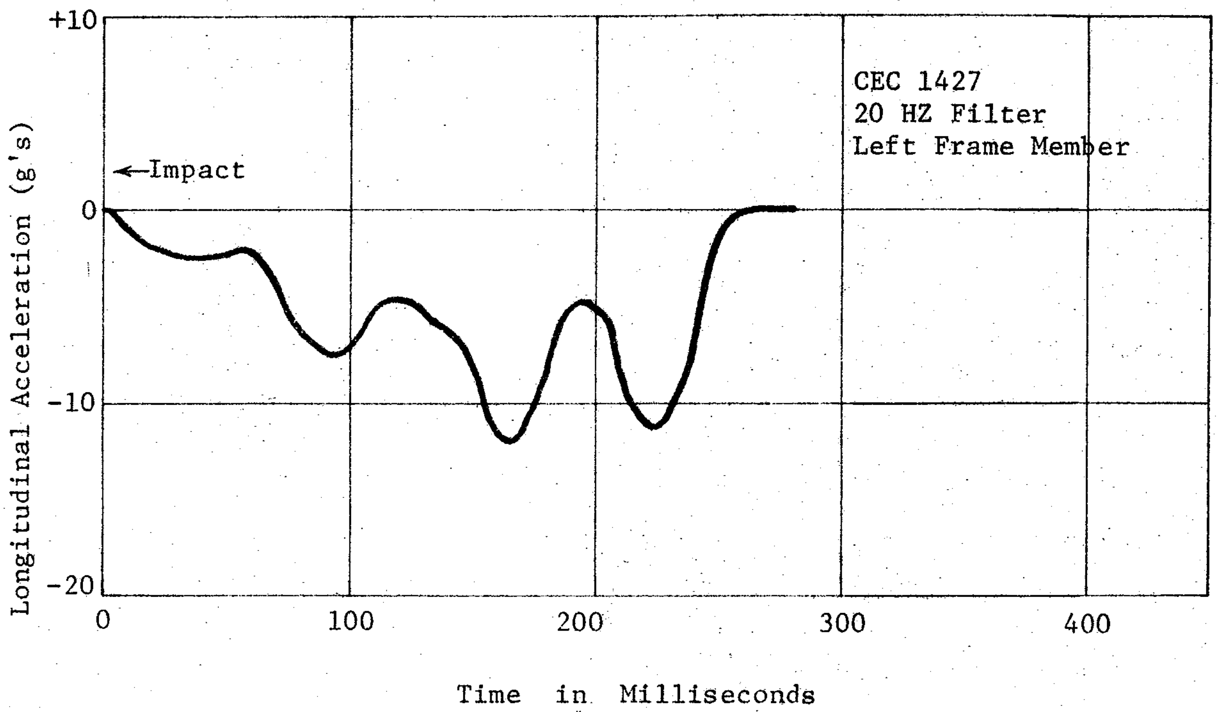
| Time (milliseconds) | Displacement (feet) | Time (milliseconds) | Displacement (feet) |
|---|---|---|---|
| -60.5 | -4.5 | (continued) | |
| -50.4 | -3.8 | 131.0 | 9.1 |
| -40.3 | -3.0 | 141.1 | 9.7 |
| -30.2 | -2.3 | 151.2 | 10.2 |
| -20.2 | -1.5 | 161.3 | 10.7 |
| -10.1 | -0.7 | 171.4 | 11.2 |
| 0 Impact | 0 | 181.4 | 11.7 |
| 10.1 | 0.8 | 191.5 | 12.2 |
| 20.2 | 1.5 | 201.6 | 12.6 |
| 30.2 | 2.3 | 211.7 | 13.0 |
| 40.3 | 3.0 | 221.8 | 13.4 |
| 50.4 | 3.7 | 241.9 | 14.0 |
| 60.5 | 4.4 | 262.1 | 14.4 |
| 70.6 | 5.1 | 282.2 | 14.8 |
| 80.6 | 5.8 | 302.4 | 15.1 |
| 90.7 | 6.5 | 322.6 | 15.3 |
| 100.8 | 7.2 | 342.7 | 15.4 |
| 110.9 | 7.8 | 362.9 | 15.5 |
| 121.0 | 8.4 | 383.0 | 15.6 |

TABLE A3

HIGH-SPEED FILM DATA

TEST 1146-8

| Time (milliseconds) | Displacement (feet) | Time (milliseconds) | Displacement (feet) |
|---|---|---|---|
| -50.7 | -4.0 | (continued | |
| -38.0 | -3.0 | 126.8 | 9.1 |
| -25.4 | -2.0 | 139.5 | 9.8 |
| -12.7 | -1.0 | 152.2 | 10.4 |
| 0 Impact | 0 | 164.9 | 11.0 |
| 7.6 | 0.6 | 177.6 | 11.6 |
| 15.2 | 1.2 | 190.2 | 12.0 |
| 22.8 | 1.8 | 202.9 | 12.4 |
| 30.4 | 2.4 | 215.6 | 12.8 |
| 38.0 | 3.0 | 228.3 | 13.0 |
| 45.7 | 3.6 | 253.6 | 13.3 |
| 53.3 | 4.1 | 279.0 | 13.5 |
| 60.9 | 4.7 | 304.4 | 13.6 |
| 68.5 | 5.2 | 329.7 | 13.8 |
| 76.1 | 5.8 | 355.1 | 14.1 |
| 83.7 | 6.3 | | |
| 91.3 | 6.8 | | |
| 98.9 | 7.3 | | |
| 106.5 | 7.8 | | |
| 114.2 | 8.3 | | |



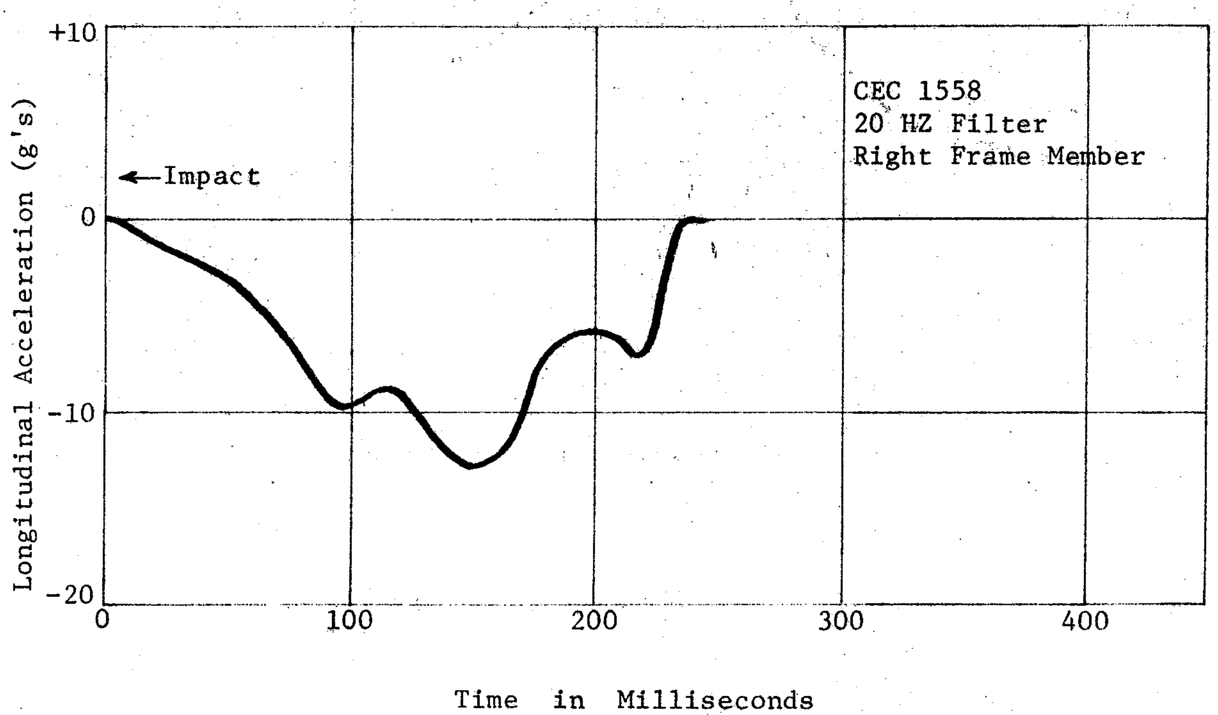




Figure A1, Longitudinal Accelerometer Data, Test 1146-6

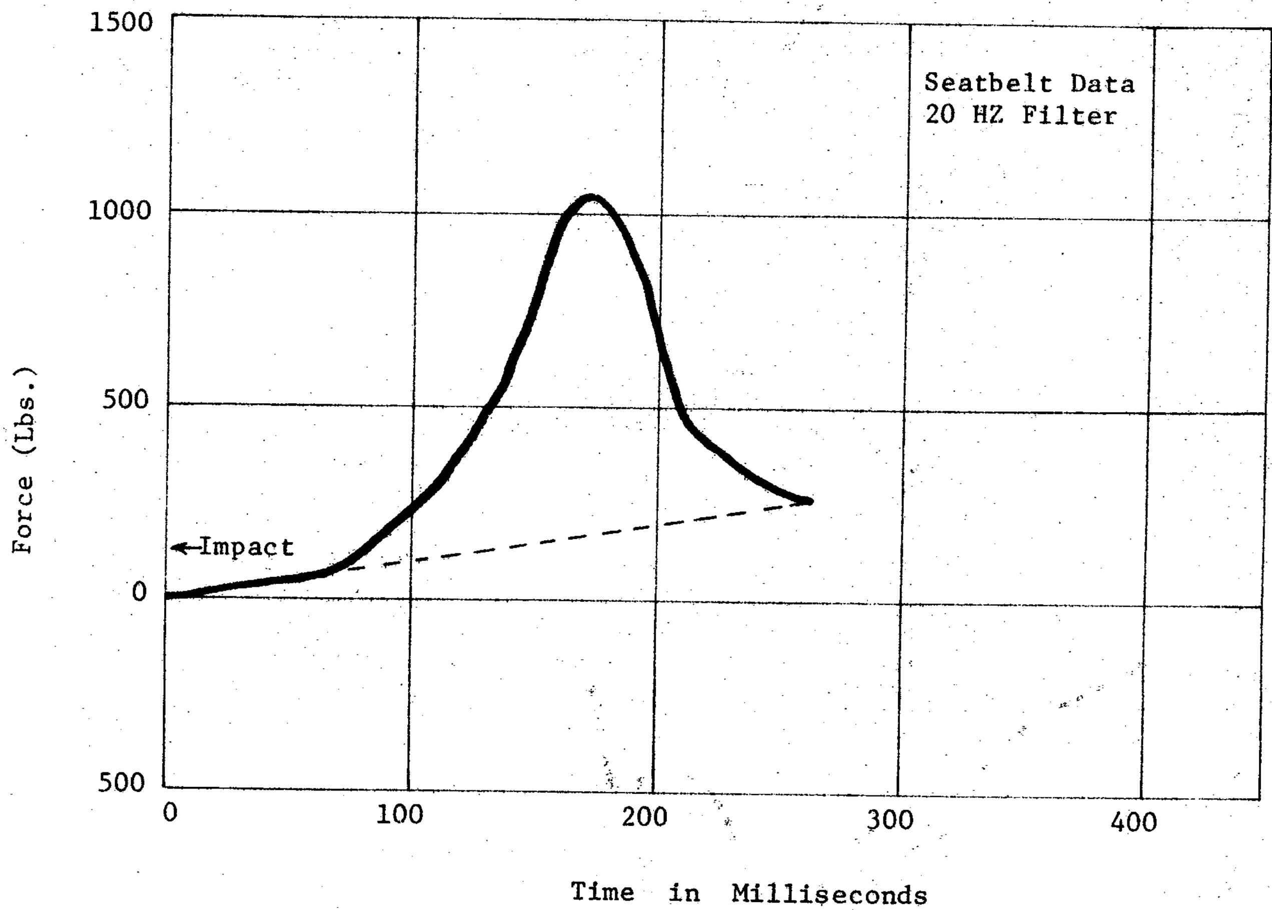
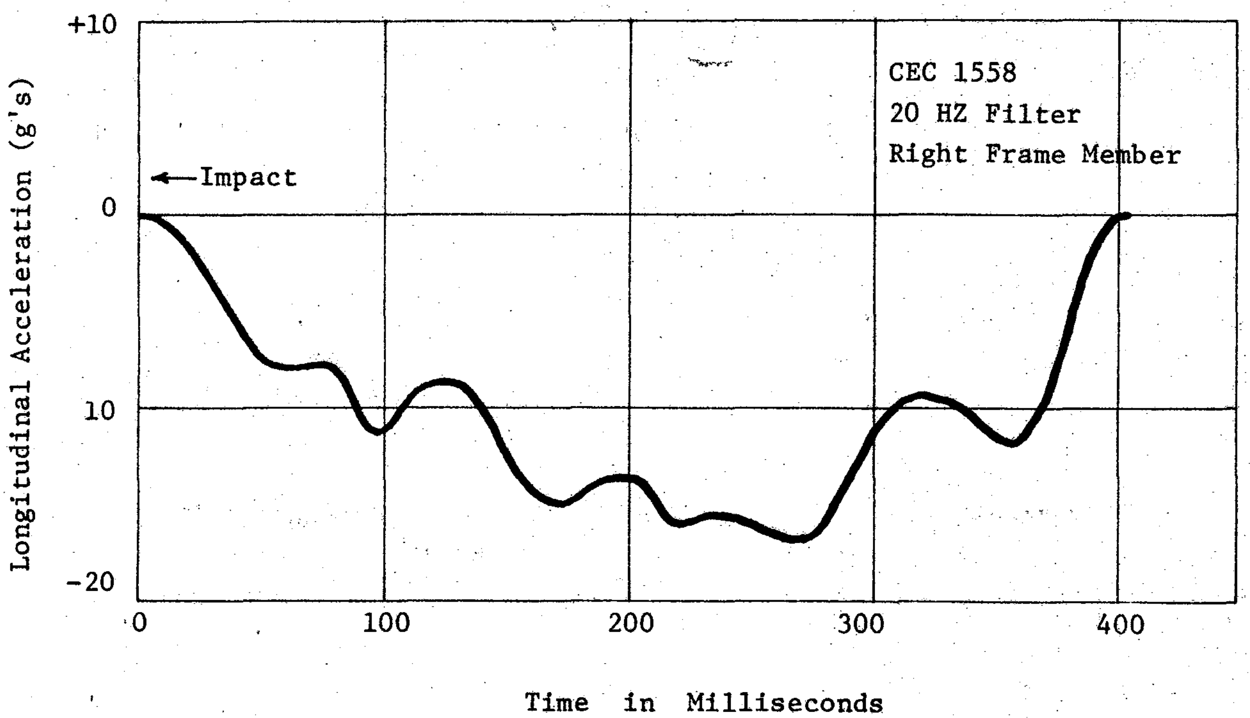



Figure A2, Seatbelt Data, Test 1146-6



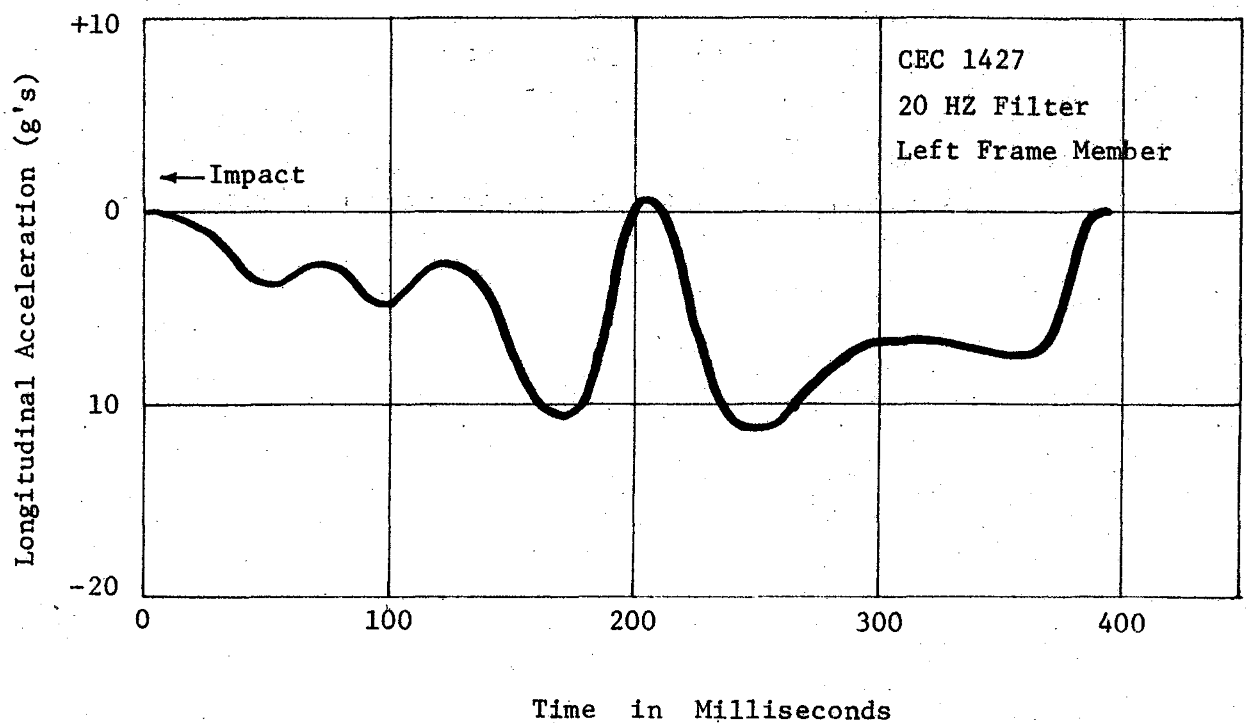




Figure A3, Longitudinal Accelerometer Data, Test 1146-7

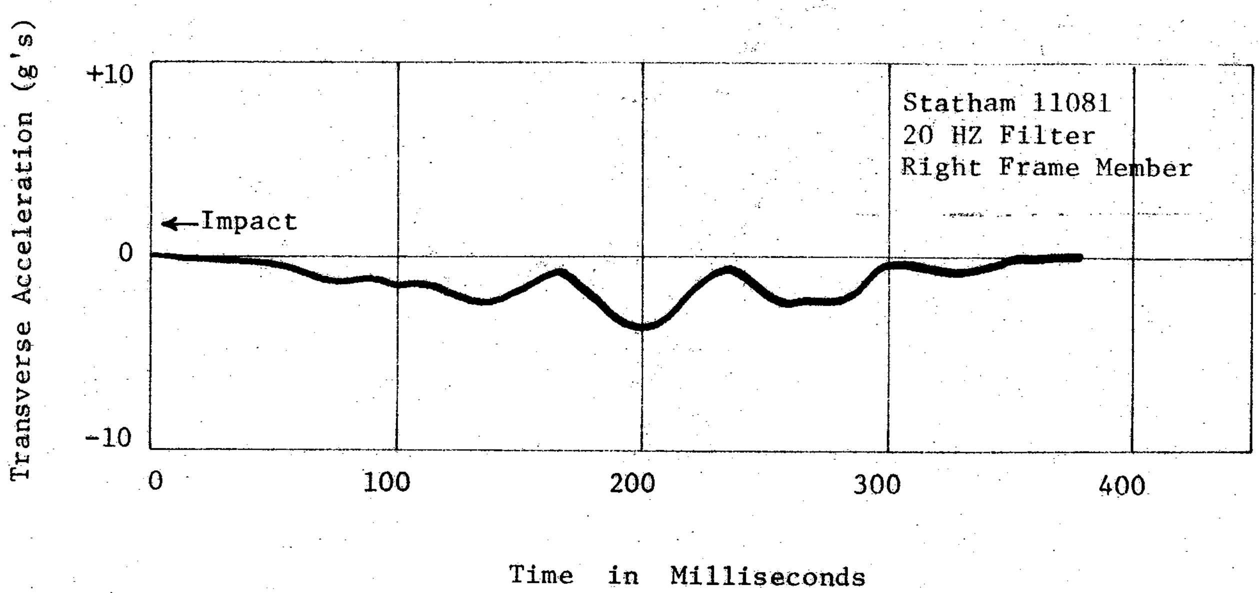



Figure A4, Transverse Accelerometer Data, Test 1147-7

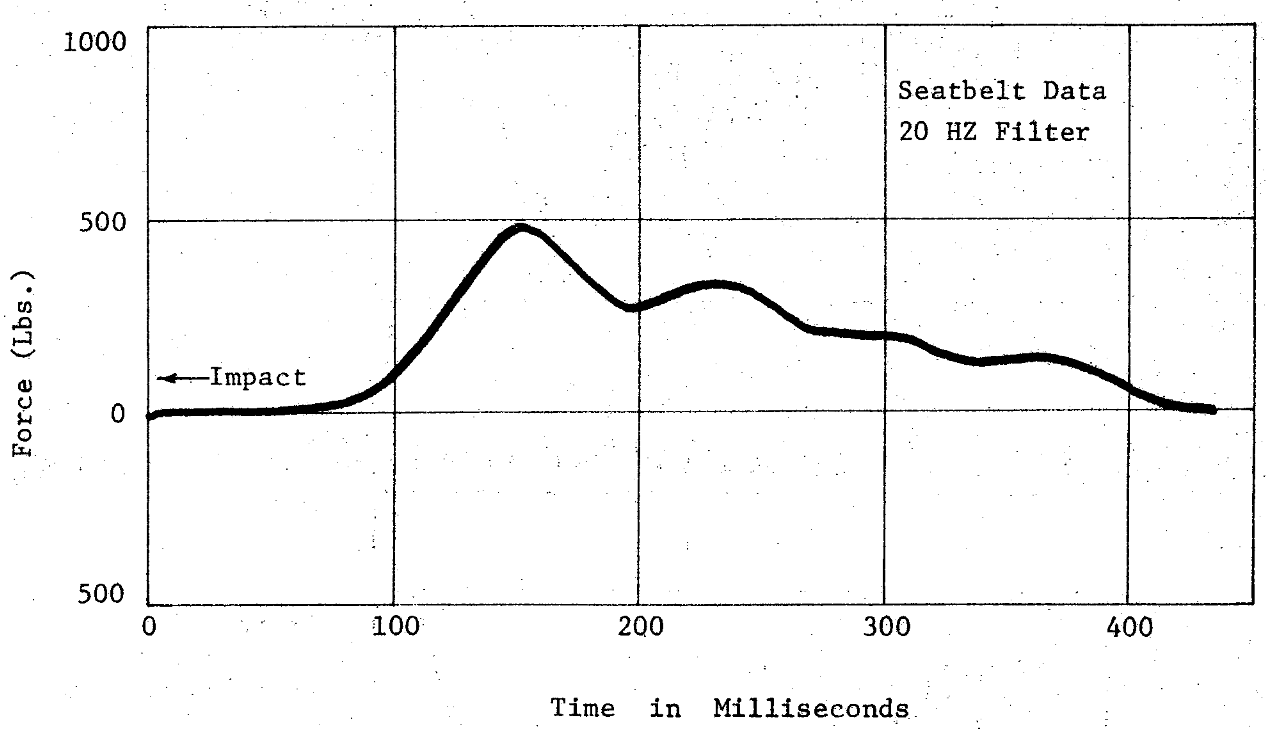
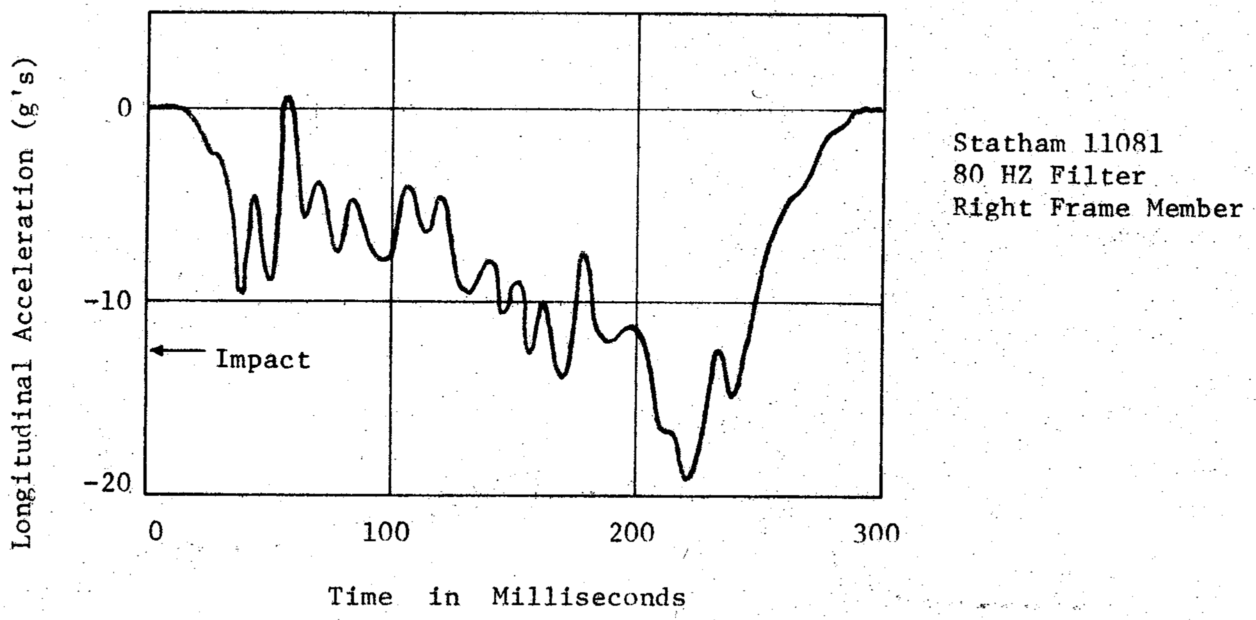



Figure A5, Seatbelt Data, Test 1146-7



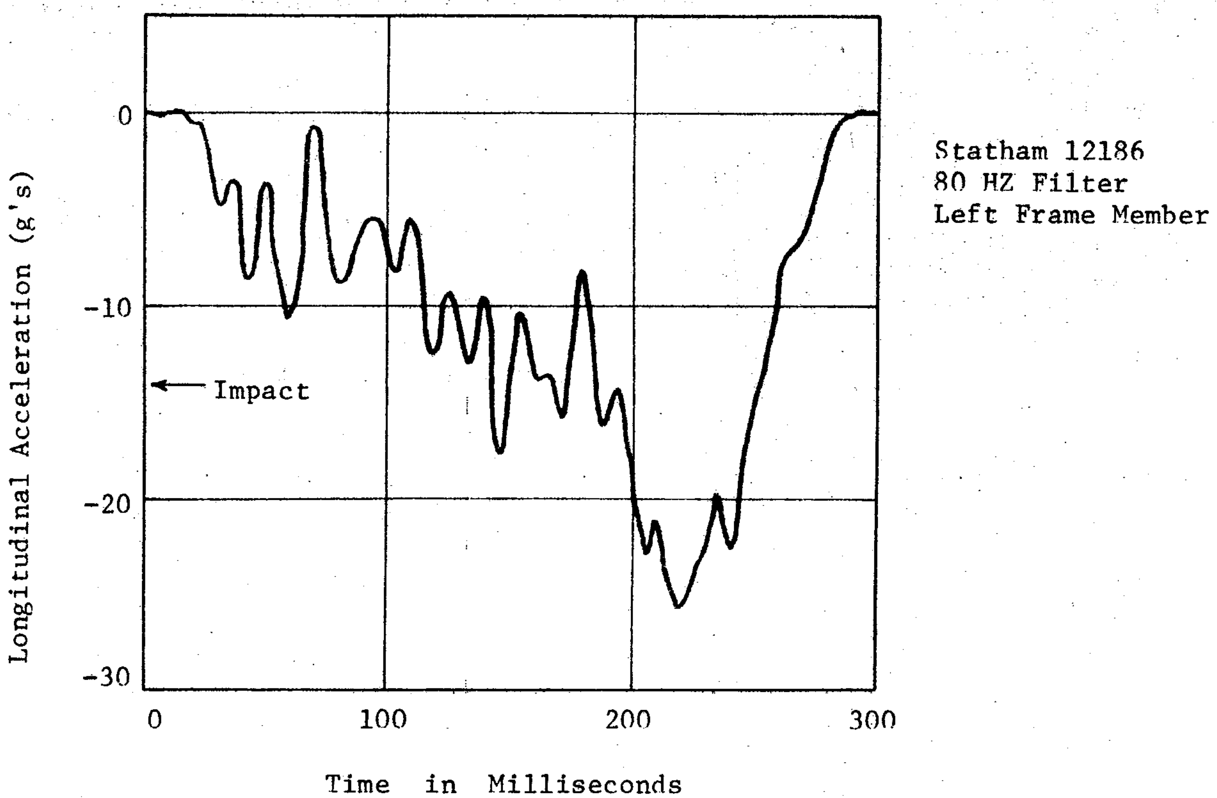
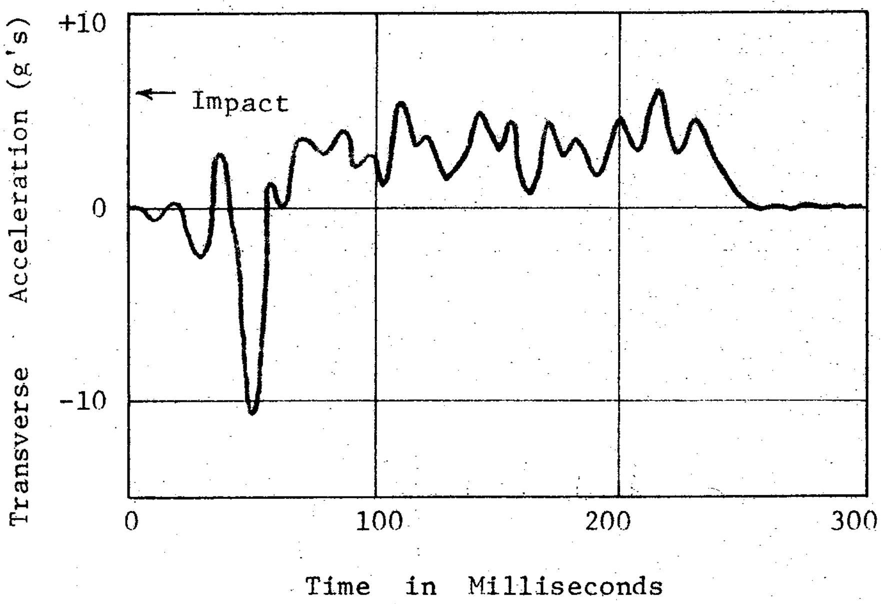
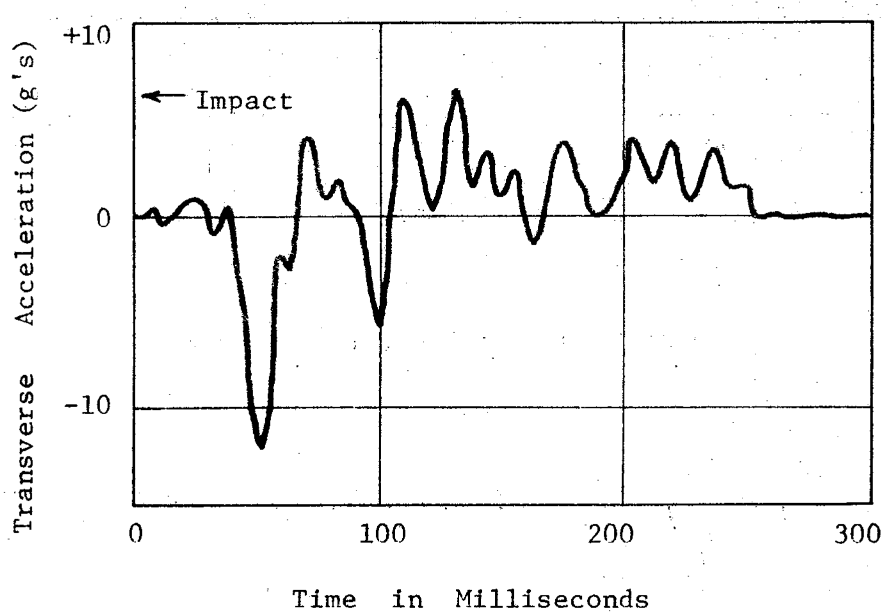




Figure A6, Longitudinal Accelerometer Data, Test 1146-8




Statham 20
80 HZ Filter
Right Frame Member




Statham 511
80 HZ Filter
Left Frame Member

Figure A7, Transverse Accelerometer Data, Test 1146-8

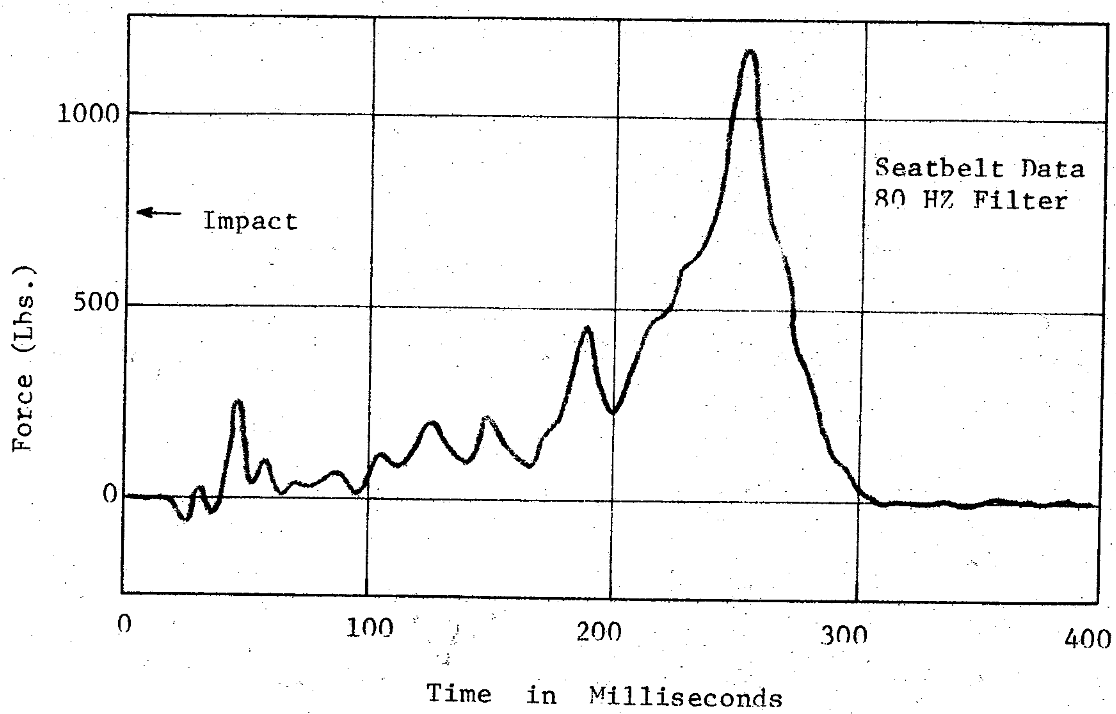



Figure A8, Seatbelt Data, Test 1146-8