TECHNICAL MEMORANDUM 505-1S

SUPPLEMENT TO 505-1

Texas Transportation Institute
Texas A&M Research Foundation

THE MODULAR CRASH CUSHION

A Tentative Progress Memorandum on Contract No. CPR-11-5851

U.S. Department of Transportation
Federal Highway Administration

by

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These crash tests and evaluations were conducted under the Office of Research and Development, Structures and Applied Mechanics Division's, Research Program on Structural Systems in Support of Highway Safety (4S Program). The opinions, findings, and conclusions expressed in this report are those of the authors and not necessarily those of the Federal Highway Administration.

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INTRODUCTION

The Modular Crash Cushion was developed under a contract with the Federal Highway Administration as an expedient measure to reduce the number of fatal automobile collisions with rigid obstacles in or near highway rights-of-way.[1*] Additional modifications and tests were sponsored by the Texas Highway Department in cooperation with the Federal Highway Administration.[2] The crash test program and subsequent field experience indicated that this system was more than an expedient measure and that it functioned very well as an impact attenuator from both the performance and economic points of view.[3,4] As part of its program on Structural Systems in Support of Highway Safety (4S Program), the Federal Highway Administration sponsored further research to improve the basic Modular Crash Cushion design.

One constraint that is placed on most impact attenuators is the geometry of the site. A crash cushion protecting a rigid wall at an elevated freeway gore, for example, cannot be much wider than the wall itself without constricting the adjacent traffic lanes. Therefore, in angled collisions toward the rear of the cushion (near the rigid wall) the distance and energy absorbing materials are usually insufficient to stop the vehicle safely before it contacts the rigid wall. In such collisions it is usually better to cause the colliding vehicle to redirect, thereby missing the rigid wall. The provisions for redirection must be such that the cushion has lateral stability, while maintaining the "soft" characteristics during head-on impacts. The results of some of the efforts to satisfy these conditions are presented in this report.

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

SYSTEMS TESTED

The three crash cushion designs which were tested used 20-gage steel tight-head drums as the basic energy absorbing modules.

The first configuration is shown in Figure 1. The columns of modules were separated by plywood inserts, and the two support cables ran between the columns of drums in a path as shown in Figure 1. Overlapping redirection panels were attached to the sides of the crash cushion. These panels were made of 3/4" plywood covered with fiber glass which was coated with a polyester resin. This gel coat was used to give more smoothness to the panel surfaces and to improve the appearance of the barrier. The front edges of the panels were hinged so that the back edges could telescope or swing out, allowing free crushing of the barrier during head-on collisions.

The second barrier which was tested is shown in Figure 2. The basic drum arrangement was the same as before, but the support cables were moved to run in a straight line between the outer modules and the redirection panels to reduce vehicle pocketing. A "truss" composed of steel straps was welded to the tops of the modules to increase the lateral strength and stiffness of the crash cushion.

The final system constructed for testing is shown in Figure 3. Steel angle spacers were used here, and the module arrangement was modified to reduce the stopping force at the onset of the collision. This modification is especially desirable when the colliding vehicle is small and lightweight. Also, the rear of the barrier was widened to provide a cushion between the end redirection panels and the rigid wall. Again, cables inside the redirection panels were used to give lateral stability without rigidity.

Photographs of each of the cushions accompany the individual test descriptions.

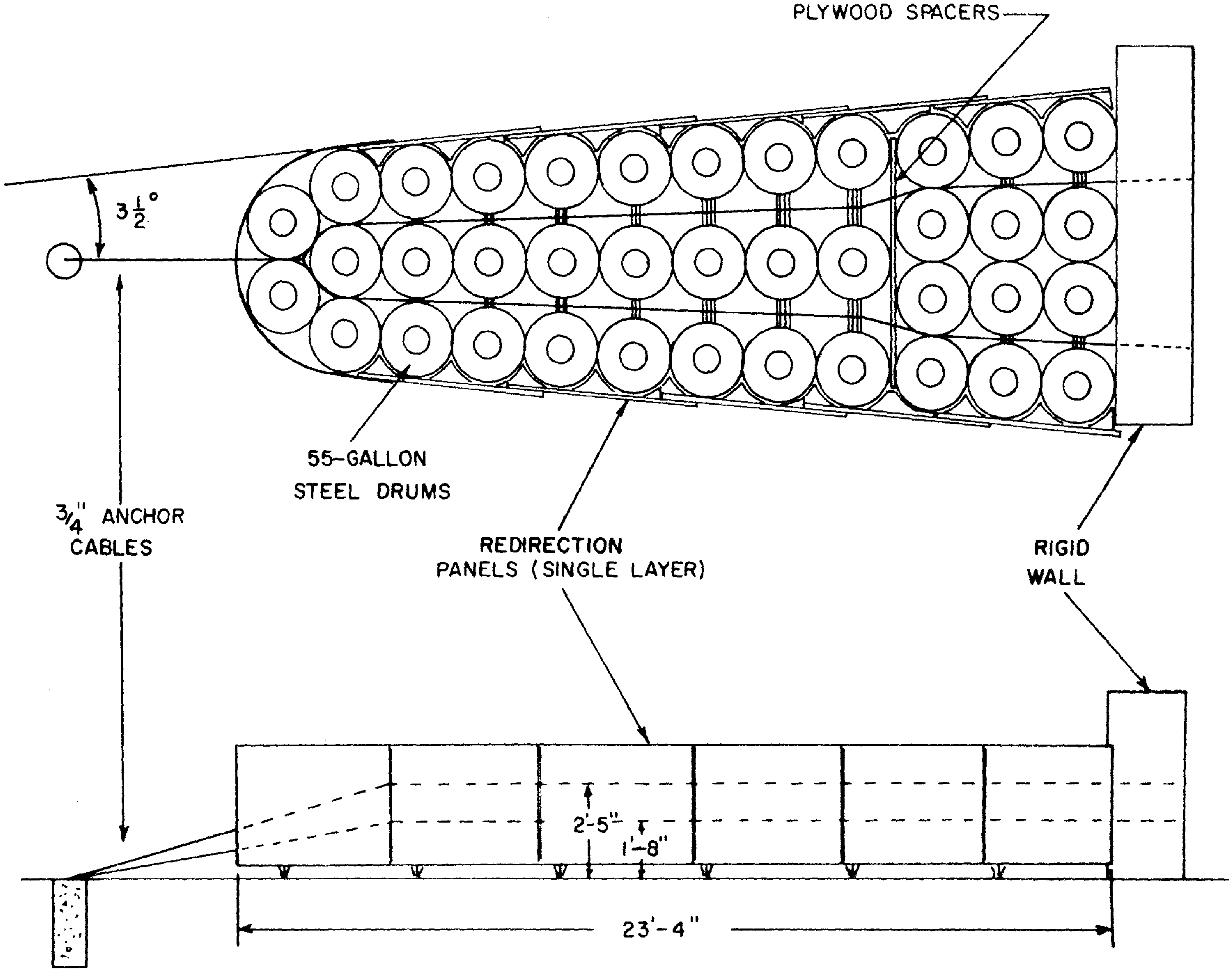


FIGURE 1, CONFIGURATION USED IN TEST 505B-A (BARRIER TYPE 1)

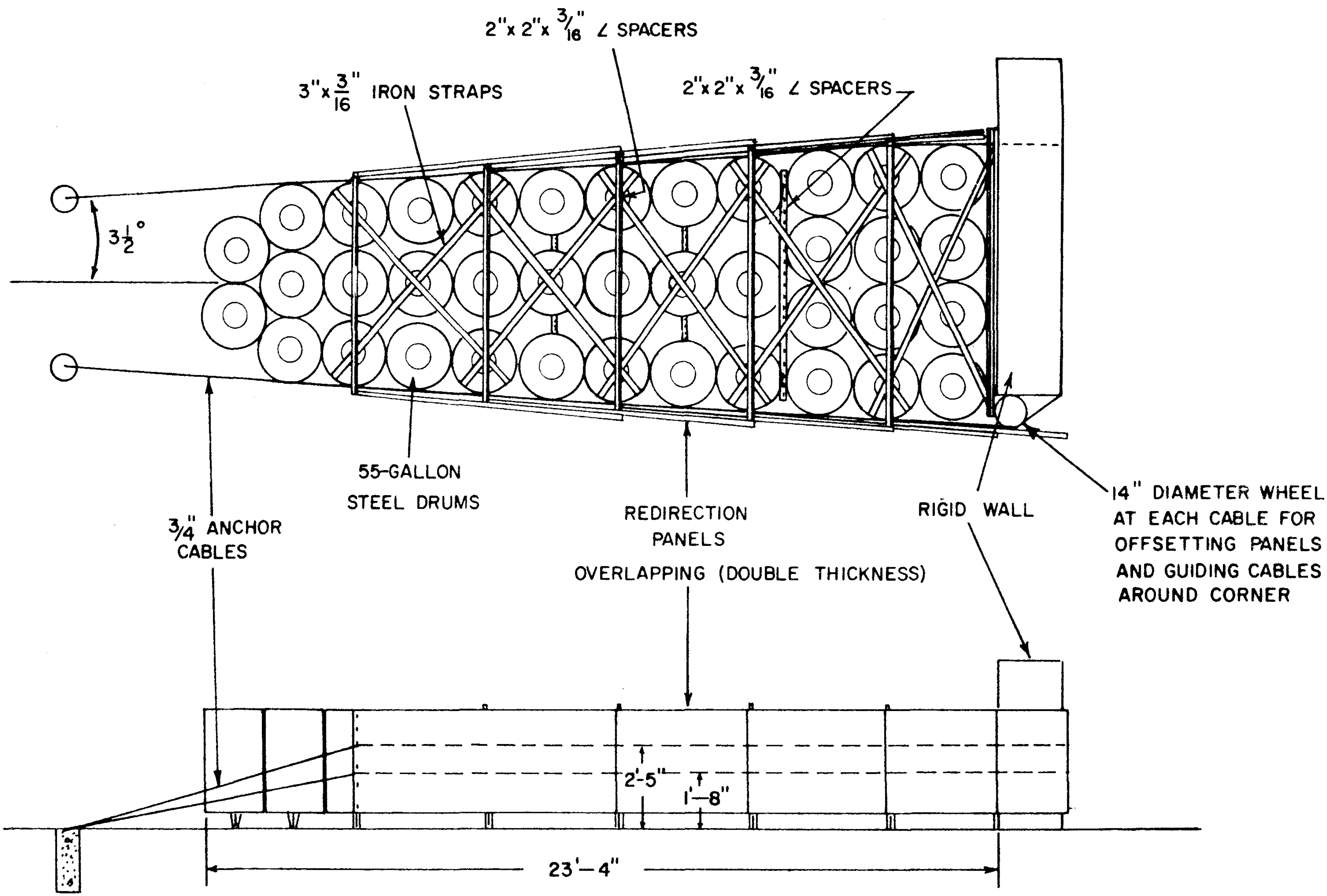


FIGURE 2, CONFIGURATION USED IN TESTS 505B-B AND 505B-C (BARRIER TYPE 2)

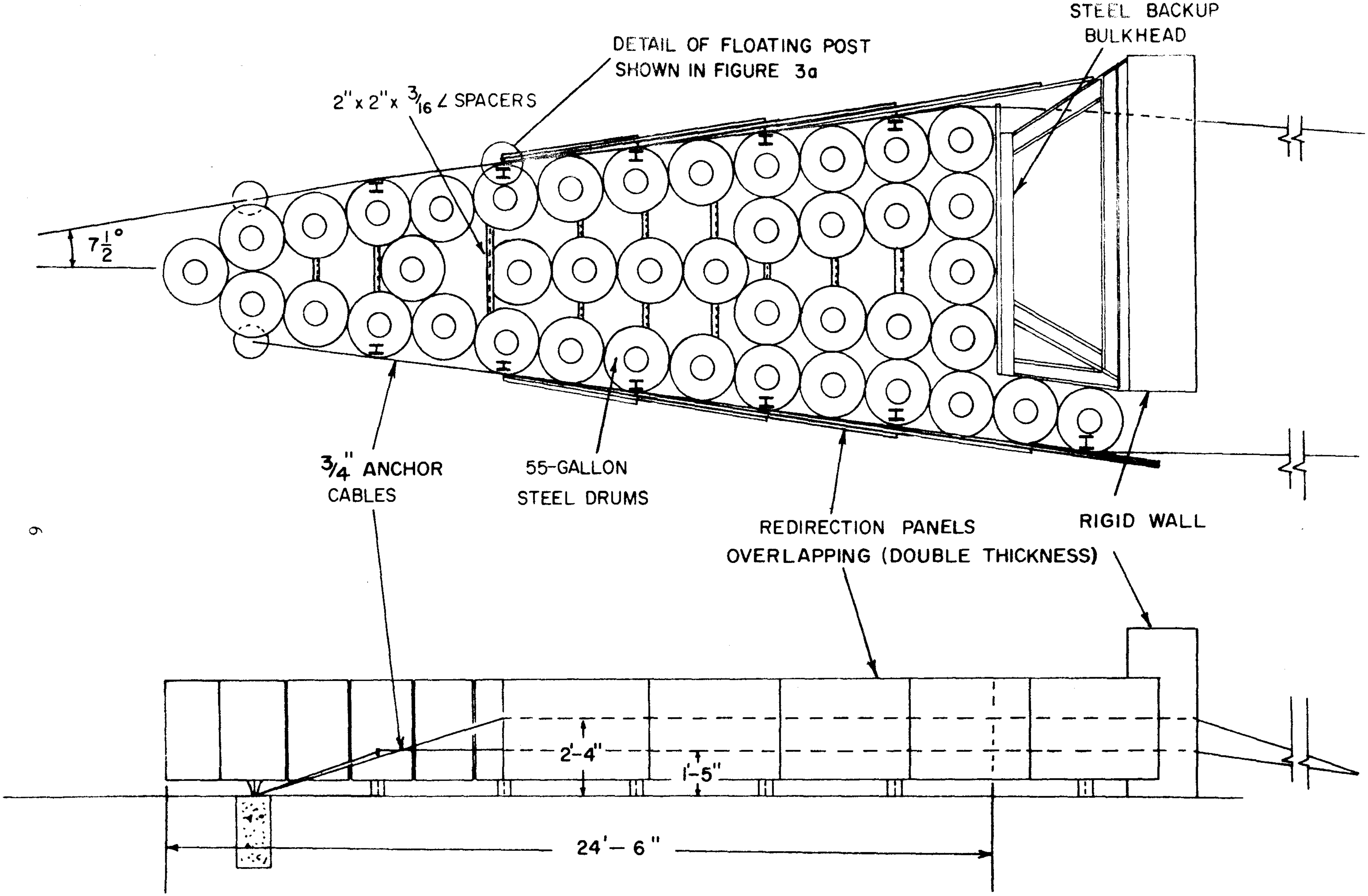


FIGURE 3, CONFIGURATION USED IN TESTS 505B-D AND 505B-E (BARRIER TYPE 3)

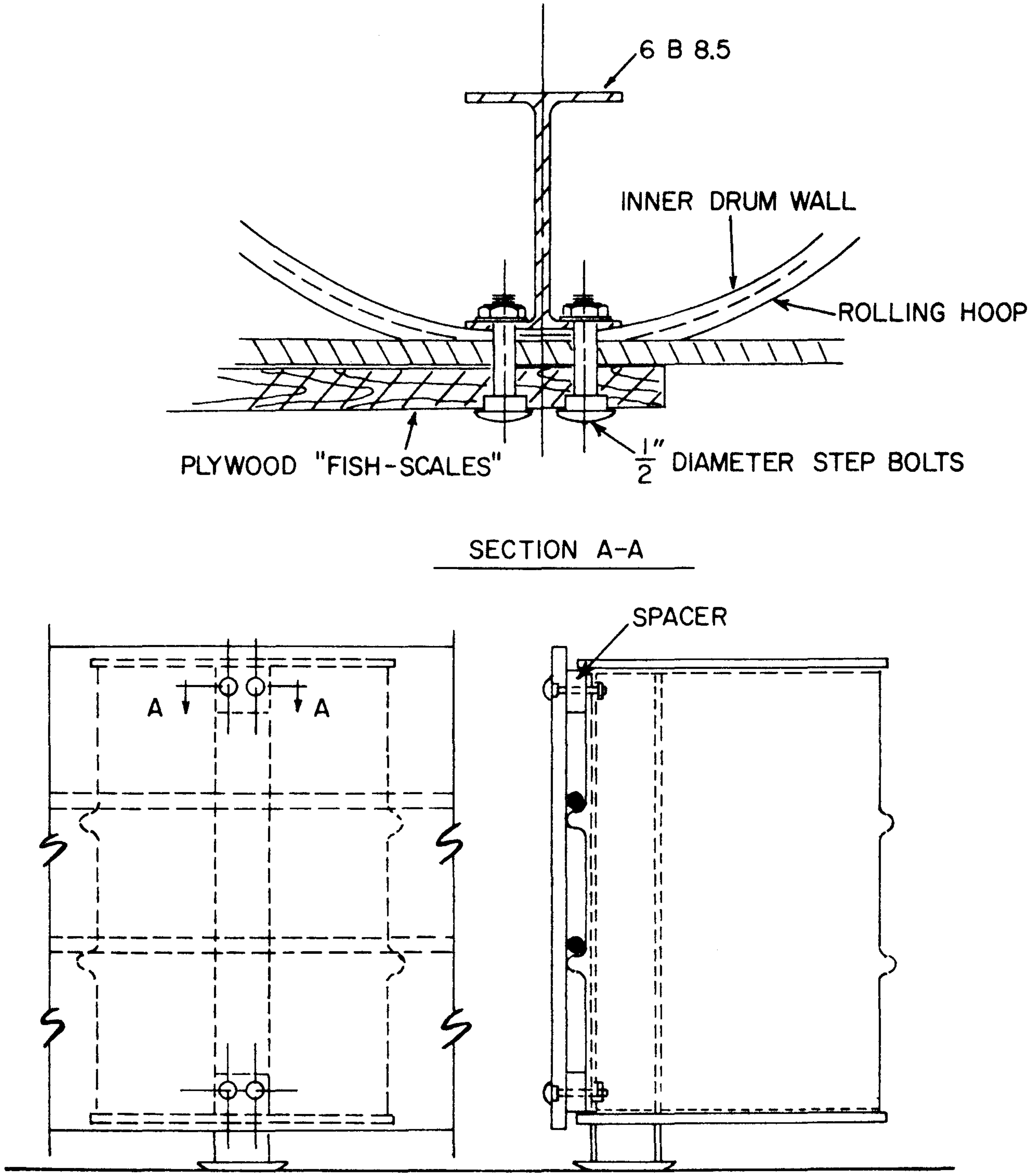


FIGURE 3a DETAIL OF FLOATING POST

TEST PROGRAM

Five full-scale crash tests were run in this series: one oblique impact on the first barrier configuration, and both an oblique and a head-on test on the other two configurations.

The tests were photographed using high-speed motion picture cameras and conventional documentary cameras. Time-displacement data was obtained from the high-speed films. The vehicles were equipped with electro-mechanical accelerometers attached to the longitudinal frame members. In addition, a mechanical Impact-O-Graph was mounted in the trunks as a secondary source of acceleration data. In tests A and E, an anthropometric dummy simulating a driver was secured with a seat belt attached to a load cell for sensing seat belt force. The signals from these transducers were transmitted by multiconductor shielded cable to recording devices. Tape switches activated by the wheels of the approaching vehicle provided a means of checking the initial speeds obtained from the high-speed films.

A typical-instrumentation summary is given in Table 1. Time-displacement data from the high-speed films and reproductions of the accelerometer traces and seat belt force curves are given in the Appendix.

Table 2 is a summary of pertinent test data. For the head-on tests, the average decelerations from the high-speed film data are considered more reliable because initial speed and stopping distance can be measured accurately by this method. The average deceleration in G's is given by $\overline{a} = V_i^2/2gS$, where V_i is the initial speed and S is the stopping distance.

The average deceleration from film data for tests in which the vehicle was redirected is given by $\bar{a} = (V_i^2 - V_f^2)/2gS$, where V_f is the speed of the vehicle at loss of contact with the barrier.

The average decelerations from the accelerometer data are obtained by integrating the area under the analog trace (Appendix) and dividing by the length (time). The deceleration times from the accelerometer traces do not coincide with the times in contact from the films because loss of contact with the barrier does not require that all forces go to zero, even though the vehicle-barrier interaction is completed.

TABLE 1

TYPICAL VEHICLE CRASH TEST INSTRUMENTATION

DEVICE	LOCATION	PURPOSE
CAMERAS:		
1 Hycam (500 frames per sec)	Perpendicular to initial path of vehicle	Initial speed
1 Hycam (500 fps)	Perpendicular to barrier	Entire event
1 Photosonics (500 fps)	Directly above barrier	Overhead view
1 Bell & Howell (128 fps)	Oblique to barrier	Documentary
1 Cine Special (64 fps)	Perpendicular to barrier	Documentary
ACCELEROMETERS:		
1 Statham* and 1 CEC**	Right vehicle frame member	Longitudinal and Transverse acceleration
1 Statham* and 1 CEC**	Left vehicle frame member	Longitudinal and Transverse acceleration
1 Impact-O-Graph	Trunk of vehicle	Triaxial accelerations
OTHER:		
1 Pair of Tape Switches	About 16 ft. before impact	Initial speed
1 Tape Switch	At impact point on barrier	Time of impact
1 Tape Switch and Flash Bulb	On vehicle	Indicate impact visually
1 Seat Belt Strain Gage	Attached to seat belt	Seat belt force on Alderson articulated anthropometric dummy

*Strain gage type
**Piezoelectric type

TABLE 2

SUMMARY OF TEST DATA

TEST	A	B	C	D	E
Barrier Type	1	2	2	3	3
Vehicle, Year Make	1963 Valiant	1963 Valiant	1960 Pontiac	1963 Buick	1959 Renault
Vehicle Weight, lbs	3000	3080	4180	4350	1500
Impact Angle, deg	20	20	0	20	0
FILM DATA					
Initial Speed, mph ft/sec	56.9 83.4	59.3 87.0	46.6 68.4	56.8 83.3	58.2 85.4
Average Longitudinal Deceleration, g's	6.8	7.4	6.2	4.0	9.1
Distance in Contact*, ft	16.0	12.6	11.7	24.2	12.4
Time in Contact, sec	.290	.210	.365	.624	.280
Final Speed, mph ft/sec	0 0	26.7 39.1	0 0	19.0 27.8	0 0
ACCELEROMETER DATA					
Longitudinal					
Max. Deceleration, g's	53.0	15.9	7.0	11.3	14.1
Avg. Deceleration, g's	10.8	8.0	3.7	4.6	7.6
Time, sec	.400	.226	.414	.452	.403
Transverse					
Max. Deceleration, g's	3.8	7.3	--	4.3	--
Avg. Deceleration, g's	1.1	3.2	--	0.6	--
Time, sec	.360	.226	--	.292	--

*For Tests A, C, and E, this is the stopping distance.

Test 505 B-A

In this first test, a 1963 Valiant weighing 3000 lbs impacted the Modular Crash Cushion at 56.9 mph. The vehicle centerline made a 20° angle with the centerline of the barrier at impact. The barrier is shown in Figure 4. The redirection panels consisted of 3/4" plywood with two layers of heavy fiber glass roving followed by one layer of gel coat. These panels overlapped approximately 11 inches. Between the columns of barrels were smaller sections of plywood.

After initial contact, the lateral stability of the redirection panels was not sufficient to prevent the vehicle from "pocketing" and crushing several barrels before impacting the edge of the rigid wall. This was the reason for the high maximum longitudinal deceleration of 53 g's. Duration of this high deceleration was about 80 msec, as can be seen from Figures A1 and A2. Contact with the rigid wall occurred about 240 msec after impact, at which time the g level on the accelerometer traces begins to rise sharply (see Figures A1 and A2 in the Appendix).

Analysis of the accelerometer traces showed the average deceleration to be 10.8 g's longitudinally and 1.1 g's laterally. Damage to the vehicle was rather severe due to the impact with the rigid wall (see Figure 6).

This redirection system did not perform as intended. The undesired behavior was attributed to lack of lateral attenuation space at the rear of the barrier adjacent to the edge of the rigid wall. In addition, the barrier had insufficient lateral stability due to the anchor cable positions and to insufficient overlapping of the redirection panels. Subsequent test cushions incorporated design changes which resulted in better redirection capabilities.

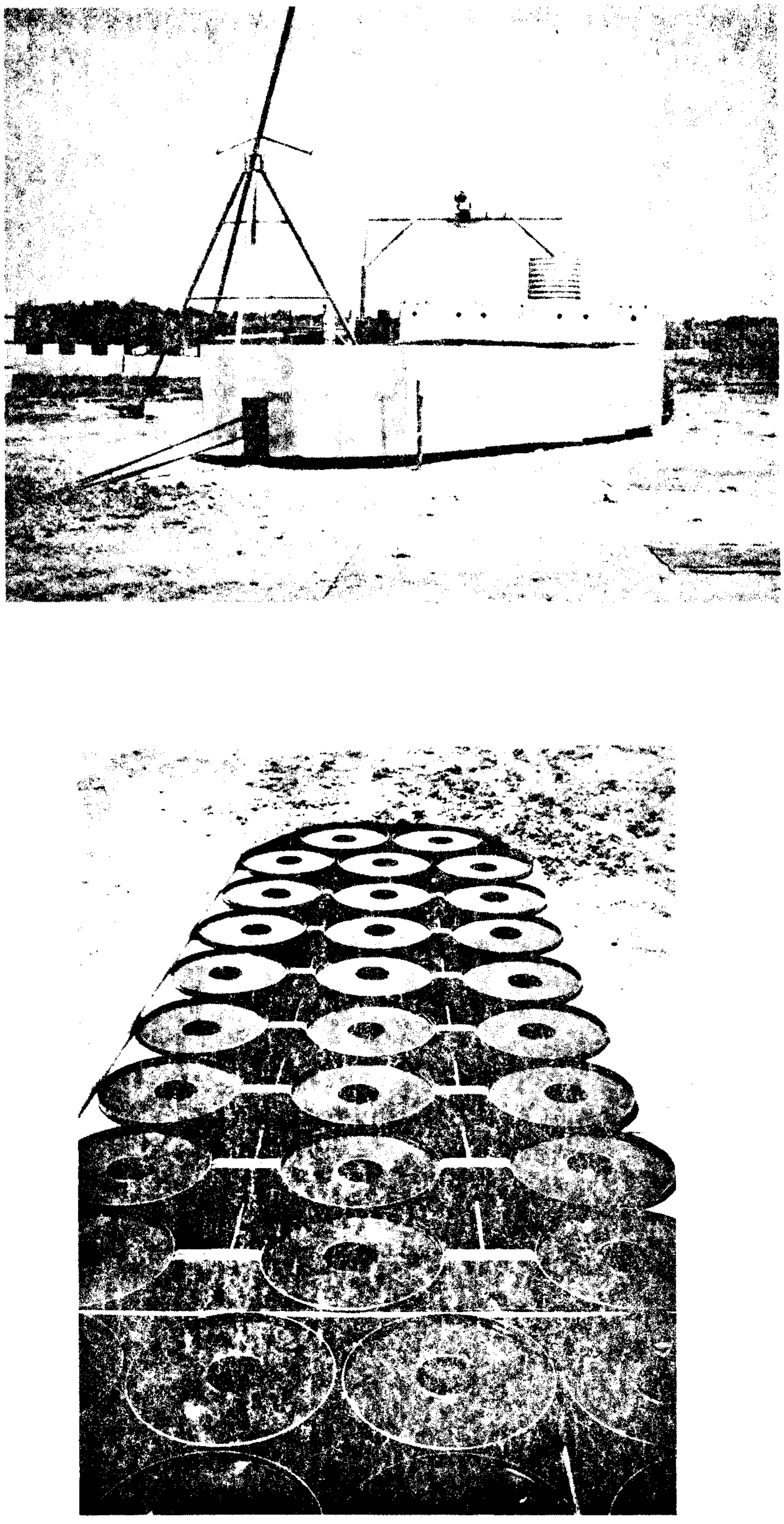


Figure 4, Modular Crash Cushion Before Test 505 B-A.

Figure 5, Vehicle Before Test 505 B-A.

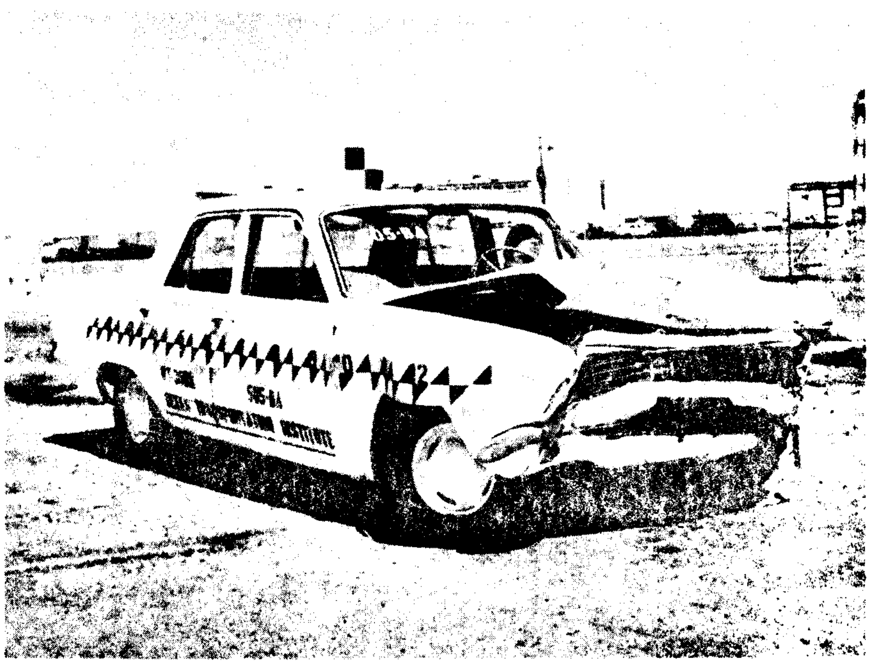
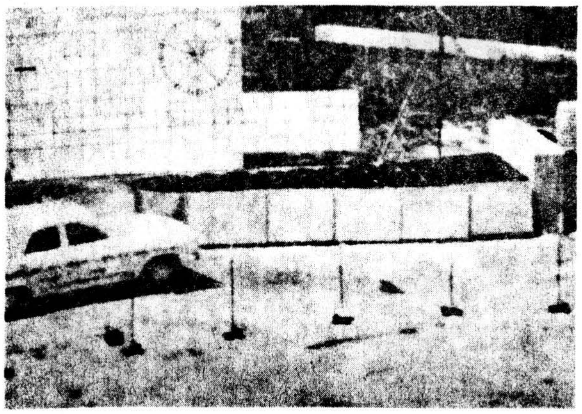


Figure 6, Vehicle After Test 505 B-A.



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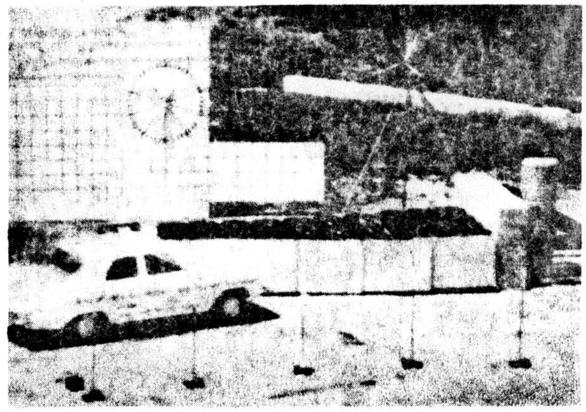

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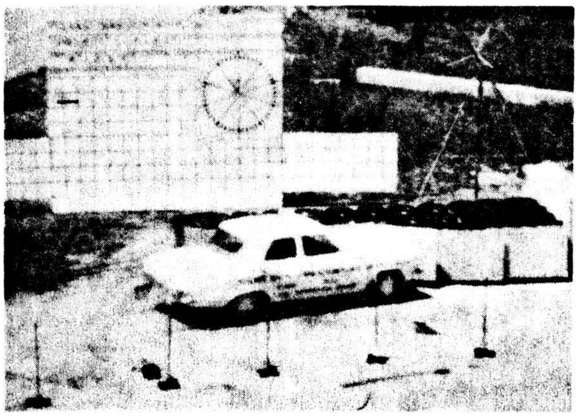

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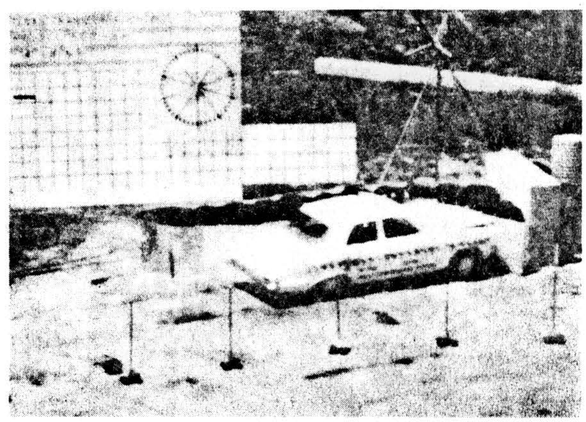

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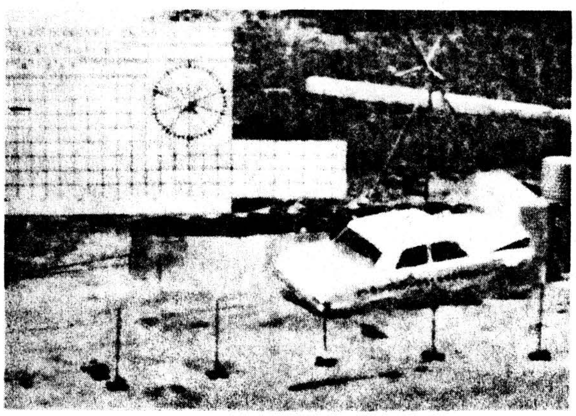

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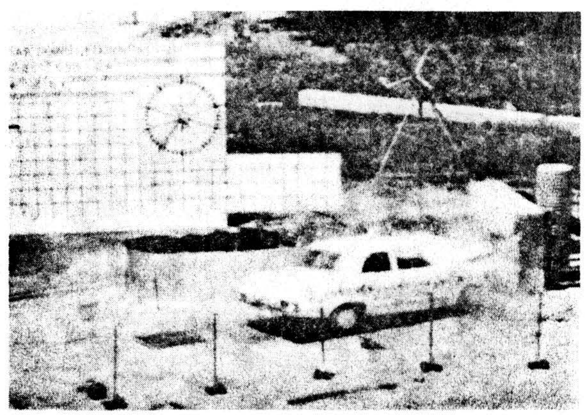

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Figure 7, Sequential Photographs of Test 505 B-A.
(Side View)

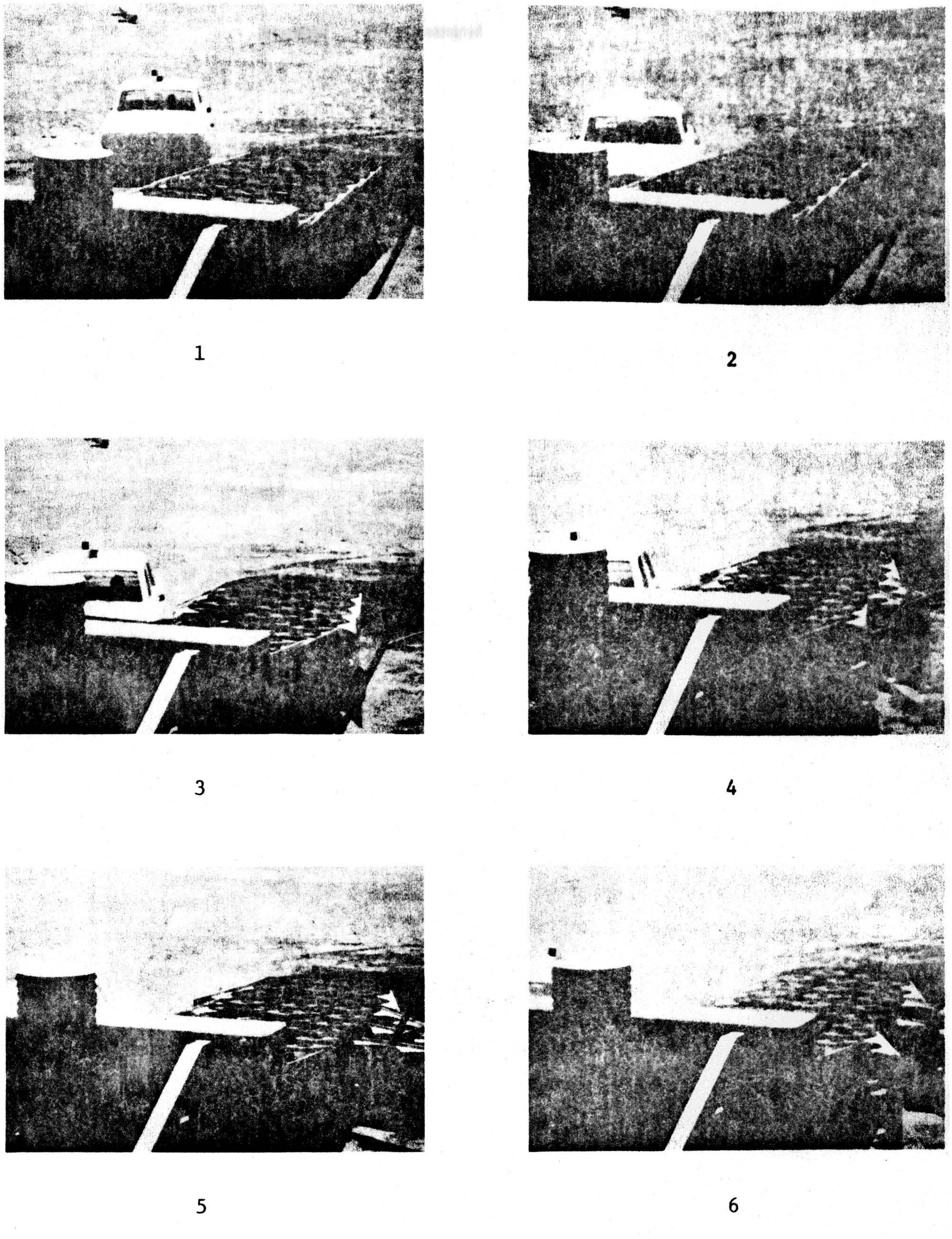


Figure 8, Sequential Photographs of Test 505 B-A.

Figure 9, Crash Area After Test 505 B-A.

Test 505 B-B

In order to provide acceptable redirection capabilities, the basic system previously tested was modified. Instead of the plywood spacers between the barrels, metal straps were welded across the top of the barrels as shown in Figure 12. In addition, the anchor cables were placed just inside the deflection panels and were aligned straight and taut. This was done to increase the lateral stability of the system during angle hits for better vehicle redirection. Also, the redirection panels were positioned to overlap each other 4 feet, creating a double thickness of plywood along the impact area.

A 3080 lb Valiant impacted the barrier about 11 ft in front of the rigid wall. The vehicle at contact made an angle of 20° with the centerline of the barrier, and was traveling at 59.3 mph. The vehicle was redirected, leaving the barrier at 26.7 mph after 210 msec. The average longitudinal deceleration during this time was 8.0 g's, and the average transverse deceleration was 3.2 g's.

The left front end of the vehicle was permanently deformed about 1.5 ft. Damage to the barrier was slight. Since only a few barrels were crushed, as seen in Figure 15, the barrier was easily repaired before the next test. This test was considered successful in that the vehicle was redirected as intended, with deceleration levels well within acceptable human tolerances.[5]

Figure 10, Vehicle Before Test 505 B-B.

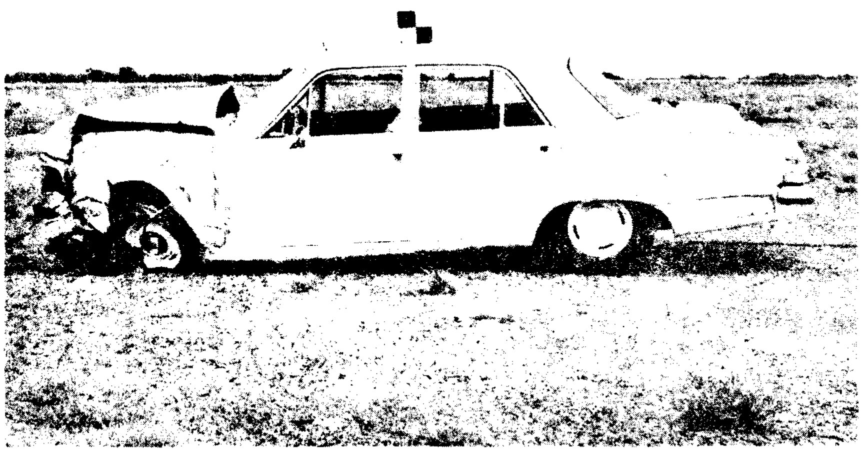


Figure 11, Vehicle After Test 505 B-B.

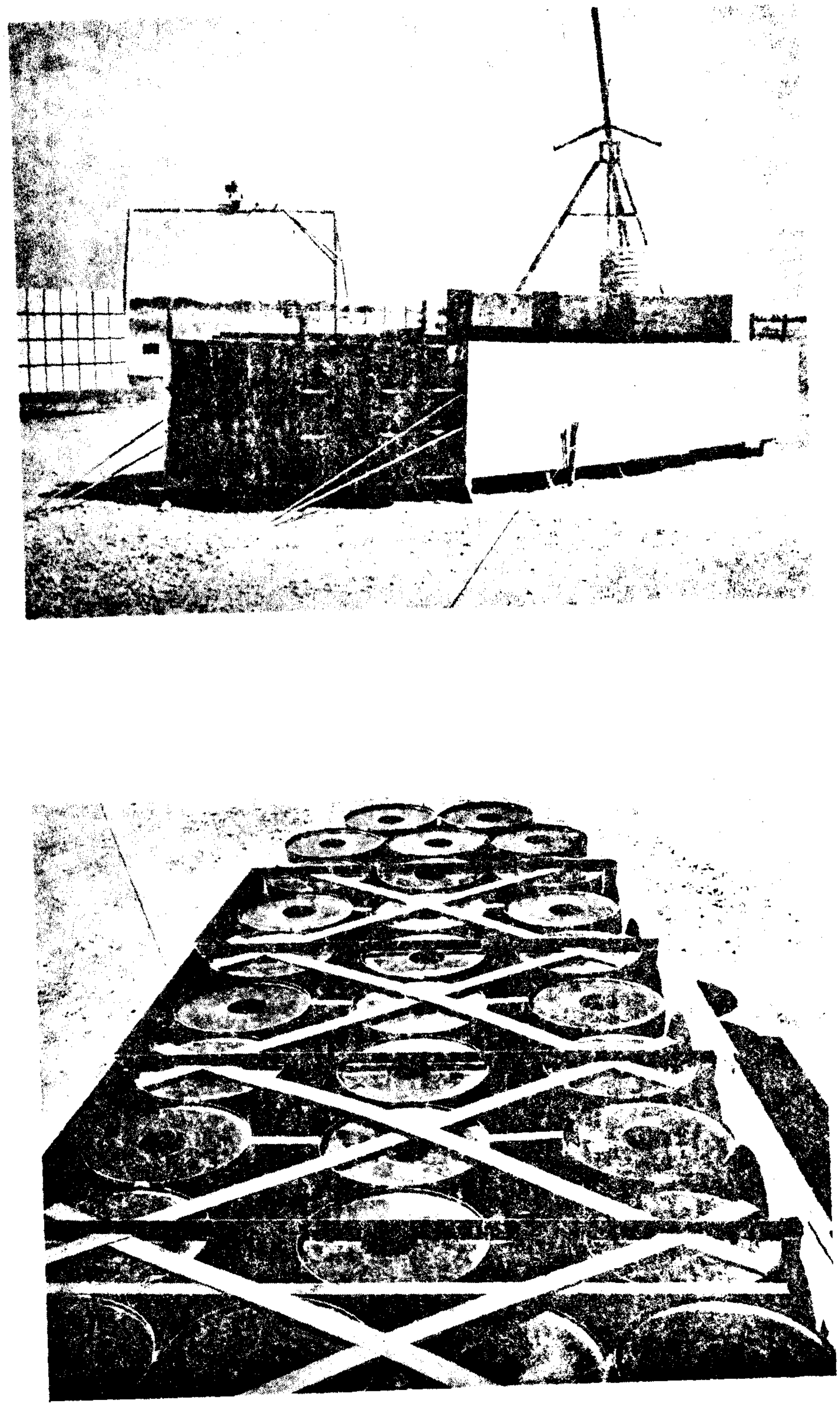


Figure 12, Modular Crash Cushion Before Test 505 B-B.

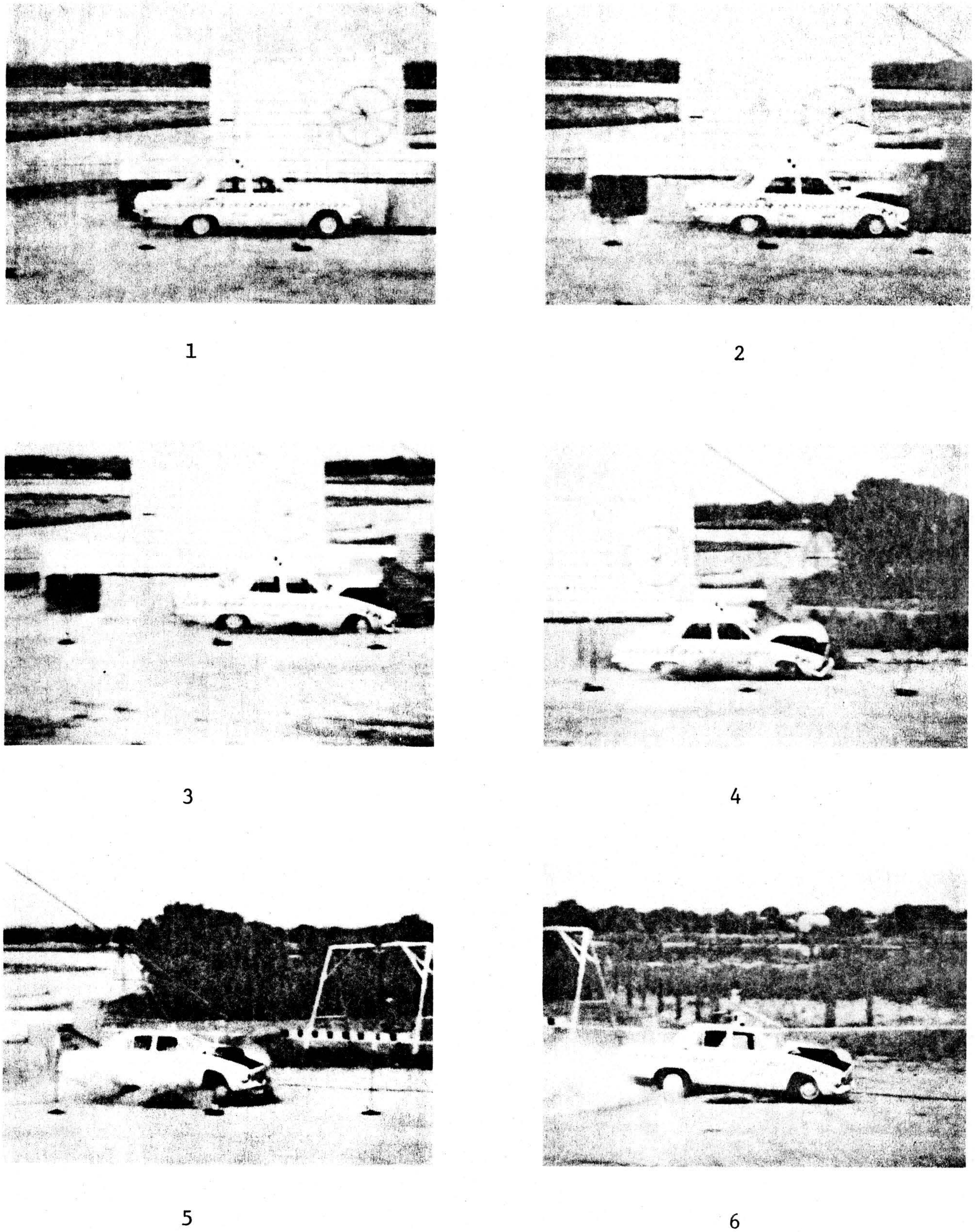
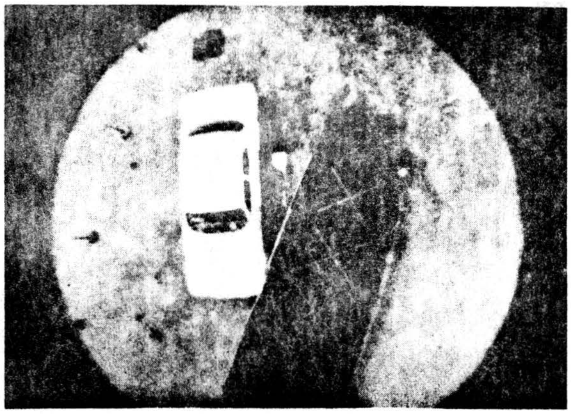


Figure 13, Sequential Photographs of Test 505 B-B.
(Side View)



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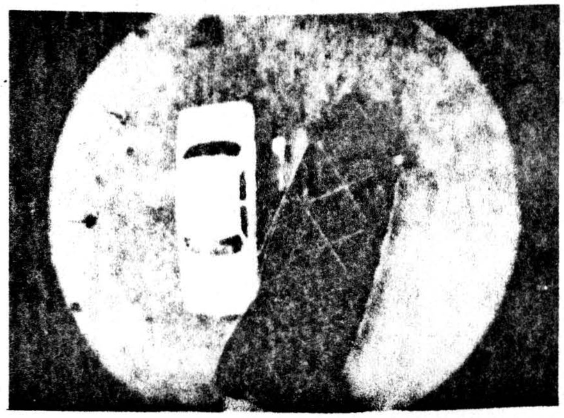

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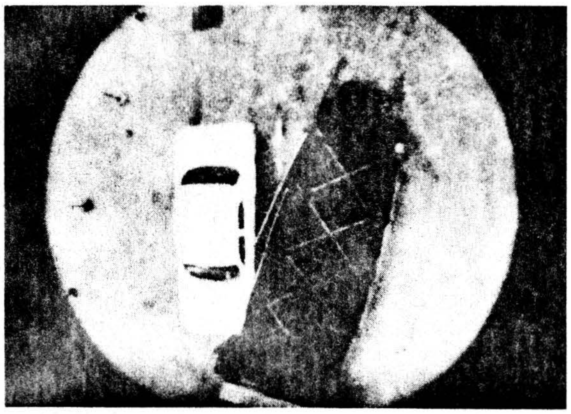

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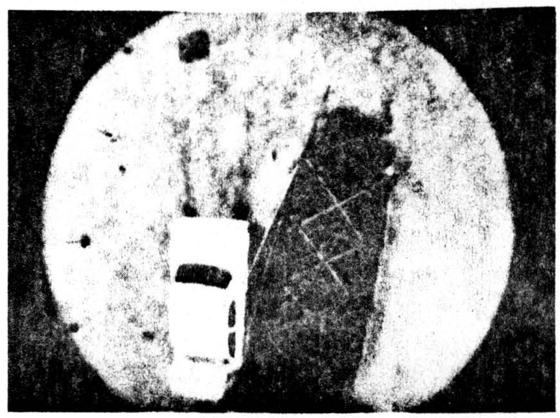

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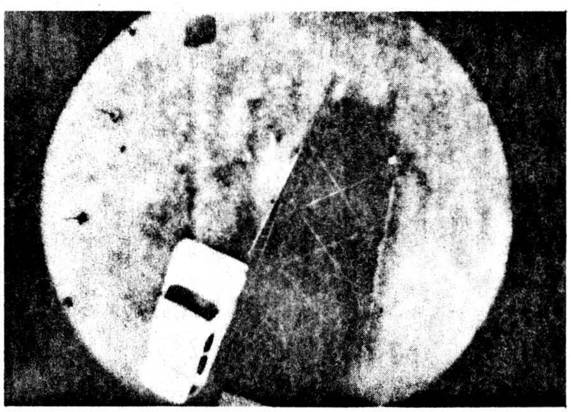

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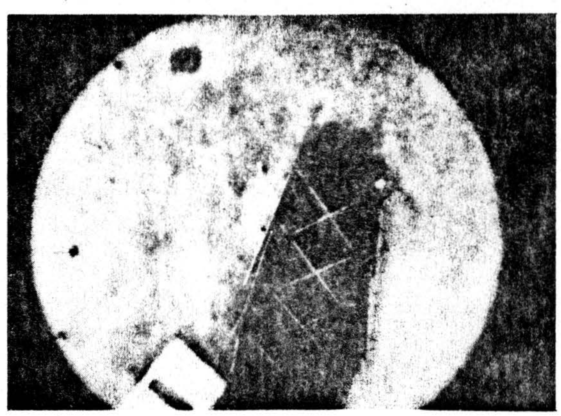

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Figure 14, Sequential Photographs of Test 505 B-B.
(Overhead View)

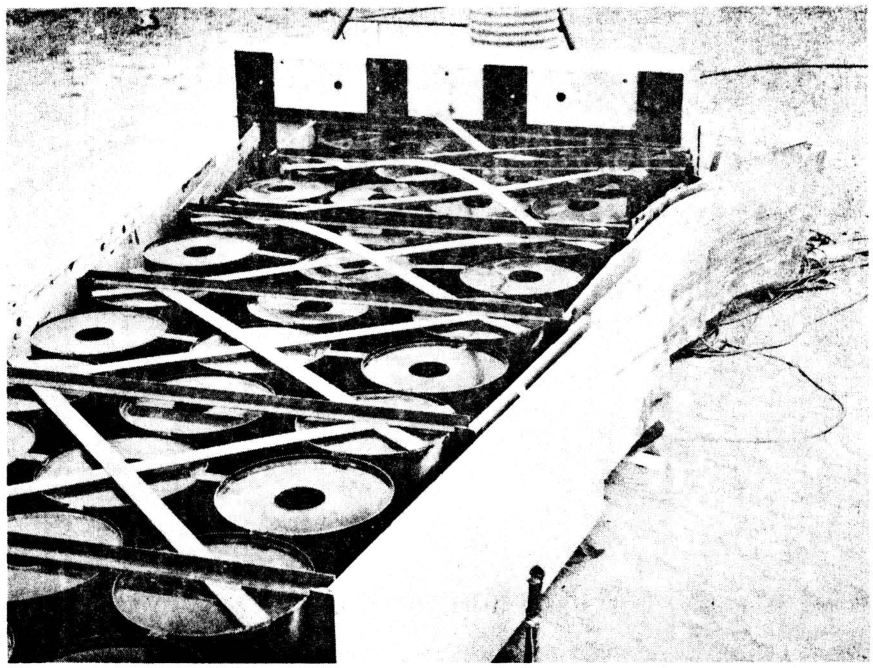


Figure 15, Impact Area After Test 505 B-B.

Test 505 B-C

After a few minor repairs were made, the same crash cushion used in Test B was subjected to a head-on crash test. The purpose of this test was to evaluate the longitudinal response of the modified barrier to a head-on collision. Lateral strength and stiffness had been built into the crash cushion for safe redirection of vehicles impacting at an angle. At the same time, however, this system had been designed to maintain its relatively soft, crushable characteristics for head-on impacts.

The barrier stopped the 4180 lb Pontiac, which was traveling 46.6 mph, in 11.7 ft with an average longitudinal deceleration of 6.2 g's. Deceleration levels were well within the limits considered tolerable to properly restrained humans.[5]

The system performed as designed. The vehicle damage was very minor as shown in Figure 17. Permanent vehicle front end deformation was only 2 inches. The headlights of the vehicle were not broken.

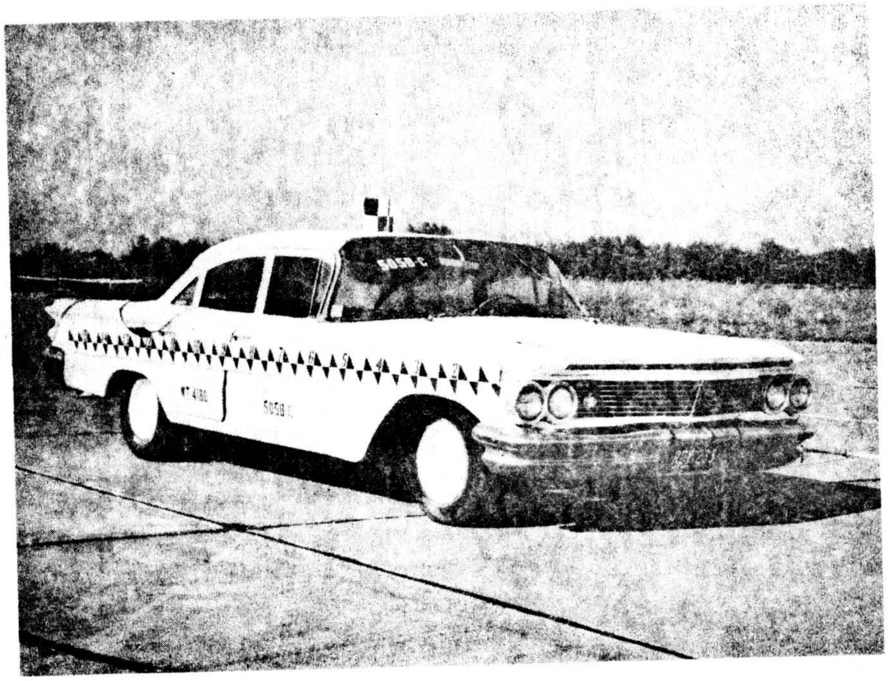


Figure 16, Vehicle Before Test 505 B-C.

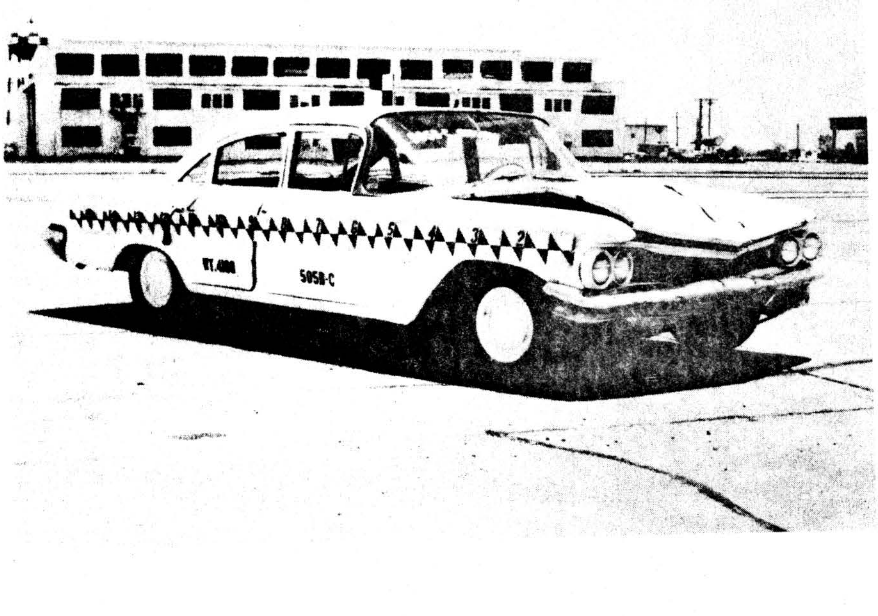


Figure 17, Vehicle After Test 505 B-C.

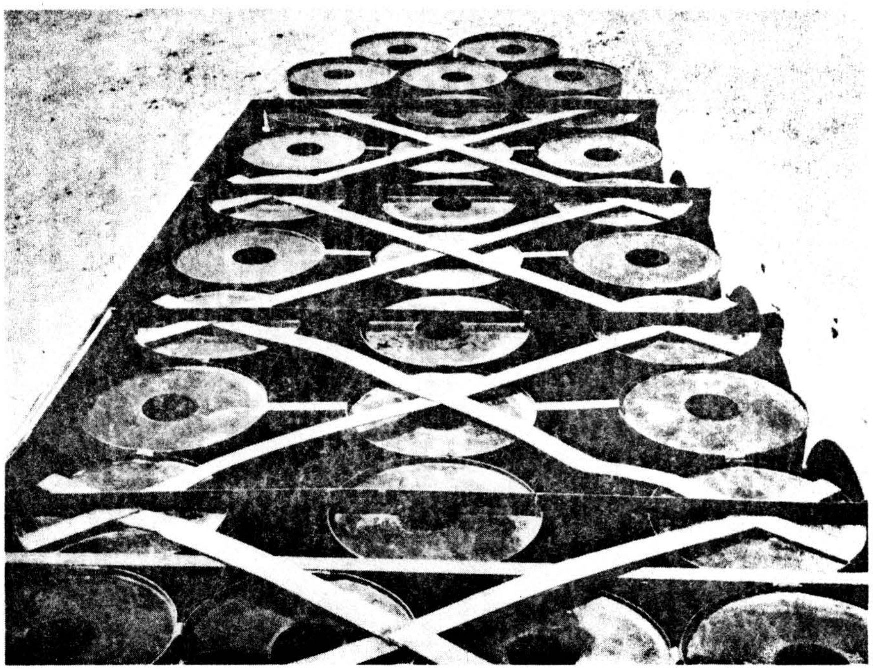
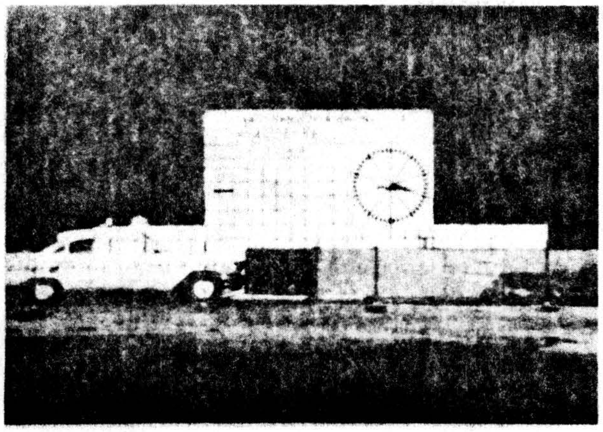


Figure 18, Repaired Modular Crash Cushion
Before Test 505 B-C.



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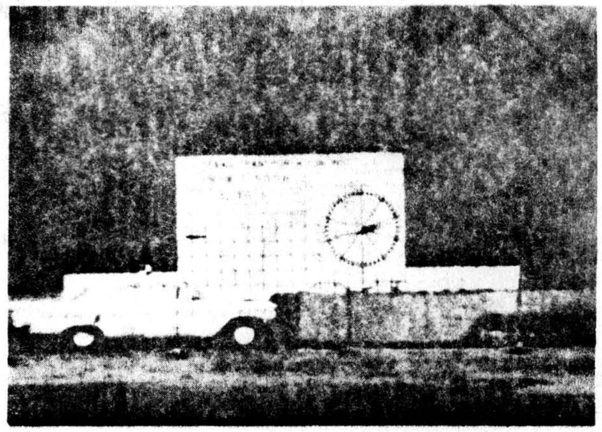

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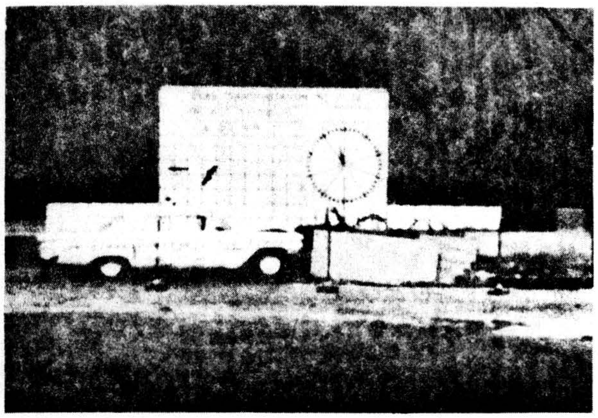

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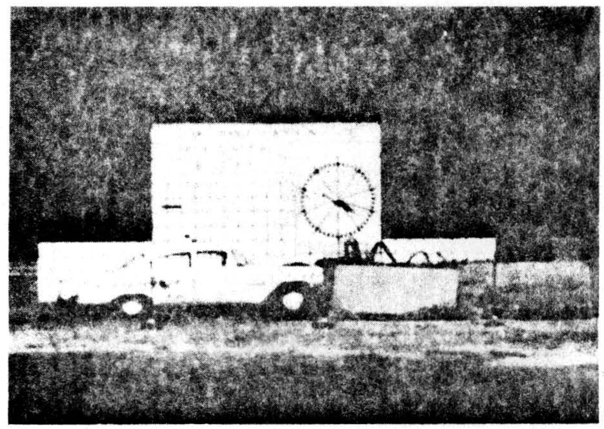

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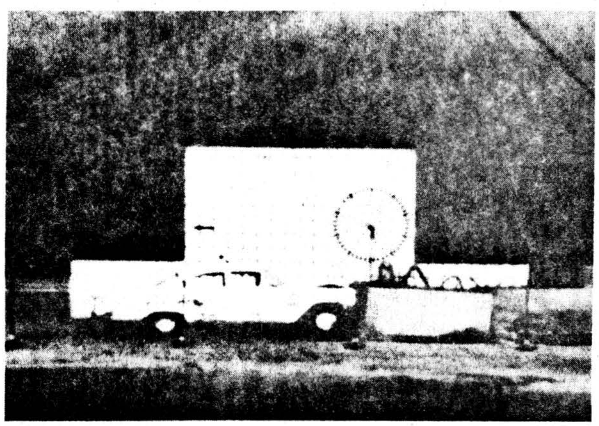

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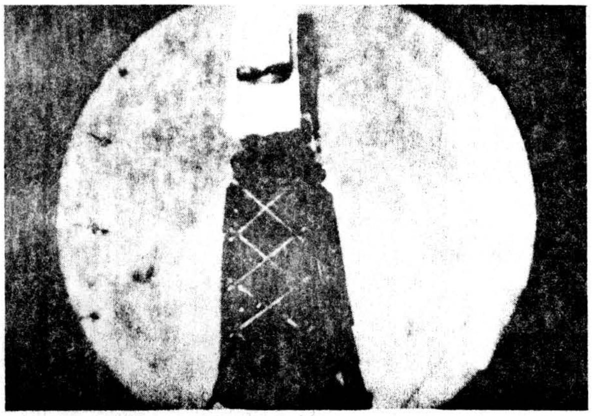
Figure 19, Sequential Photographs of Test 505 B-C.
(Side View)



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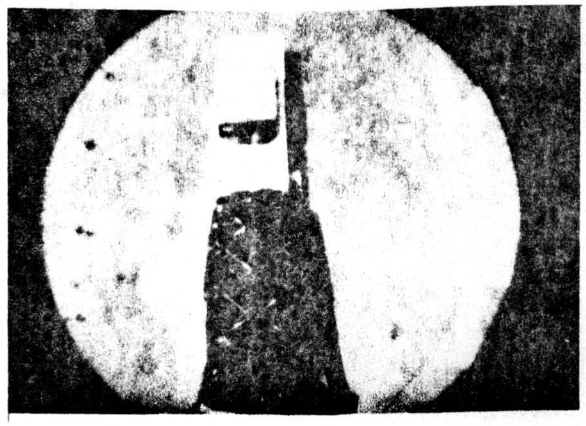

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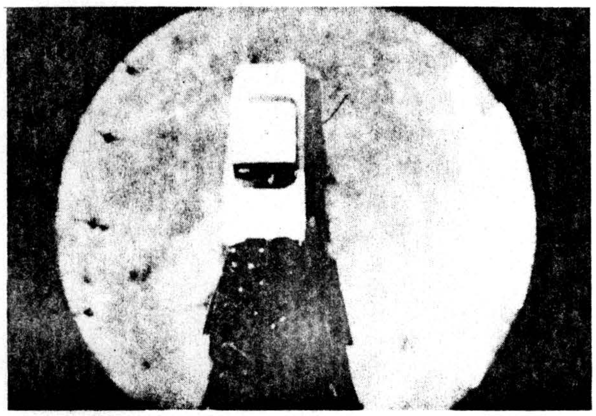

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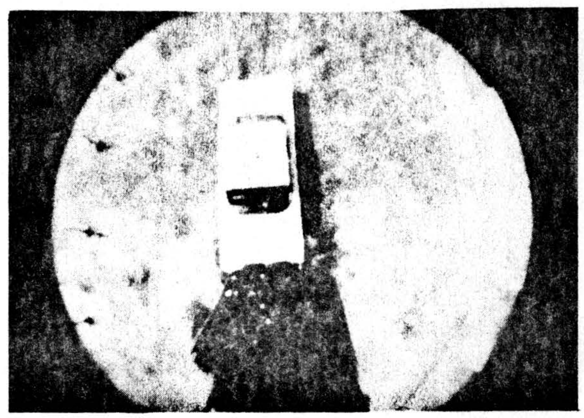

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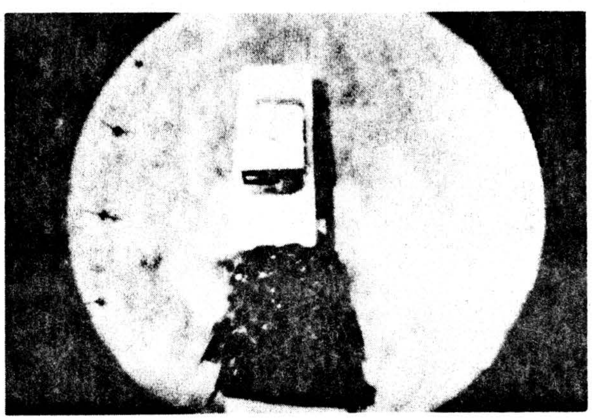

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Figure 20, Sequential Photographs of Test 505 B-C.
(Overhead View)

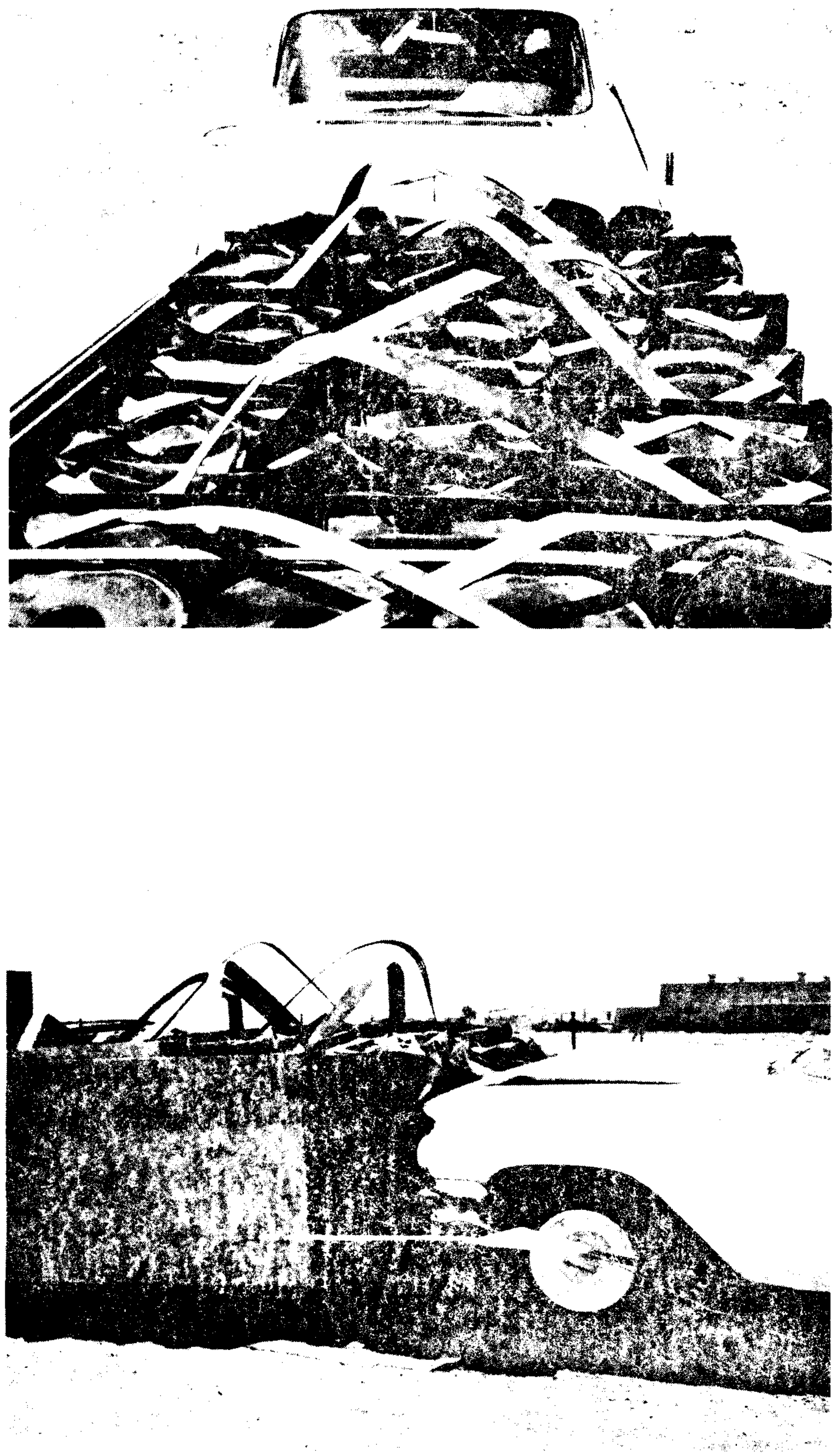


Figure 21, Vehicle and Crash Cushion After Test 505 B-C.

Test 505 B-D

Two modifications were made in the crash cushion used for this test. The rigid back-up wall was modified to simulate a tapered concrete retaining wall at an elevated freeway gore. This type of retaining wall makes it feasible to extend modules of the crash cushion along its sides. The configuration which was tested had modules extending along only the side which was hit, as modules along the opposite side would have been superfluous for the purposes of these tests. The straight, taut cables and overlapping plywood panels were believed to be sufficient for redirecting a vehicle without the use of the metal "truss" as used in tests B and C. In addition, the barrel modules were arranged in a more triangular shape to provide a softer nose for better head-on attenuation of small, lightweight vehicles.

A 20° angle side impact was conducted using a 1963 Buick which weighed 4350 lbs. The initial speed of the vehicle was 56.8 mph, and the vehicle remained in contact with the barrier for 624 msec. The average longitudinal deceleration from the accelerometer traces was 4.6 g's. Average lateral deceleration was 0.6 g's from the same source. A "ramping" tendency was observed; that is, the vehicle climbed up the side of the cushion to a height of about two feet due to a vertical component of force at the left front of the vehicle. However, the test vehicle remained upright throughout the test. A possible cause of the ramping may have been that the upper support cable, being longer than the lower cable, had more potential to displace transversely, allowing the deflection panels to lean slightly inward at the top.

During the time in contact, the cushion demonstrated sufficient lateral stability to prevent "pocketing" and to redirect the test vehicle. The barrier was damaged moderately, and the left front end of the vehicle was permanently deformed 3.25 ft (see Figures 23 and 27).

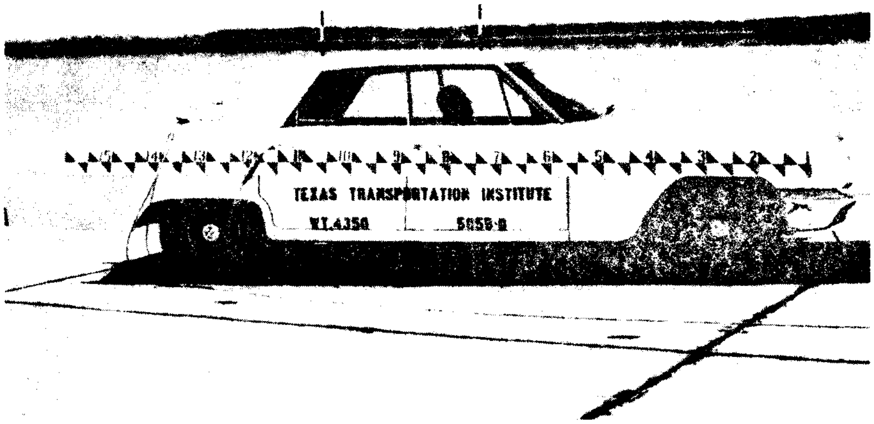


Figure 22, Vehicle Before Test 505 B-D.

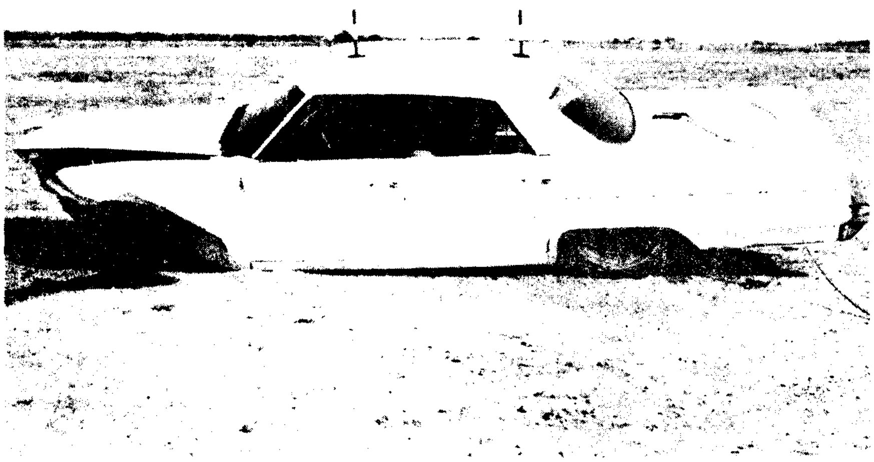


Figure 23, Vehicle After Test 505 B-D.

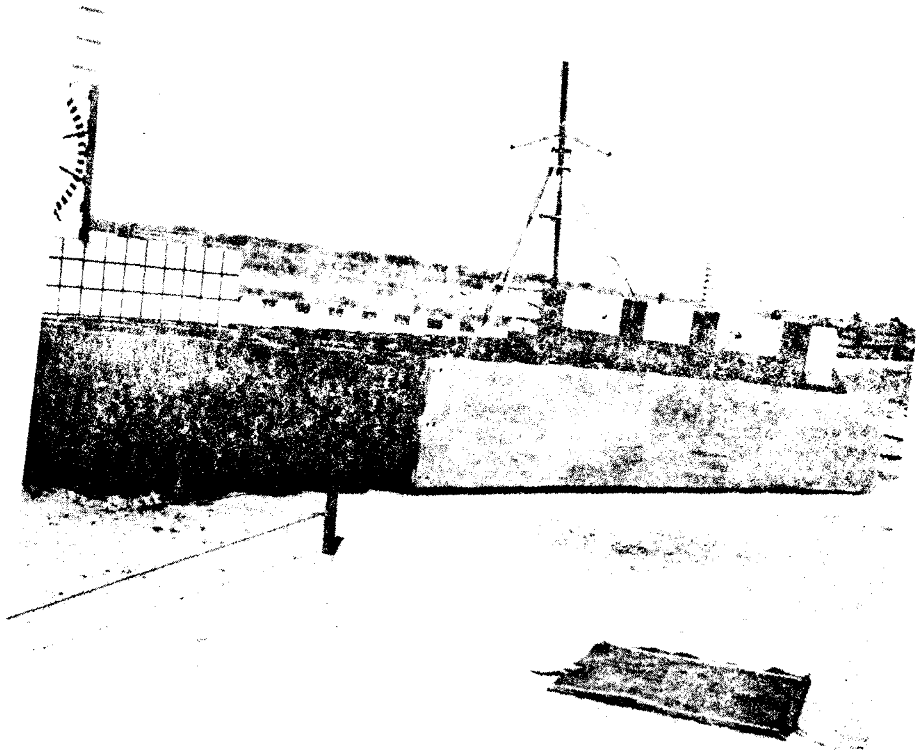
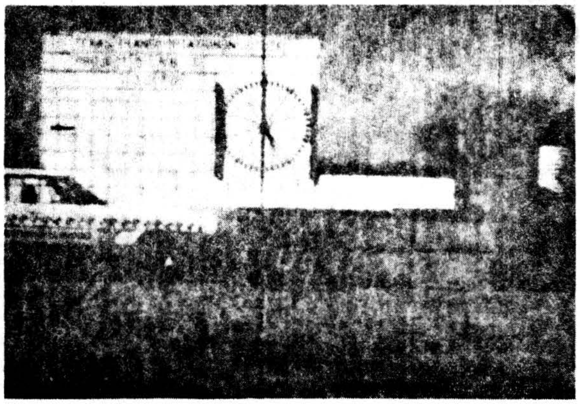


Figure 24, Modular Crash Cushion Before Test 505 B-D.



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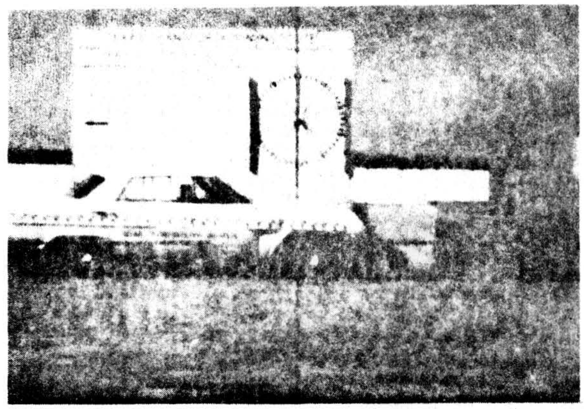

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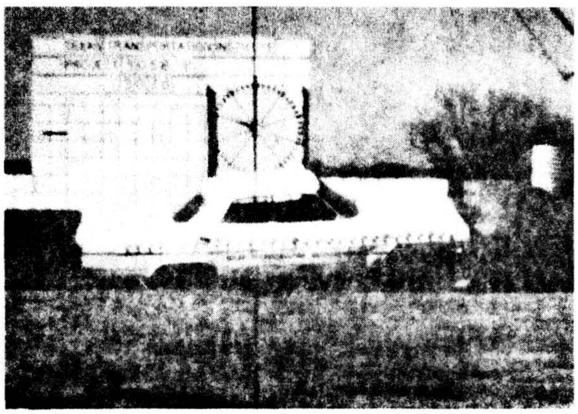

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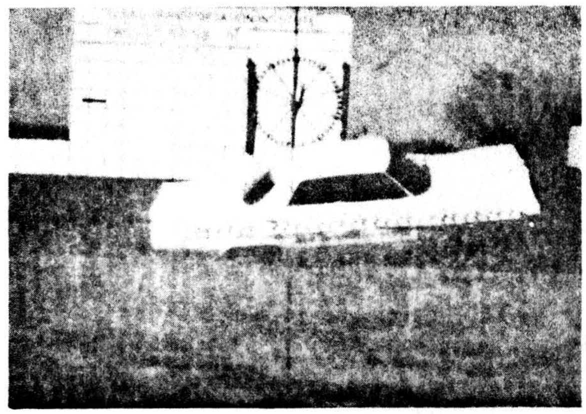

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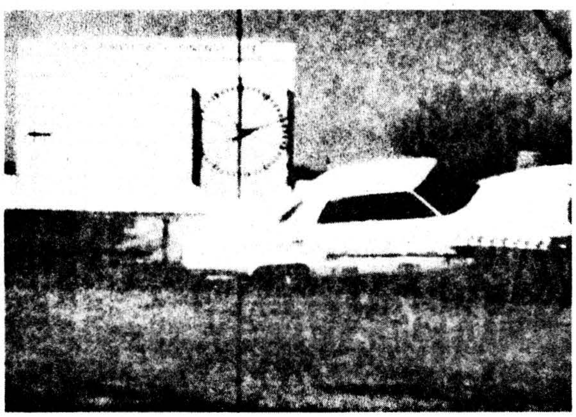

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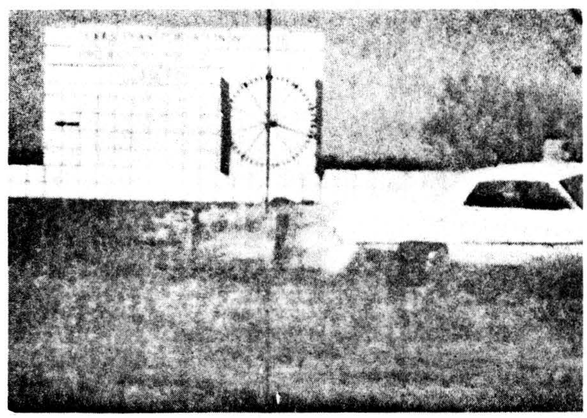
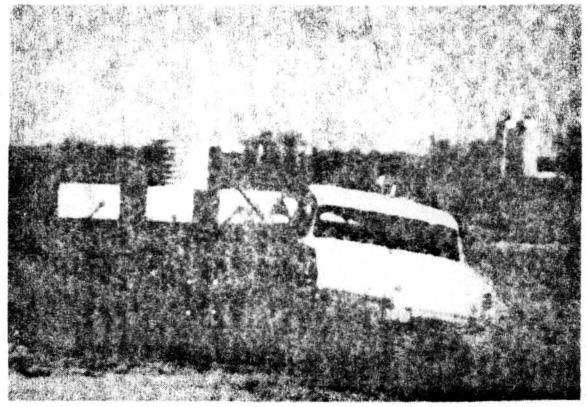


6

Figure 25, Sequential Photographs of Test 505 B-D.
(Side View)

1



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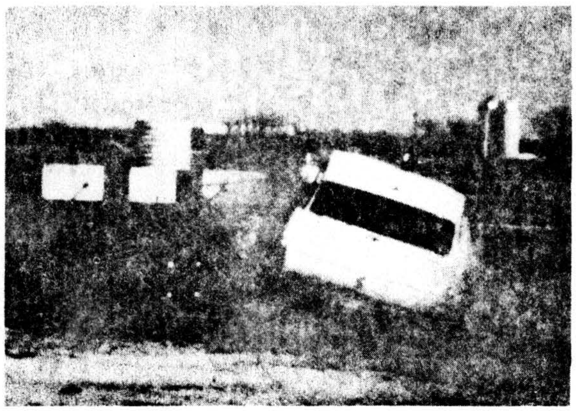

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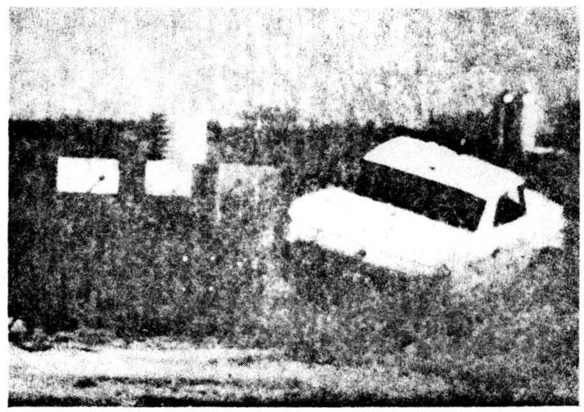

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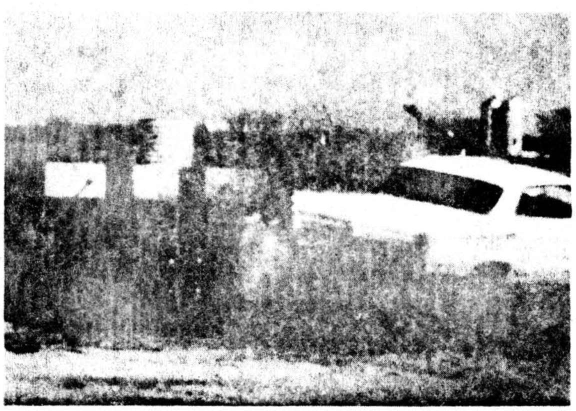

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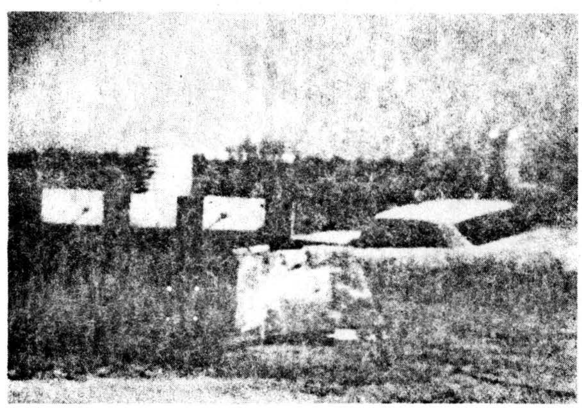
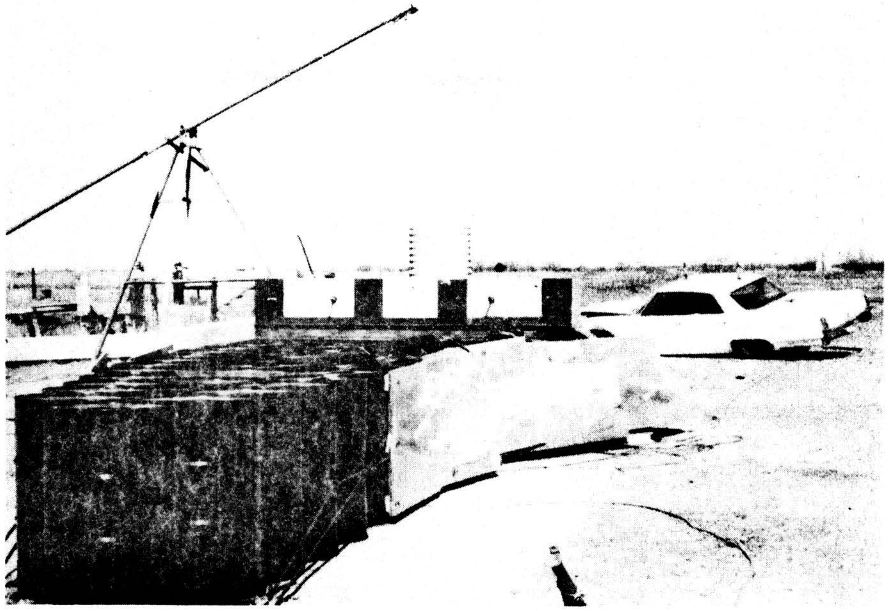


6

Figure 26, Sequential Photographs of Test 505 B-D.
(End View)



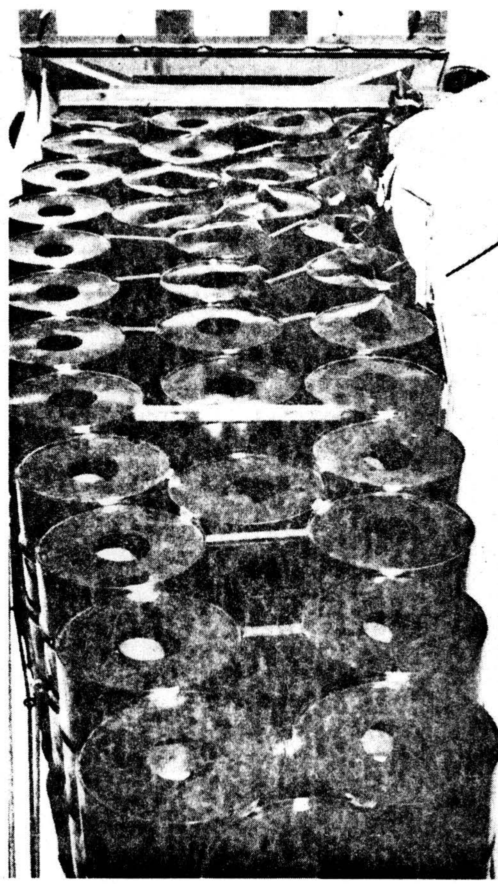


Figure 27, Modular Crash Cushion After Test 505 B-D.

Test 505 B-E

The purpose of this test was to evaluate the effectiveness of the previous barrier in head-on impacts with small vehicles. After minor repairs, the same cushion used in Test 505 B-D was hit by a 1959 Renault at 58.2 mph. This lightweight vehicle (1500 lbs) was stopped in 12.4 ft with an average longitudinal deceleration of 9.1 g's. The sheet metal portion of the front end of the vehicle was severely buckled, which would be expected in a lightweight, low front profile, rear-engine vehicle. The vehicle was stopped smoothly, without tendency to roll or spin.

The deceleration encountered by the lightweight vehicle (9.1 g's) was well below the FHWA Program criteria of 12 g's for research and development testing.[6]

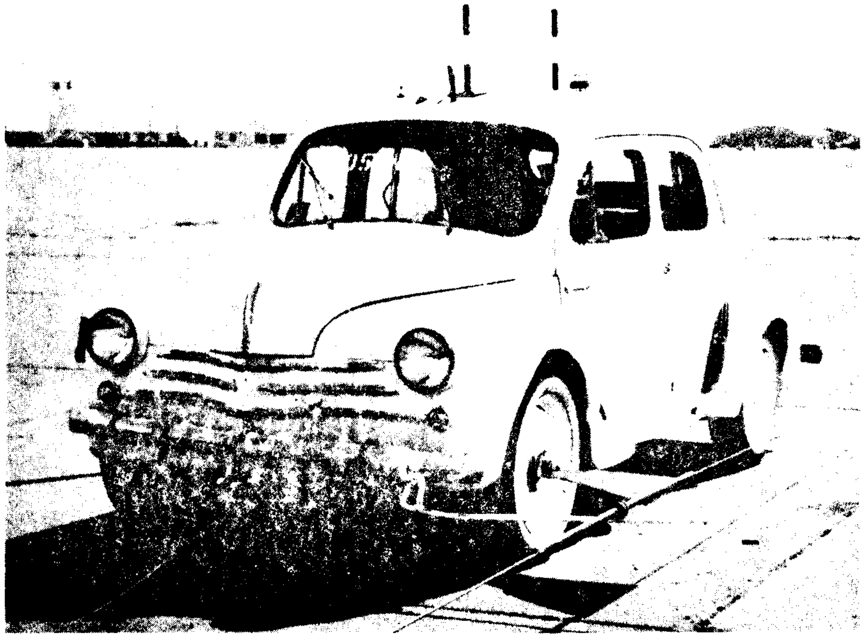


Figure 28, Vehicle Before Test 505 B-E.

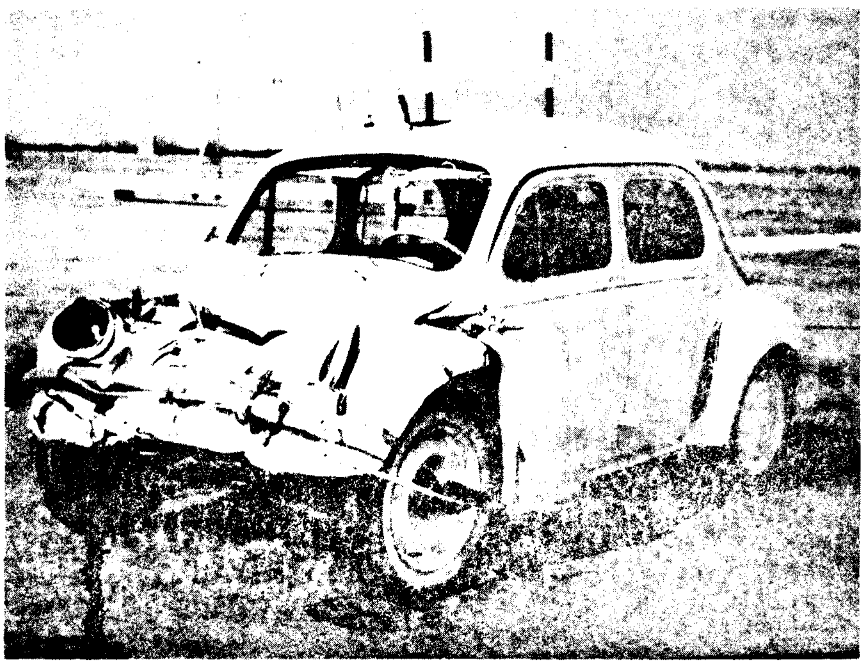
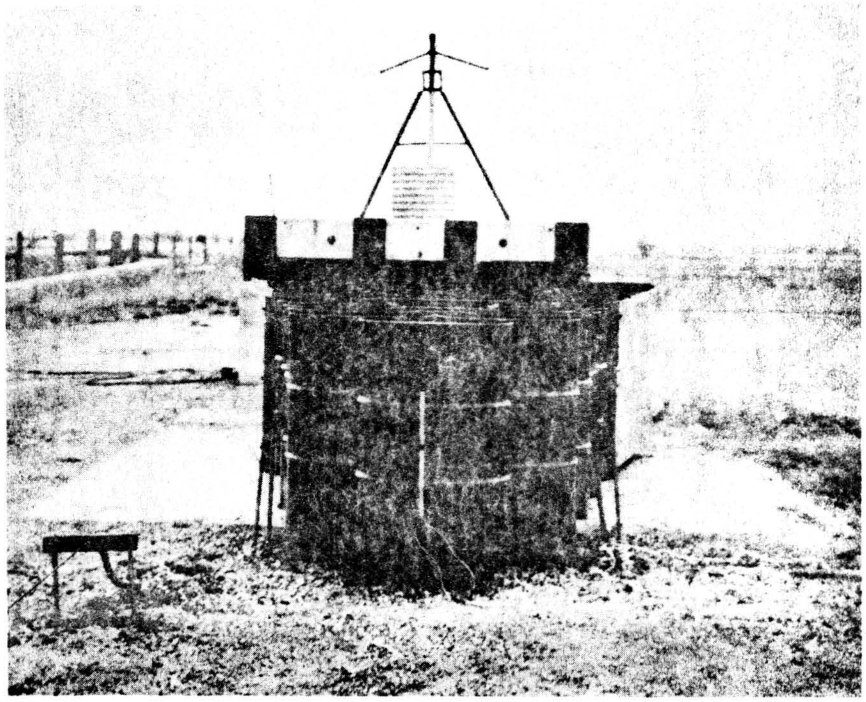


Figure 29, Vehicle After Test 505 B-E.



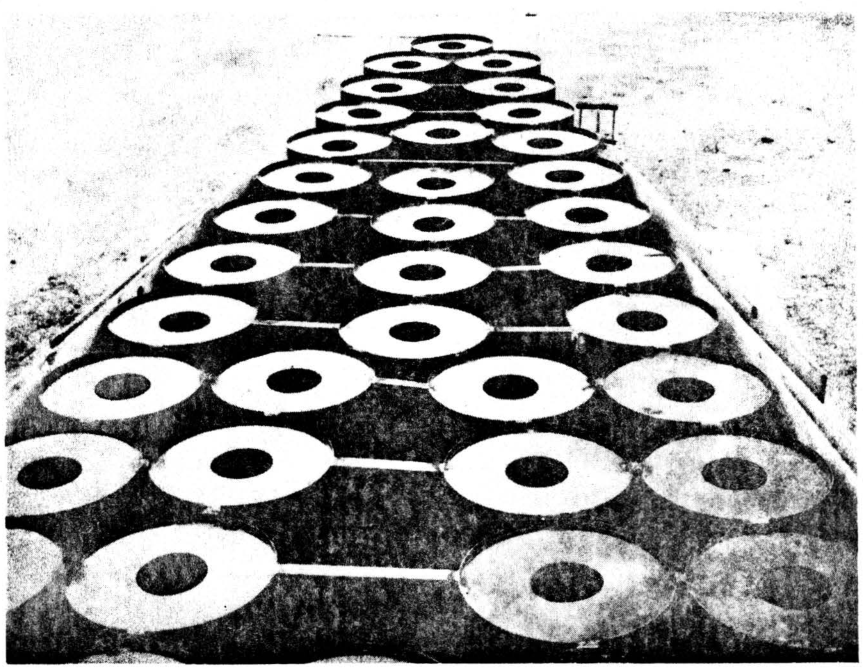


Figure 30, Modular Crash Cushion Before Test 505 B-E.

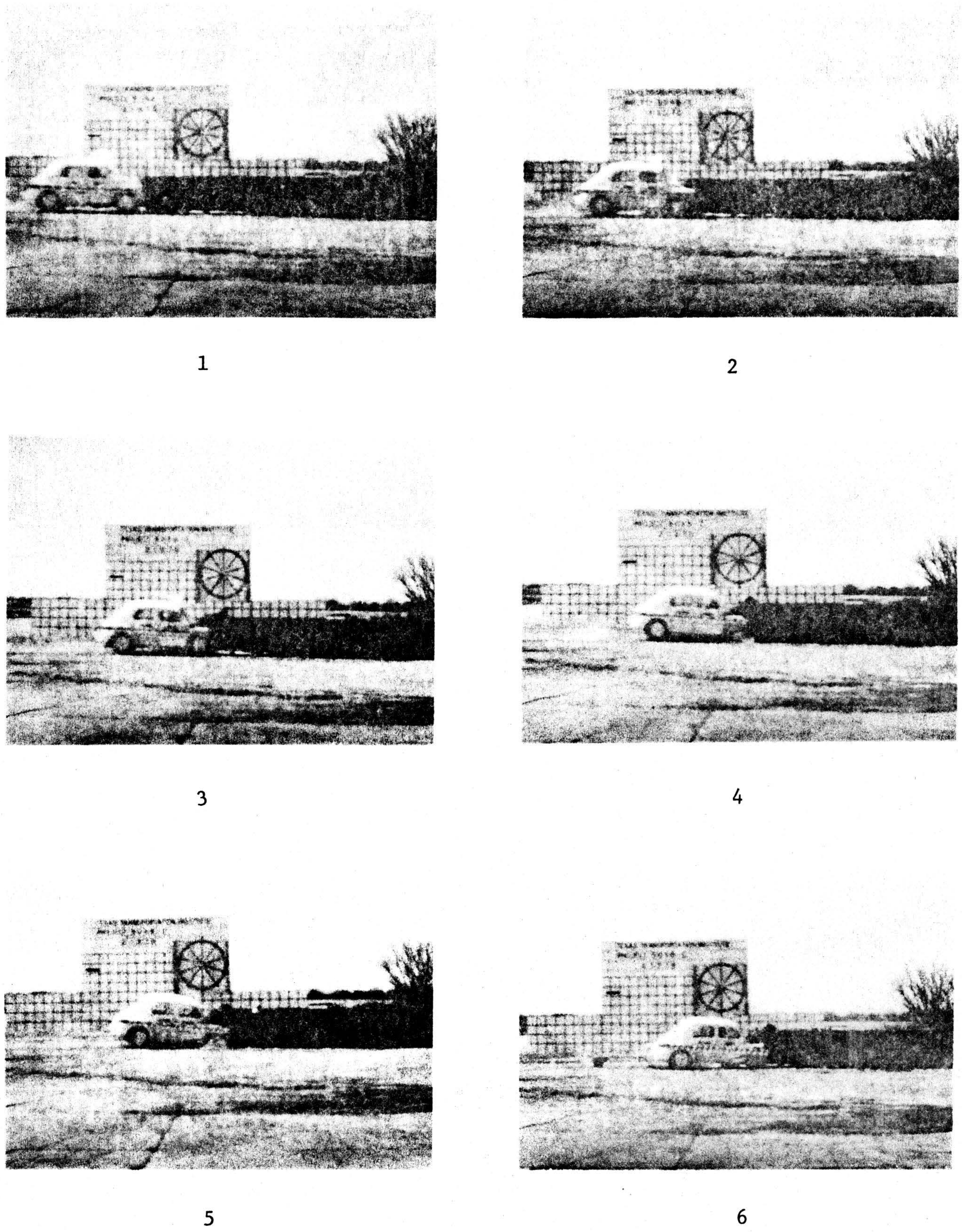
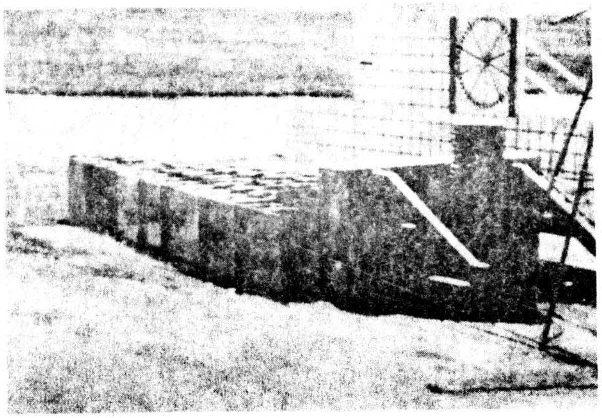


Figure 31, Sequential Photographs of Test 505 B-E.
(Side View)



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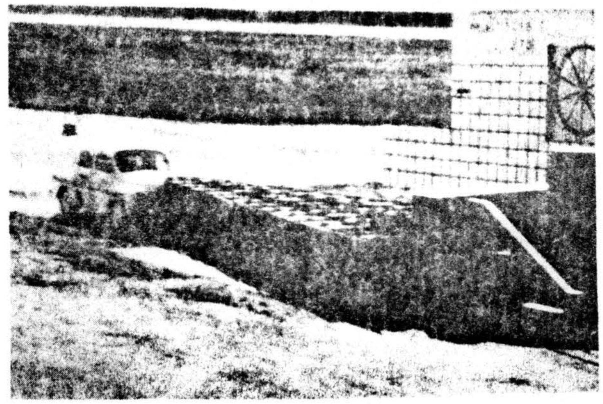

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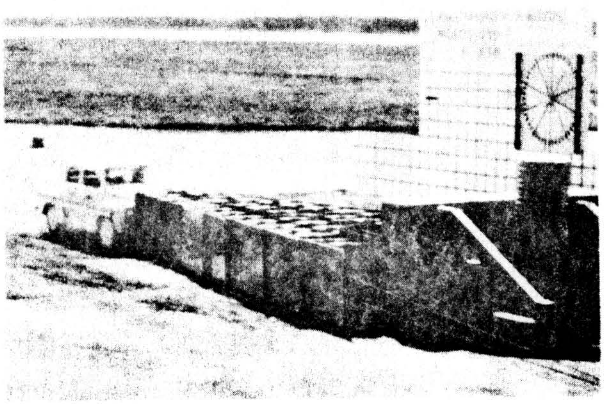

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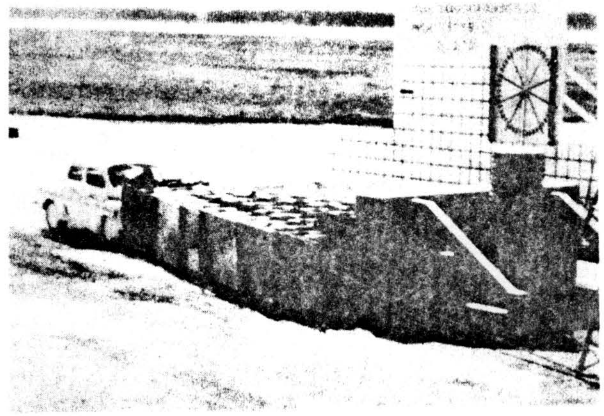

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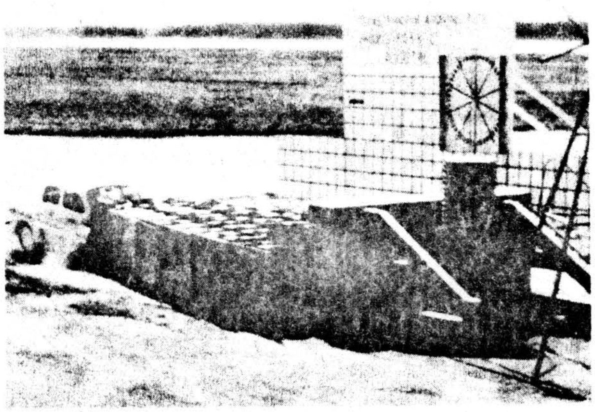

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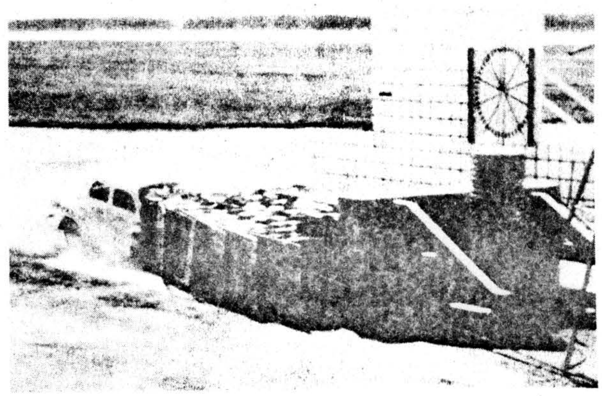
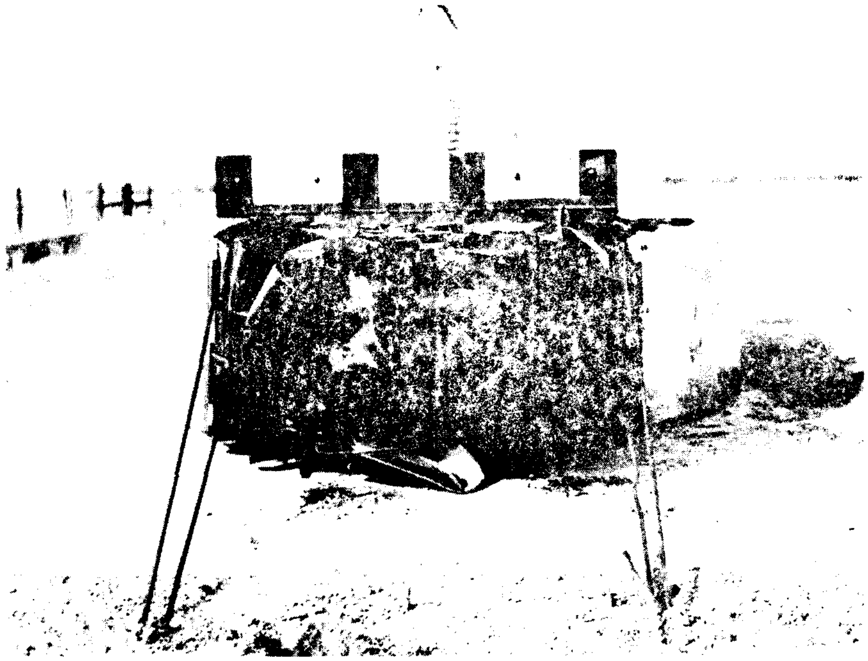


6

Figure 32, Sequential Photographs of Test 505 B-E.
(Oblique View)



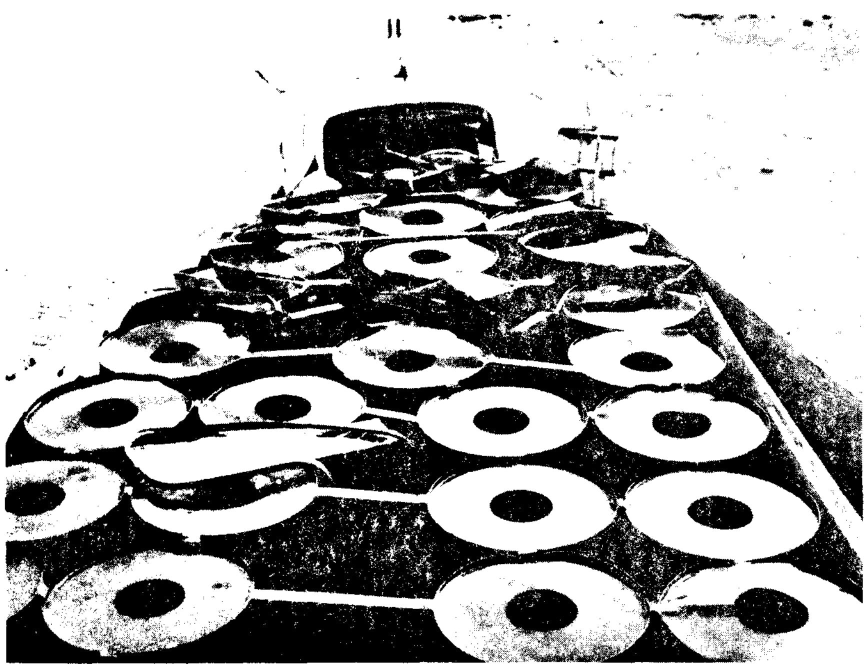


Figure 33, Modular Crash Cushion After Test 505 B-E.

DISCUSSION AND CONCLUSIONS

In order to redirect a vehicle which strikes the crash cushion at an angle and prevent it from contacting a rigid obstacle, the crash cushion must have lateral stability, present a smooth side surface, and be rather "hard" in the lateral direction to prevent vehicle pocketing. The more the side of the cushion is allowed to deform, the greater the angular redirection must be in order to prevent contact with the rigid backup wall. At the same time, the attenuator must not be constrained in the longitudinal direction in order to be acceptable for head-on or near head-on impacts in which all the vehicle kinetic energy must be absorbed.

The first attenuator tested in this series presented an acceptable redirectional surface, but because of the insufficient interior support by the anchor cables and because of the crushable plywood module spacers, it did not provide the necessary lateral strength or stability for redirection of the vehicle.

The second crash cushion design tested had sufficient lateral stability and strength, as well as a smooth redirectional surface, and the test vehicle was redirected without contacting the rigid wall. The redirection over a short time interval causes significant damage to the vehicle, somewhat comparable to the damage which would result from a guardrail or bridge rail collision. The forces measured were considered tolerable or acceptable for properly restrained passengers.

The subsequent head-on test on the repaired cushion showed that a relatively soft, crushable behavior was retained for head-on collisions.

The third crash cushion configuration also successfully redirected the vehicle during the angle impact. However, the absence of the "truss" on barrier type 3 reduces the weight of the structure and permits easier and more economical construction and maintenance.

The head-on test of the third crash cushion prototype utilized a lightweight, rear-engine vehicle. Although the damage to the vehicle's front end was severe, it was expected in this case since the engine was in the rear and only a light, sheetmetal luggage compartment protected the front end. Actually, this crushing too is part of the attenuation process. The passenger compartment was not penetrated. The g levels were not excessive considering the weight and speed of the test vehicle. The vehicle maintained a stable posture throughout the impact, with no overturning tendency.

It appears from this series of tests that for the Modular Crash Cushion lateral support adequate for vehicle redirection can be accomplished without sacrificing longitudinal attenuation. This can be achieved by using well anchored cables running in a straight line along the outside of the modules, with overlapping, hinged plywood panels outside these cables to provide the required lateral strength and stability. A similar redirectional system is in use on the HI-DRO Cushion and has performed satisfactorily on that type of barrier.[7]

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2. Hirsch, T. J. and Ivey, Don L., "Vehicle Impact Attenuation by Modular Crash Cushion," Research Report No. 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, Bureau of Public Roads, June 1969.
3. Hirsch, T. J., Ivey, Don L., and White, Monroe C., "The Modular Crash Cushion--Research Findings and Field Experience," *Highway Safety, Special Report 107,* Highway Research Board, Washington, D. C., 1970, pp. 140-148.
4. White, Monroe C., Ivey, Don L., and Hirsch, T. J., "In-Service Experiences on Installations of Texas Modular Crash Cushions," Research Report 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, Bureau of Public Roads, July 1970.
5. Damon, Albert; Stoudt, Howard W.; and McFarland, Ross A., *The Human Body in Equipment Design,* Harvard University Press, Cambridge, Massachusetts, 1966.

6. Tamanini, F. J. and Viner, John G., "Structural Systems in Support of Highway Safety." ASCE Meeting Preprint 930, July 21-25, 1969.

7. Hayes, Gordon G., Ivey, Don L. and Hirsch, T. J., "Performance of the 'HI-DRO Cushion' Vehicle Impact Attenuator," Technical Memorandum 505-11, Texas Transportation Institute, Texas A&M University, August 1970.

A P P E N D I X

TABLE A1

TEST 505 B-A

High-Speed Film Data

Time (milliseconds)	Displacement (feet)	Time (milliseconds)	Displacement (feet)
-48.0	-4.0	(continued)	
-36.0	-3.0	200.0	13.6
-24.0	-2.0	250.0	14.6
-12.0	-1.0	300.0	16.0
0 Impact	0	350.0	15.8
20.0	1.6	400.0	15.6
50.0	4.0	450.0	15.3
60.0	4.7	500.0	15.1
80.0	6.2	600.0	14.6
100.0	7.6	700.0	14.1
120.0	8.9	800.0	13.7
140.0	10.2	900.0	13.3
160.0	11.4	1000.0	13.1
180.0	12.6	1400.0	13.0

TABLE A2

TEST 505 B-B

High-Speed Film Data

Time (milliseconds)	Displacement (feet)	Time (milliseconds)	Displacement (feet)
-30.0	-2.6	(continued)	
-20.0	-1.7	160.0	10.9
-10.0	-0.9	180.0	11.7
0 Impact	0	200.0	12.3
10.0	0.9	220.0	13.0
20.0	1.8	240.0	13.7
30.0	2.6	260.0	14.5
40.0	3.4	280.0	15.2
50.0	4.2	300.0	16.0
60.0	5.0	320.0	16.8
70.0	5.7	340.0	17.6
80.0	6.4	360.0	18.4
90.0	7.1	380.0	19.2
100.0	7.7	400.0	20.0
120.0	8.9	420.0	20.9
140.0	10.0		

TABLE A3

TEST 505 B-C

High-Speed Film Data

Time (milliseconds)	Displacement (feet)	Time (milliseconds)	Displacement (feet)
-50.8	-3.4	(continued)	
-40.6	-2.8	101.5	6.0
-30.4	-2.1	121.8	6.9
-20.3	-1.4	142.1	7.8
-10.2	-0.7	162.4	8.5
0 Impact	0	182.7	9.1
10.2	0.7	203.0	9.7
20.3	1.4	223.3	10.2
30.4	2.0	243.6	10.6
40.6	2.7	263.9	11.0
50.8	3.3	284.2	11.2
60.9	3.9	304.5	11.5
71.0	4.4	324.8	11.6
81.2	5.0	345.1	11.7
91.4	5.5	365.4	11.7

TABLE A4

TEST 505 B-D

High-Speed Film Data

Time (milliseconds)	Displacement (feet)	Time (milliseconds)	Displacement (feet)
-49.7	-4.1	(continued)	
-41.4	-3.4	216.7	14.4
-33.2	-2.7	236.4	15.2
-24.9	-2.1	256.1	15.8
-16.6	-1.4	275.8	16.2
- 8.3	-0.7	295.5	16.7
0 Impact	0	315.2	17.2
9.8	0.8	334.9	17.6
19.7	1.5	354.6	18.0
29.6	2.3	374.3	18.3
39.4	3.1	394.0	18.8
49.2	3.8	413.7	19.2
59.1	4.6	433.4	19.7
69.0	5.3	453.1	20.1
78.8	6.1	512.2	21.6
88.6	6.8	571.3	23.1
98.5	7.5	630.4	24.8
118.2	8.8	689.5	26.4
137.9	10.2	748.6	28.0
157.6	11.4	807.7	29.7
177.3	12.5	866.8	31.3
197.0	13.5	925.9	32.7

TABLE A5

TEST 505 B-E

High-Speed Film Data

Time (milliseconds)	Displacement (feet)	Time (milliseconds)	Displacement (feet)
-48.6	-4.1	(continued)	
-36.4	-3.1	97.2	7.2
-24.3	-2.1	121.5	8.6
-12.2	-1.0	145.8	9.7
0 Impact	0	170.1	10.6
12.2	1.0	194.4	11.2
24.3	2.0	218.7	11.7
36.4	3.0	243.0	12.1
48.6	3.9	267.3	12.3
60.8	4.7	291.6	12.4
72.9	5.6	315.9	12.3
85.1	6.4	340.2	12.2

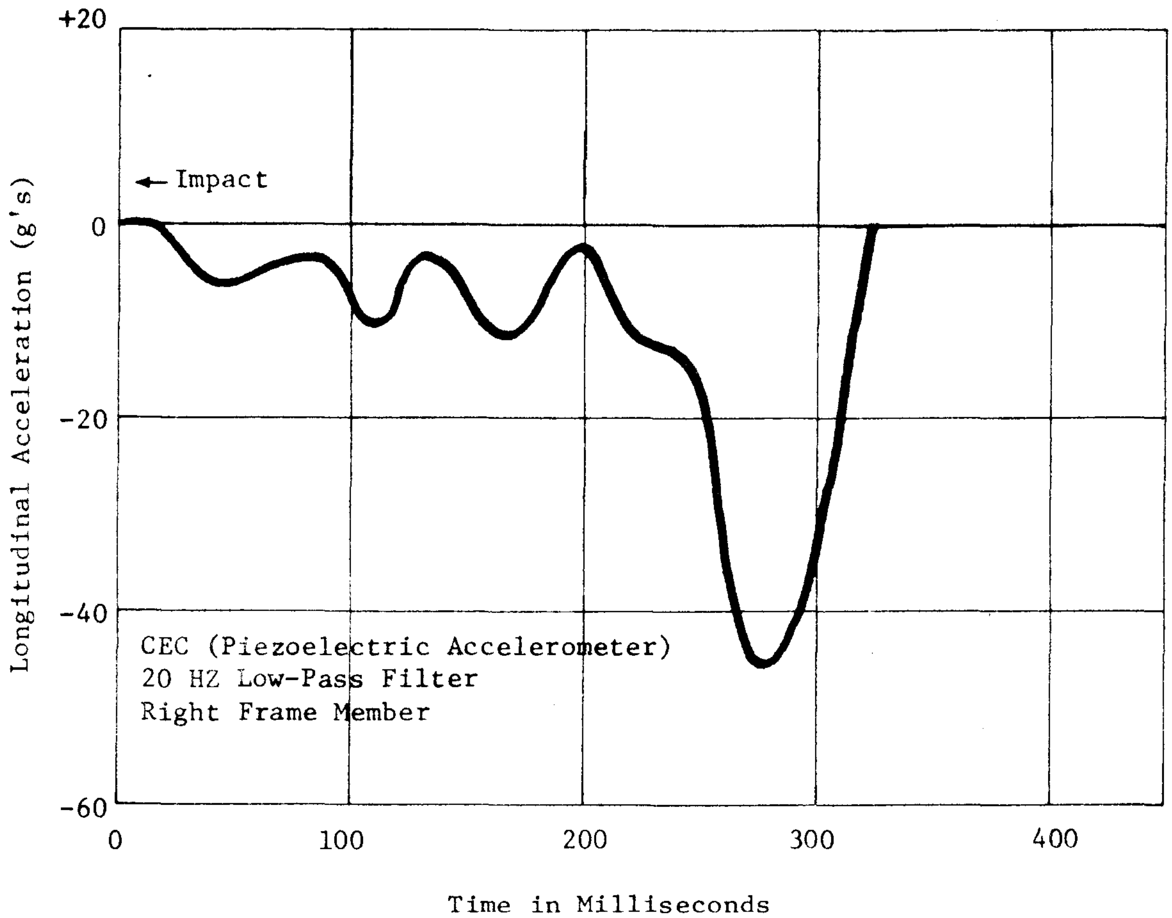


Figure A1, Longitudinal Accelerometer Data, Test 505 B-A.

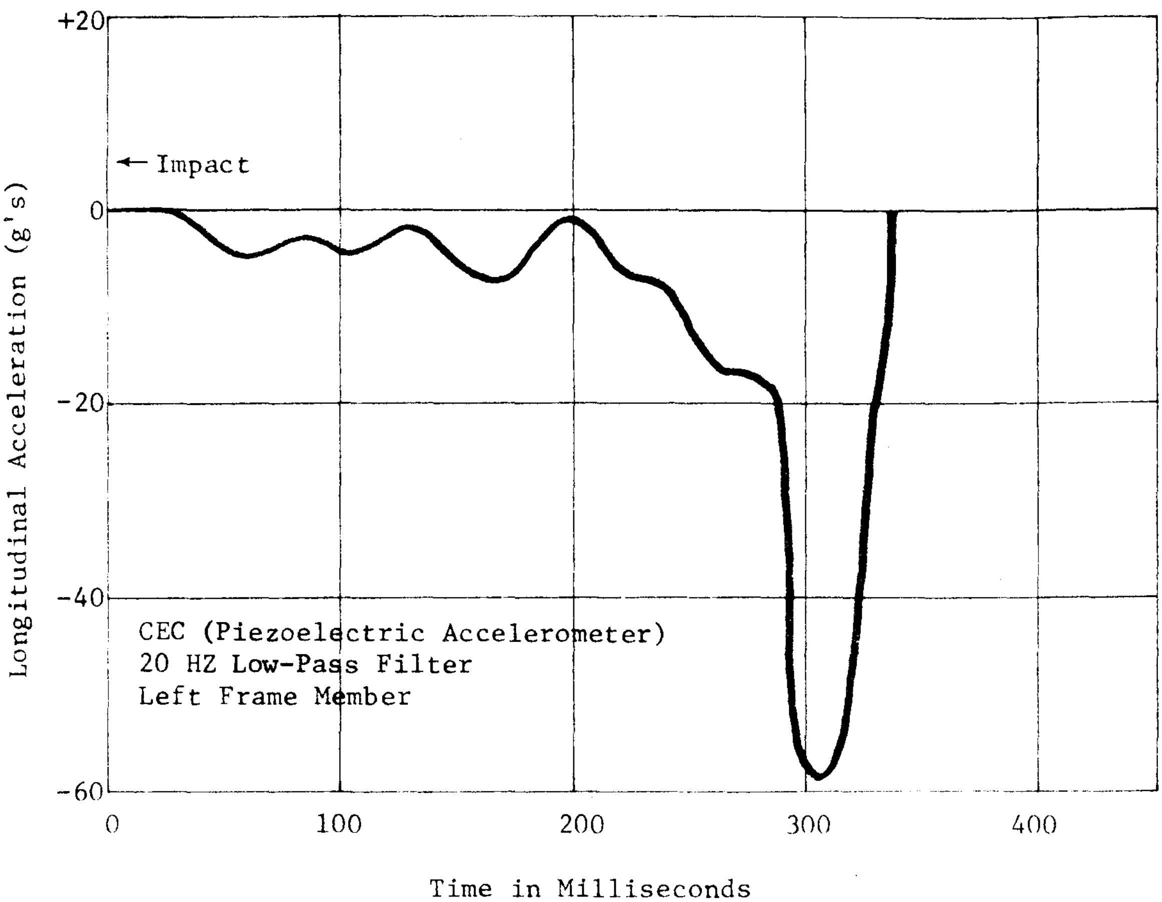


Figure A2, Longitudinal Accelerometer Data, Test 505 B-A.

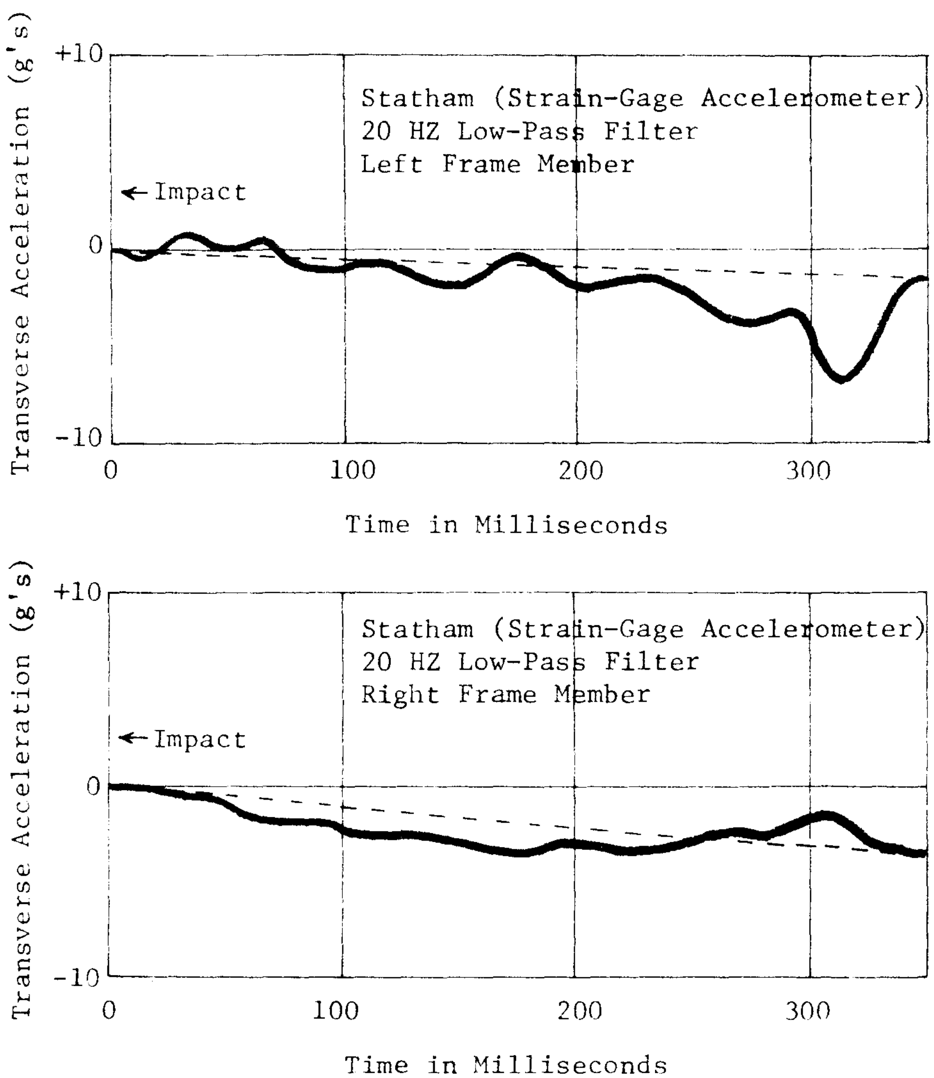


Figure A3, Transverse Accelerometer Data, Test 505 B-A.

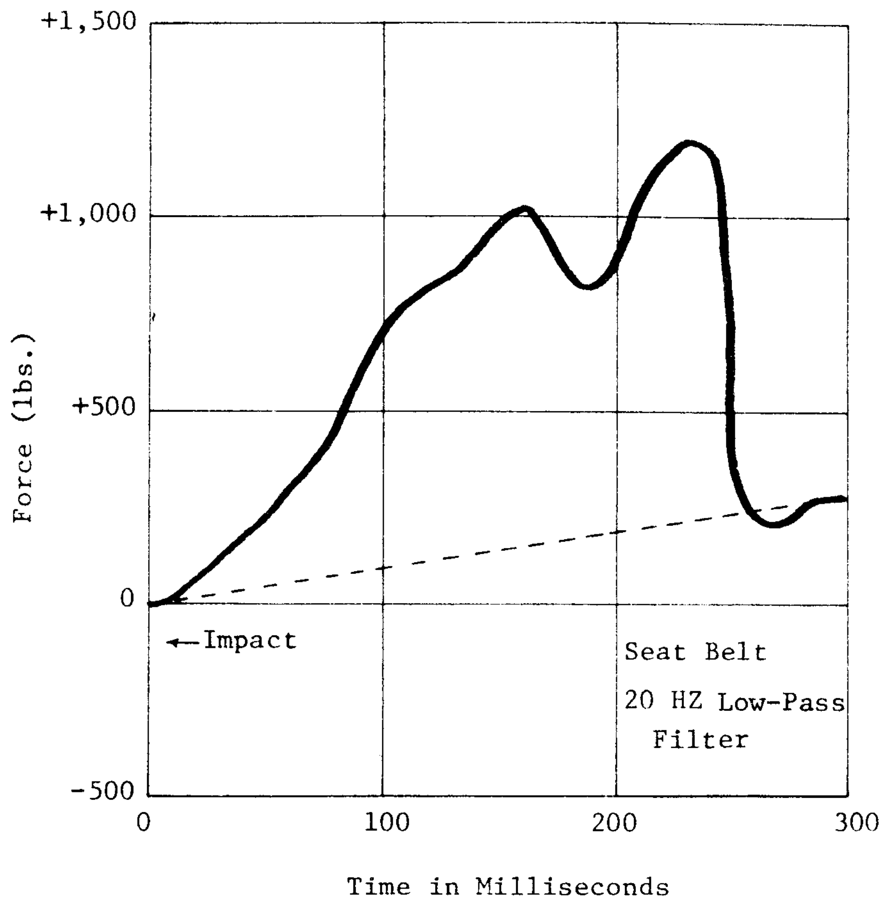
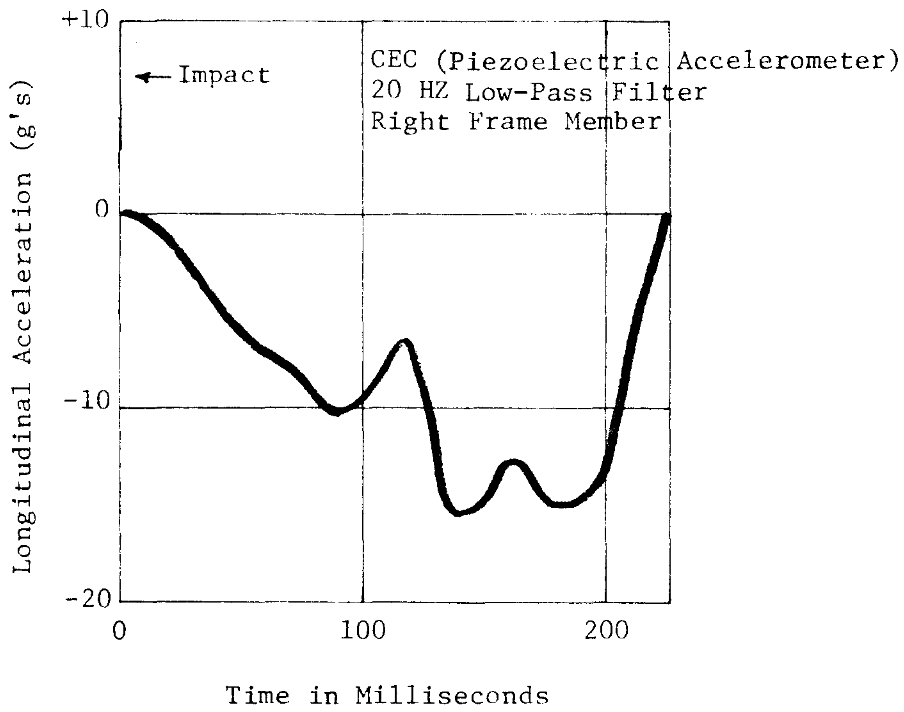


Figure A4, Seat Belt Data, Test 505 B-A.



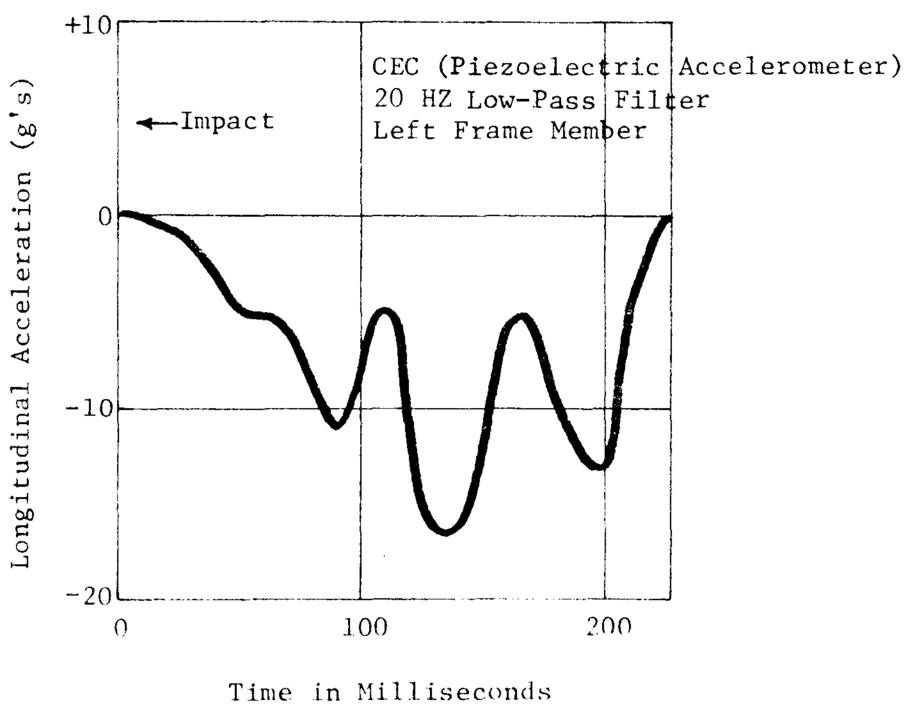


Figure A5, Longitudinal Accelerometer Data, Test 505 B-B.

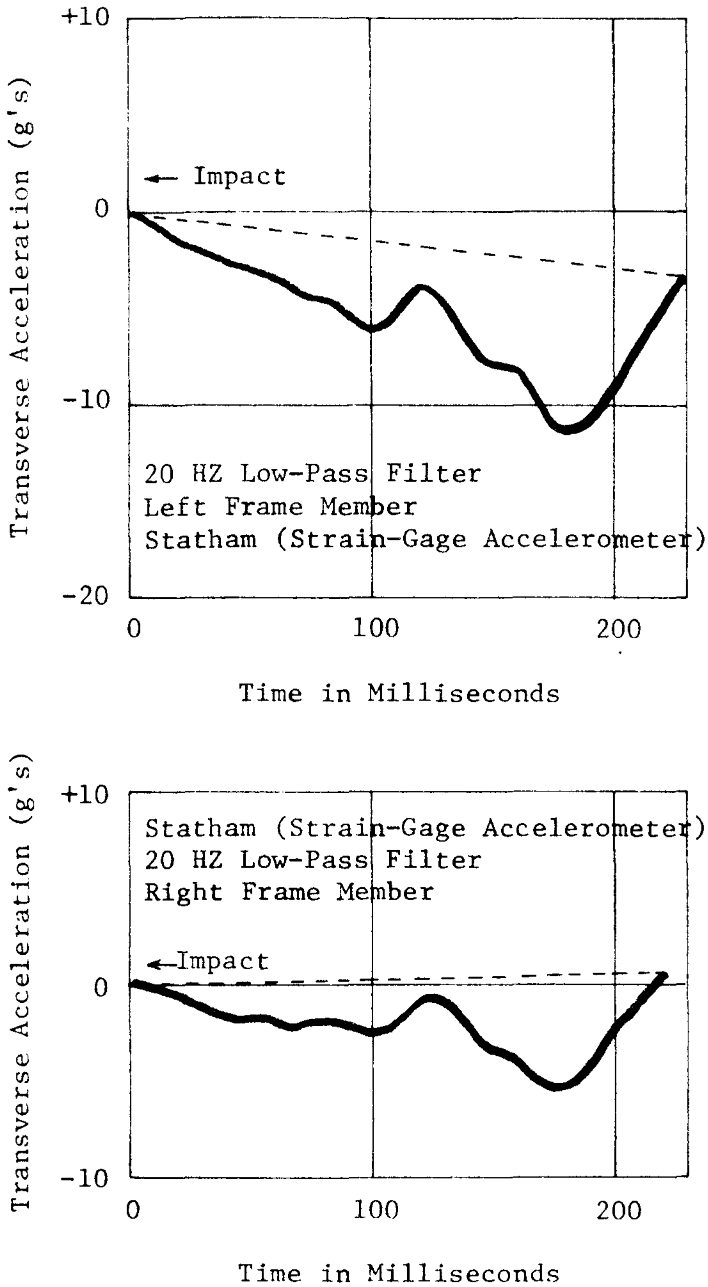
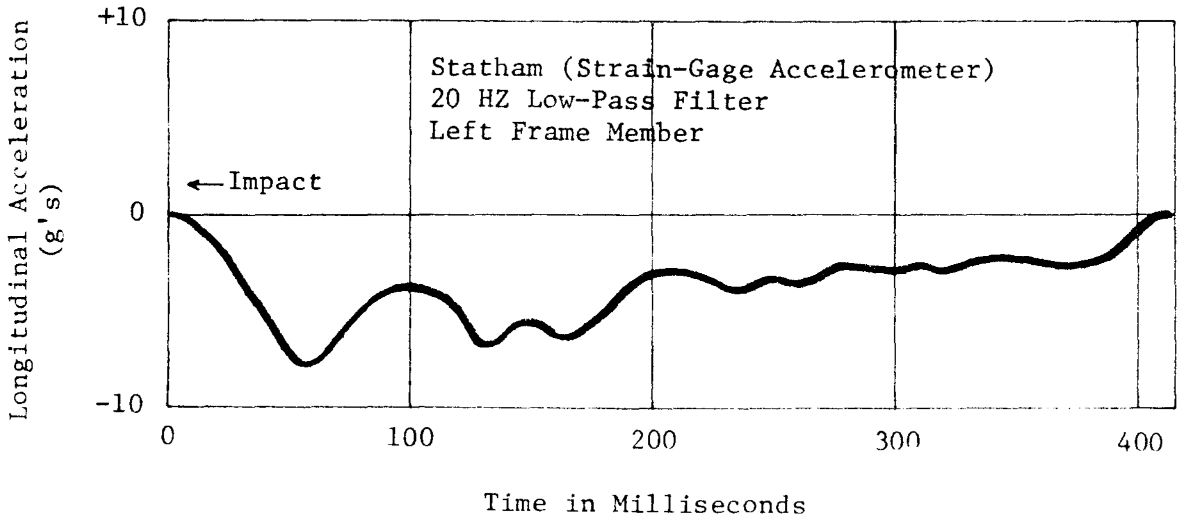


Figure A6, Transverse Accelerometer Data, Test 505 B-B.



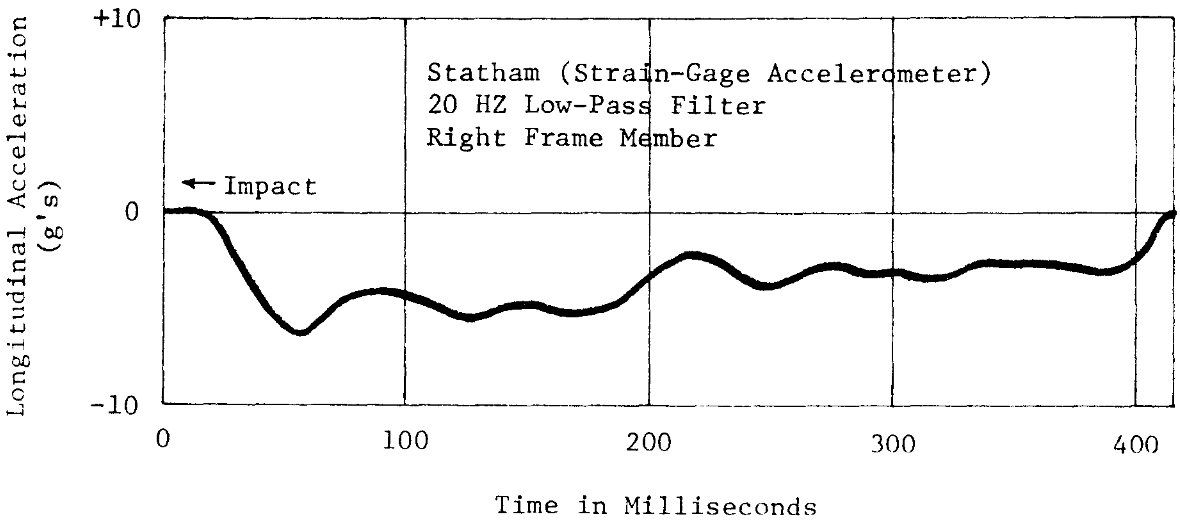
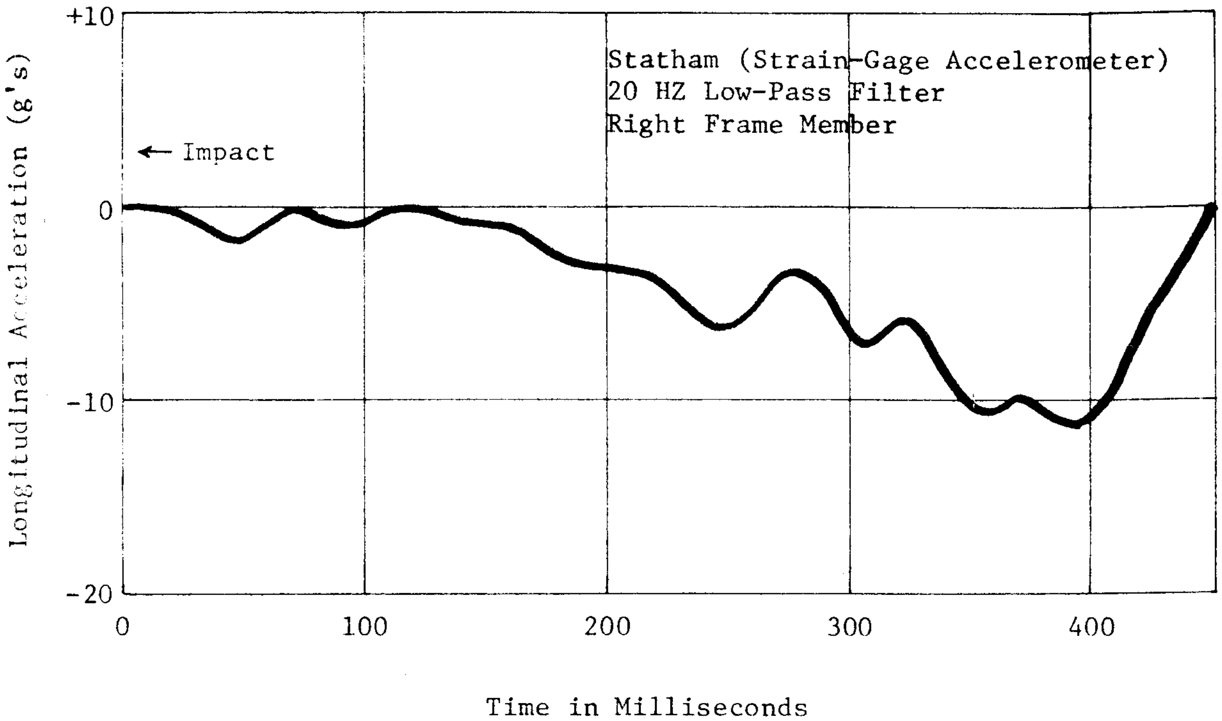


Figure A7, Longitudinal Accelerometer Data, Test 505 B-C.



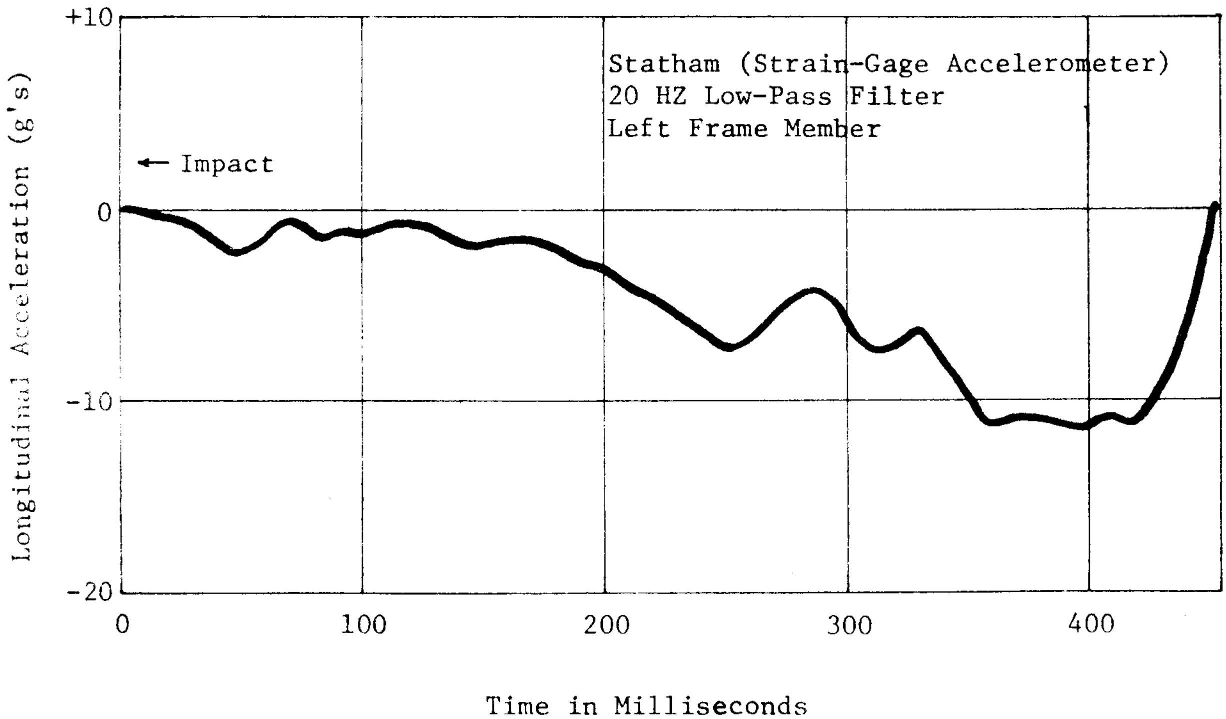
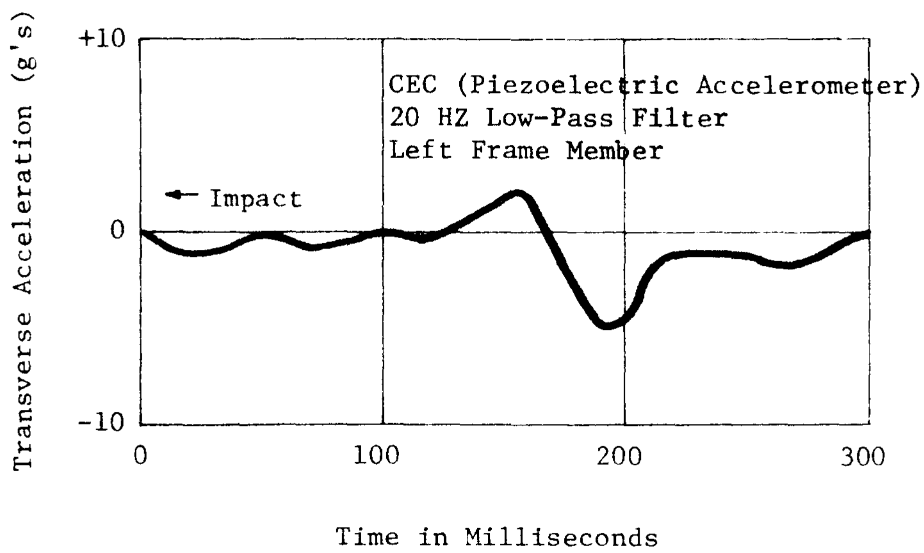


Figure A8, Longitudinal Accelerometer Data, Test 505 B-D.



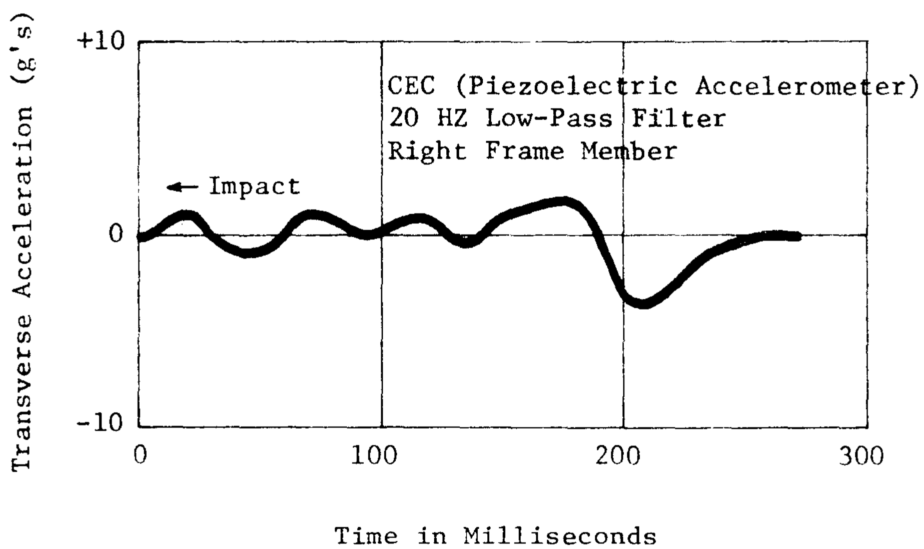
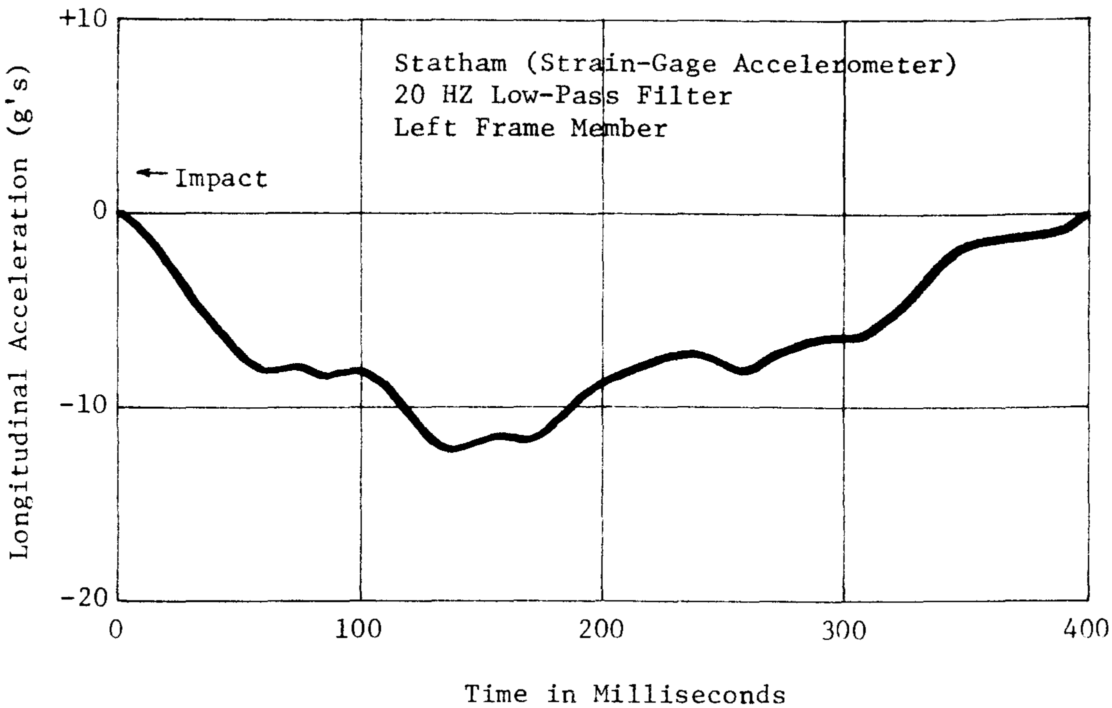


Figure A9, Transverse Accelerometer Data, Test 505 B-D.



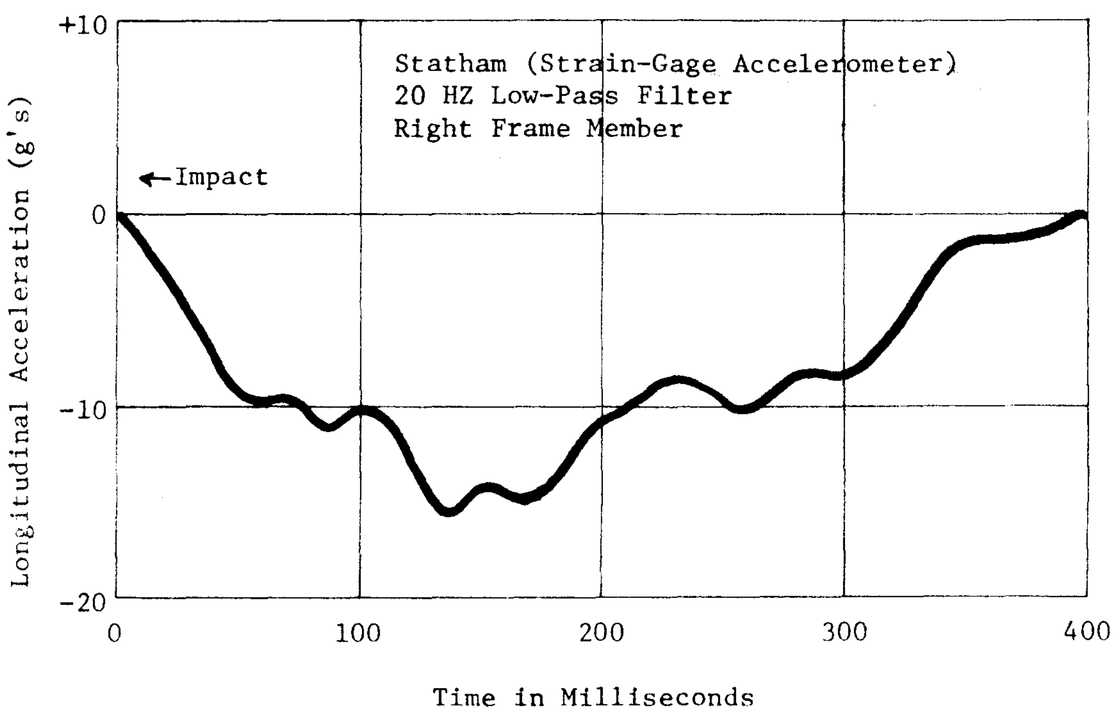


Figure A10, Longitudinal Accelerometer Data, Test 505 B-E.

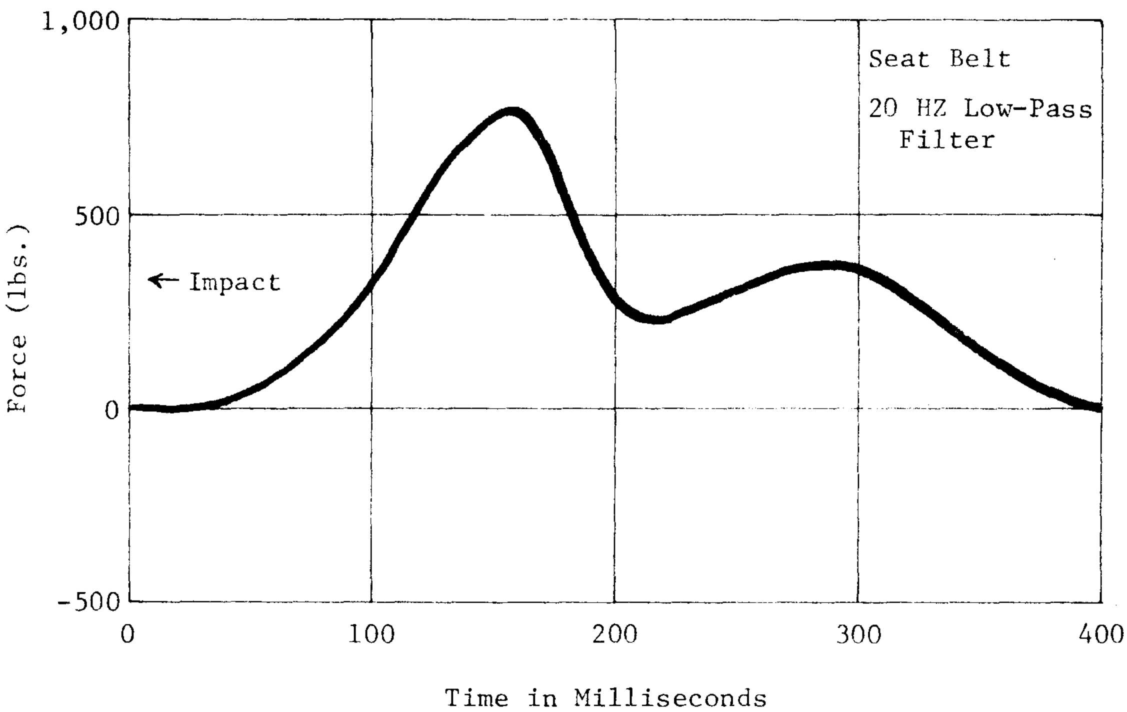


Figure A11, Seat Belt Data, Test 505 B-E.