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16. Abstract

An crash cushion was developed and crash tested to shield the ends of the concrete safety shape barrier (CSSB) and other narrow rigid objects. Steel barrels, some empty and some containing sand ballast, were used in conjunction with thrie-beam fish scales in the design. Factors considered in its development were safety, performance, cost, ease of installation and maintenance, and the use of readily available components.

Four full-scale vehicular crash tests were conducted to evaluate the impact behavior of the design in accordance with recommended procedures in NCHRP 230. The crash cushion satisfactorily met the performance standards of NCHRP 230.

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A CRASH CUSHION FOR NARROW OBJECTS

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Research Report 296-1F

Research Study No. 2-8-81-296
Safe End Treatment for
Concrete Median Barrier

Sponsored by
State Department of Highways and Public Transportation

in cooperation with
U.S. Department of Transportation
Federal Highway Administration

September 1982

Texas Transportation Institute
Texas A&M University
College Station, TX

(Revised February 1983)

DISCLAIMER

The contents of this report reflect the views of the authors who are responsible for the opinions, findings, and conclusions presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

KEY WORDS

End Treatment(s), Crash Test(s), Safety, Concrete Barrier(s)

ACKNOWLEDGMENTS

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ABSTRACT

A crash cushion was developed and crash tested to shield the ends of the concrete safety shape barrier (CSSB) and other narrow rigid objects. Steel barrels, some empty and some containing sand ballast, were used in conjunction with thrie-beam fish scales in the design. Factors considered in its development were safety, performance, cost, ease of installation and maintenance, and the use of readily available components.

Four full-scale vehicular crash tests were conducted to evaluate the impact behavior of the design in accordance with recommended procedures in TRC 191. The crash cushion satisfactorily met the performance standards of NCHRP 230 and TRC 191.

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INTRODUCTION

The concrete safety shape barrier (CSSB) has gained widespread use in recent years and has proven to be both a cost-effective and crashworthy system. However, when the barrier must be terminated within the "clear zone", the exposed end becomes a serious hazard to traffic. As discussed in reference 1, there are currently no inexpensive crash cushions for the CSSB available which are both crashworthy for permanent installations and are suitable for use in narrow medians. Therefore, this study was undertaken to develop a crash cushion for the concrete safety shape barrier that will satisfy the following design criteria:

1. meets impact performance standards as outlined in NCHRP Report 230, dated March, 1981;
2. can be used as a treatment for both median barrier and roadside barrier applications;
3. is reasonably inexpensive to install and maintain; and
4. is constructed of readily available materials.

A portable crash cushion for the concrete safety shape barrier was recently developed at the Texas Transportation Institute (1) which should be both inexpensive and suitable for narrow medians. This crash cushion was developed for use in construction zones and is constructed of empty and sand-filled steel drums with W-beam guardrail attached for redirection purposes. The attenuator is not permanently anchored and is not suitable for permanent installations. However, its development has proven the merit of a crash cushion constructed from empty and sand-filled steel drums. Texas Transportation Institute engineers have developed a crash cushion for the CSSB based on this concept that should meet all design criteria presented above.

CRASH CUSHION DESIGN

An end treatment must perform as a crash cushion if hit head-on and as a longitudinal barrier if hit downstream from the nose. Design of a system to satisfy both requirements presents special problems. The first function was achieved by the combined effect of a steel drum, energy absorbing crash cushion, and a sand barrel, inertial cushion. This was accomplished with a single row of 55 gallon steel drums, some of which were empty, some partially filled, and others completely filled with sand. Two 5/8 in. steel cables placed on each side of the row of barrels assist in redirecting a vehicle impacting from the side. Thrie-beam "fish scales" distribute side impact forces between the drums and prevent vehicles impacting the side of the treatment from snagging on the steel drums.

The crash cushion is described in detail by Figures 1 and 2. As shown in the drawings, each drum is mounted on two C4 x 5.4 steel channels. The channels prevent snagging of the drums on the ground during head-on and side impacts. If the drums do not slide freely, excessive stopping forces could be transmitted to a vehicle impacting head-on or the drums could overturn during side impacts and cause wheel snagging to become a problem. Further, the channels and false bottoms, placed in drums containing less than 500 lb (227 kg) of sand, raise the center of gravity of the system which reduces the possibility of vehicle ramping.

Other desirable features of the crash cushion are its size and construction. This crash cushion is only slightly wider than the concrete safety shaped barrier and can therefore be placed in very narrow medians as well as on the roadside. It is constructed of readily available materials, many of which are already used by highway maintenance personnel. All components of

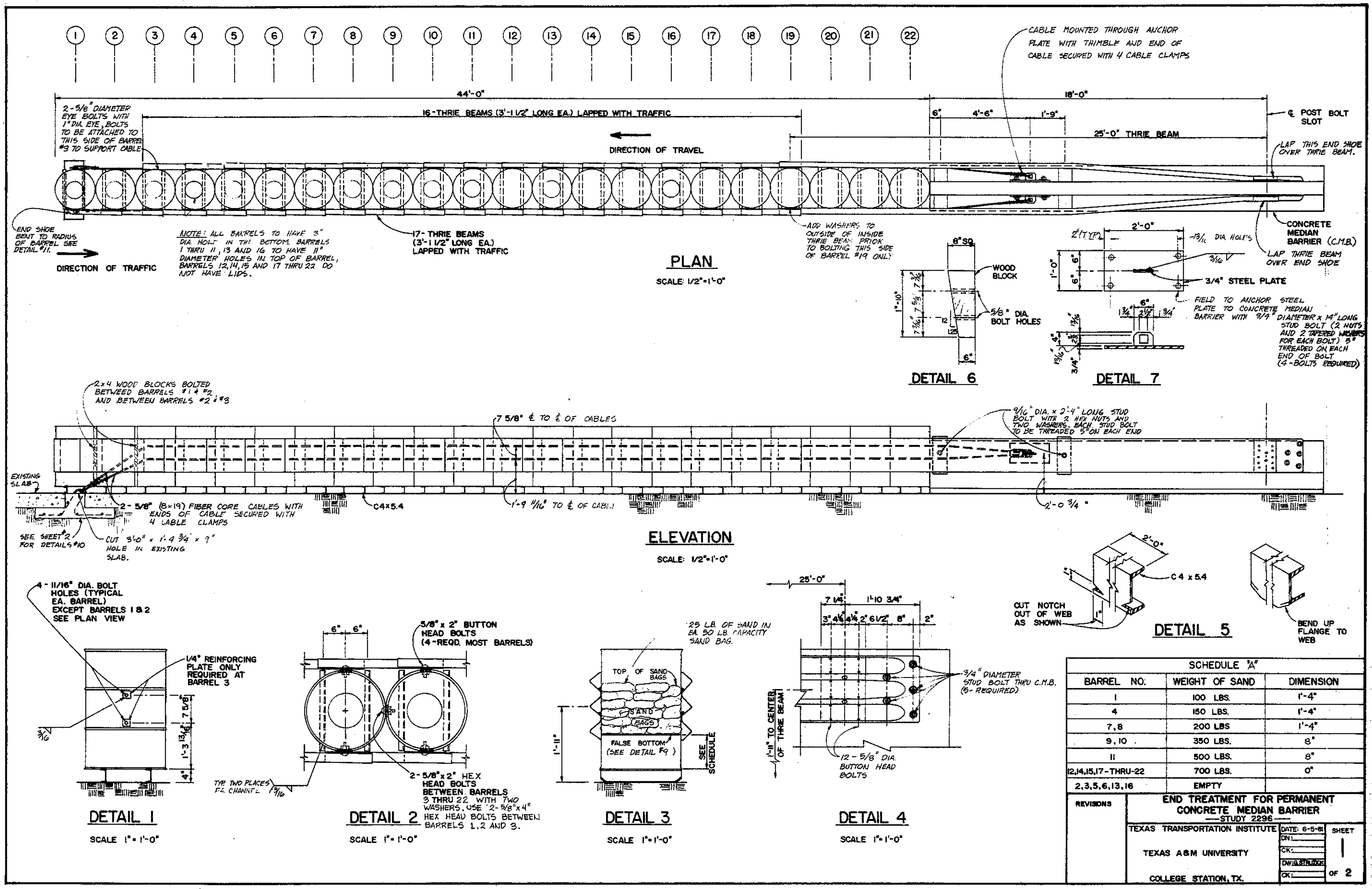


FIGURE 1. CONSTRUCTION DRAWINGS FOR NARROW HAZARD CRASH CUSHION.

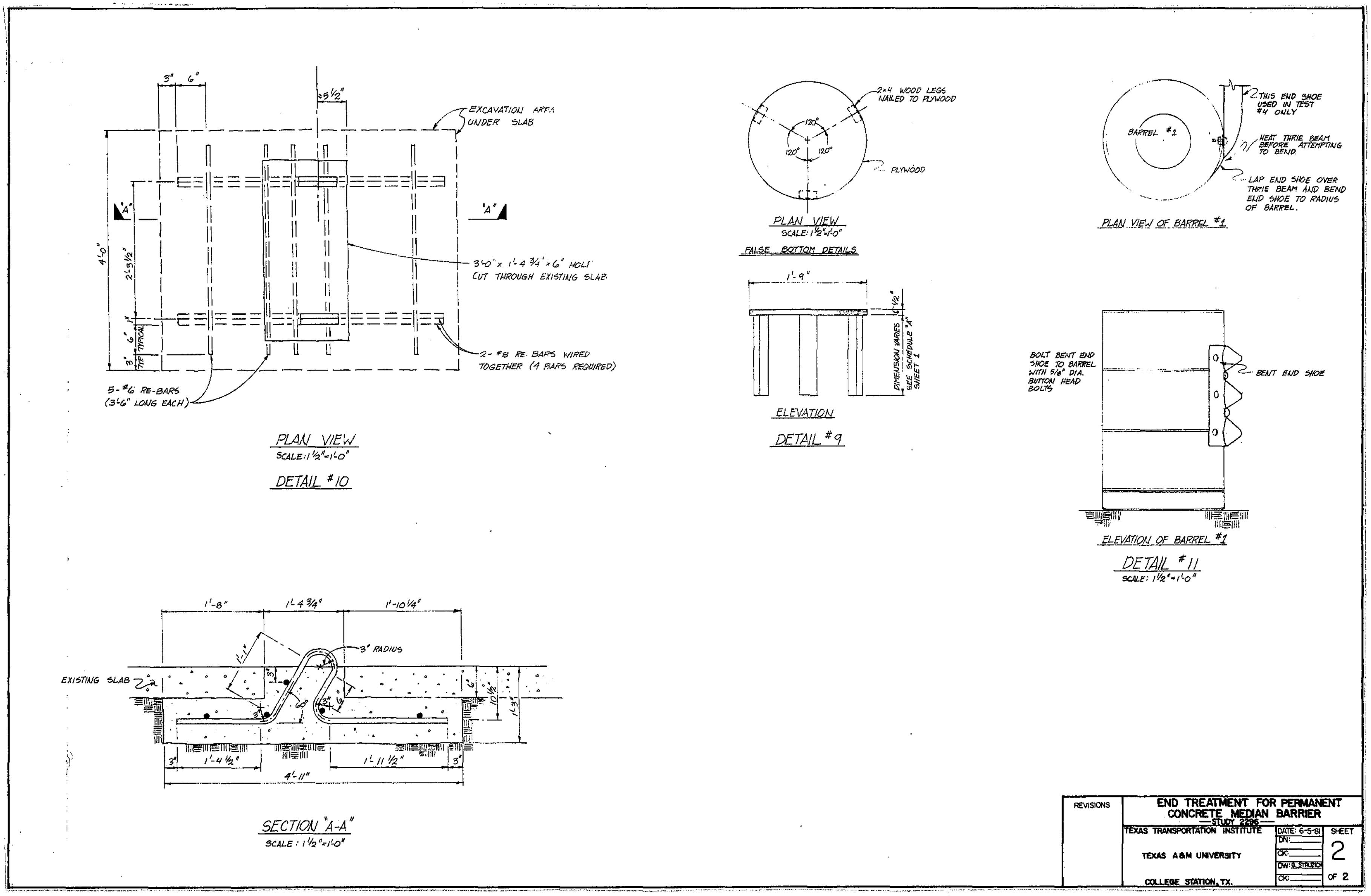


FIGURE 1 (CONTINUED). CONSTRUCTION DRAWINGS FOR NARROW HAZARD CRASH CUSHION.

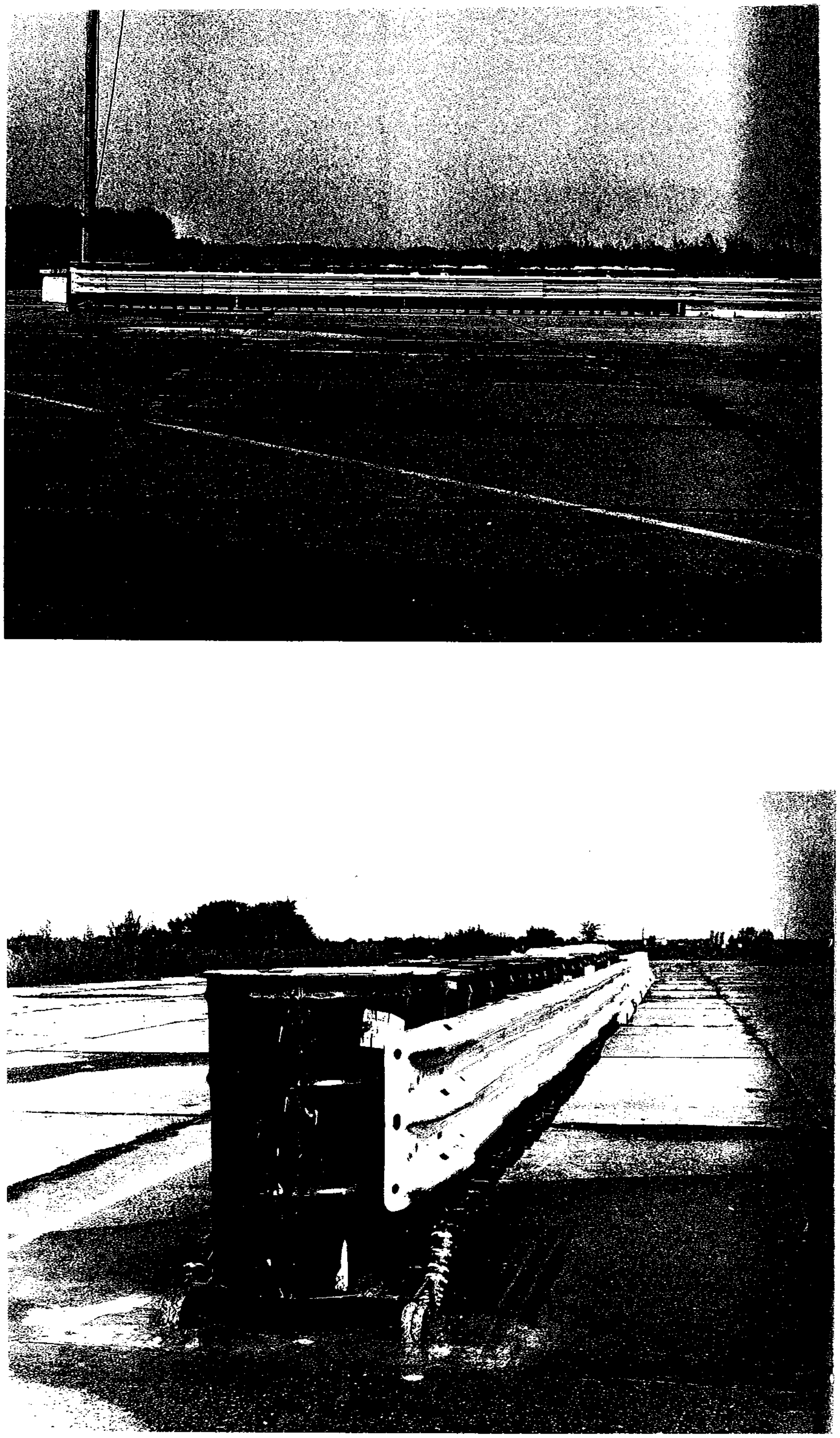


FIGURE 2 . NARROW HAZARD CRASH CUSHION.

the attenuator can be shop-fabricated and assembled in the field. Repair of the device is facilitated by the ease with which a drum can be replaced. The sand is placed in bags and can easily be lifted out of a damaged drum. Individual drums can be replaced without taking the other drums out of the device. For most impacts all thrie-beam fish scales and steel channels can be salvaged from damaged drums, thereby reducing material costs. Therefore the crash cushion should be inexpensive to install and maintain.

ANALYSIS

The crash cushion is designed to provide a yielding structure for vehicles impacting the nose of the device. A vehicle impacting the cushion head-on is smoothly decelerated by crushing the empty and partially filled drums and accelerating the sand-filled drums from rest. Head-on impact with the crash cushion can be analyzed by applying the laws of conservation of energy and momentum.

When a vehicle impacts and crushes an empty drum the kinetic energy of the vehicle is reduced by the energy required to crush the drum. The energy required to dynamically crush an 18-gage steel drum a distance of 18 in. (45.7 cm) was found by Hirsch and Ivey (2) to be 27 kips-ft (36.6 kilojoules). By applying the law of conservation of kinetic energy, the velocity change of the vehicle and the average acceleration during the event can be estimated.

$$KE_i - KE_d = KE_f$$

$$\frac{1}{2} m V_i^2 - KE_d = \frac{1}{2} m V_f^2$$

$$V_F = \sqrt{\frac{mV_i^2 - 2KE_d}{m}}$$

$$a_{avg} = \frac{V_i^2 - V_F^2}{2d}$$

where KE_i = kinetic energy of vehicle prior to crushing a drum

KE_f = kinetic energy of vehicle after crushing a drum

KE = energy required to crush a drum

V_i = vehicle velocity before impact

V_f = vehicle velocity after impact

m = mass of vehicle

a_{avg} = average acceleration of vehicle during event

d = distance drum is crushed

When a sand-filled drum is impacted by a vehicle the drum is crushed approximately 6 in. and accelerated to the velocity of the vehicle. The change in vehicle velocity can be estimated by applying the laws of conservation of energy and momentum. The law of conservation of energy can be applied as shown previously to determine the velocity change when the barrel is partially crushed. The law of conservation of momentum can be applied when a sand-filled drum is accelerated from rest as shown below.

$$m_i V_j = (m_i + m_d) V_F$$

$$V_F = \frac{m_i V_j}{m_i + m_d}$$

where V_j = velocity of vehicle after partially crushing a drum

V_F = velocity of vehicle after impact

m_i = mass of vehicle and previously impacted drums

m_d = mass of sand-filled drum

The occupant movement relative to the vehicle during an impact event can be estimated from the average acceleration, initial and final velocities, and travel distance of the vehicle.

$$V_f = a_{avg}t + V_i$$

$$t = \frac{V_F - V_i}{a_{avg.}}$$

$$S_V = V_i t - \frac{1}{2} a_{avg.} t^2$$

$$S_O = V_O t$$

$$S_r = S_O - S_V$$

where

a_{avg} = average vehicle acceleration during event

t = duration of event

S_V = distance traveled by vehicle

S_O = movement of occupant

V_O = velocity of occupant (vehicle velocity upon initial impact)

S_r = movement of occupant relative to vehicle

When the sum of S_r for each impact event reaches 2 ft (0.61 m), the estimated occupant impact velocity is the difference between the initial velocity of the vehicle and the current velocity of the vehicle. The average acceleration over the stopping distance can also be estimated from the previous analysis.

Predicted and test results for longitudinal occupant impact velocities and average accelerations over the stopping distance are given in Table 1. As shown in the table, the predicted results correlate extremely well with the test results for the 2250 lb (1022 kg) vehicle. The results for the 4500 lb (2043 kg) vehicle are somewhat lower than predicted values due to an unexpectedly large amount of crushing of the sand-filled drums. Although not proven by a test, the analysis shows that the crash cushion could safely decelerate an 1800 lb (817.2 kg) vehicle impacting head-on at 60 mph (96.6 km/h).

Table 1. Comparison of Predicted and Test Results.

VEHICLE WEIGHT lb (kg)	LONGITUDINAL OCCUPANT IMPACT VELOCITY ft/sec (m/sec)		AVERAGE ACCELERATION OVER STOPPING DISTANCE g's	
	PREDICTED	TEST RESULT	PREDICTED	TEST RESULT
1800 (817)	36 (11.0)	*	9.3	*
2250 (1022)	33 (10.1)	32.4 (9.9)	7.8	7.5
4500 (2043)	38 (11.6)	28.0 (8.5)	7.2	5.8

*No test.

CRASH TEST RESULTS

Four full-scale crash tests were conducted on the crash cushion as shown in Figure 2. The first test examined the redirectional performance of the crash cushion and the other tests investigated its capacity to safely decelerate vehicles to a stop. Crash tests were conducted according to nationally recognized standards (4) and are summarized in Table 2. Although the crash cushion was designed and testing was initiated under the standards set by Transportation Research Circular 191 (4), NCHRP Report 230 (3) was published prior to completion of the final crash tests. The original test matrix was completed, however the crash tests were evaluated by standards set in both reports. NCHRP 230 requires an additional crash test with a mini-car, which could not be conducted. However, the analysis shown previously indicates that the test would have been successful. Data acquisition systems are described in Appendix A. Sequential photographs selected from high-speed films of the tests are presented in Appendix B. Accelerometer traces as well as roll, pitch, and yaw rate plots are presented in Appendix C.

Test 1

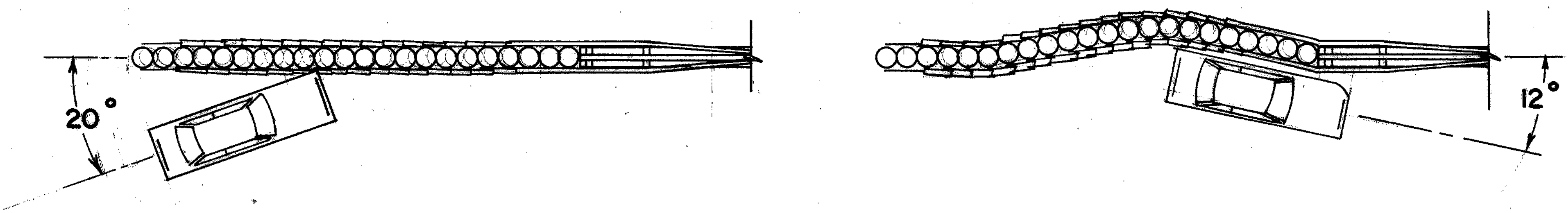
Test 1 evaluated the redirectional performance capability of the narrow hazard crash cushion and is summarized in Figure 3. For this test a 4500 lb (2043 kg) Plymouth Fury (1975) impacted the midpoint of the crash cushion at 20 degrees and 55.3 mph (89.0 km/h). This test was selected to test the transition from continuous thrie-beam rail element to thrie-beam fish scales. The test vehicle was smoothly redirected and exhibited no tendency to pocket or snag on any of the crash cushion elements. Vehicle exit angle was approximately 12 degrees and the occupant impact velocities were 19.8 ft/sec (6.0 m/sec) longitudinal and 6.6 ft/sec (2.0 m/sec) lateral. The peak 50 ms average acceleration for both longitudinal and lateral directions was 4.7 g's.

TABLE 2. SUMMARY OF CRASH TESTS

TEST NO.	VEHICLE WEIGHT	IMPACT SPEED mph (km/h)	ANGLE OF IMPACT deg	POINT OF IMPACT	VEHICLE STOPPING DISTANCE ft (m)	CUSHION DISPLACEMENT		OCCUPANT IMPACT VELOCITY		VEHICLE ACCELERATION DATA g's					VEHICLE DAMAGE CLASSIFICATION	
						Long. ft (m)	Lat. ft (m)	Long. ft/s (m/s)	Lat. ft/s (m/s)	Occupant Ridedown Peak 10 ms Avg.		Peak 50 ms Avg.		Avg. Over Stopping Distance	TAD	VDI
										Long.	Lat.	Long.	Lat.			
1	4500 (2040)	55.3 (89.0)	20	Barrel No. 11	N/A	0	3.1 0.9	19.8 (6.0)	6.6 (2.0)	3.1	0.8	4.7	4.8	N/A	10LFQ4	10LYEW4
2	2410 (1094)	58.7 (94.5)	0	Nose	15.3 (4.7)	15.3 (4.7)	-	32.3 (9.8)	a	7.5	a	11.6	0.9	7.5	12FD2	12FDEW3
3	4500 (2040)	60.5 (97.4)	0	nose	20.9 (6.4)	20.9 (6.4)	-	28.0 (8.5)	a	9.4	a	8.4	0.7	5.8	12FD2	12FDMW2
4	2335 (1060)	59.7 (96.0)	10	1 ft Offset from Nose	11.4 (3.5)	11.4 (3.5)	1.2	38.9 (11.9)	a	10.0	a	12.9	2.0	10.5	1FL4	01FDEW5

[a]No occupant impact during test

0.000 Sec. | 0.117 Sec. | 0.233 Sec. | 0.428 Sec.



Test No.	2296-1
Date	8/26/81
Installation	
Drawing Nos.	2262-1,2
Length, ft (m)	104 (31.7)
Maximum Deflections, ft (m)	
Dynamic	3.1 (0.94)
Residual	3.1 (0.94)
Vehicle Model	1975 Plymouth
Vehicle Mass, lb (kg)	4500 (2093)
Impact Conditions	
Speed, mph (kph)	55.3 (89.0)
Angle, deg	20

Exit Conditions	
Speed, mph (kph)	38.0 (61.1)
Angle, deg	12
Occupant Impact Velocity, ft/s (m/s)	
Longitudinal	19.8 (6.0)
Lateral	6.6 (2.0)
Vehicle Accelerations, g's	
Occupant Ride Down	
Longitudinal	3.1
Lateral	0.8
Peak 50 ms avg	
Longitudinal	4.7
Lateral	4.7
Vehicle Damage Classification	
TAD	10-LFQ-4
VDI	10LYEW4

FIGURE 3. SUMMARY OF TEST 1.

All of these occupant risk values as well as the vehicle trajectory hazard are below recommended values (3, 4) for a redirectional test. The large lateral deflections shown in Table 2 resulted from longitudinal movement of the portable concrete barrier elements to which the crash cushion was attached. In a permanent installation, the crash cushion would normally be attached to a continuous concrete barrier which cannot displace longitudinally.

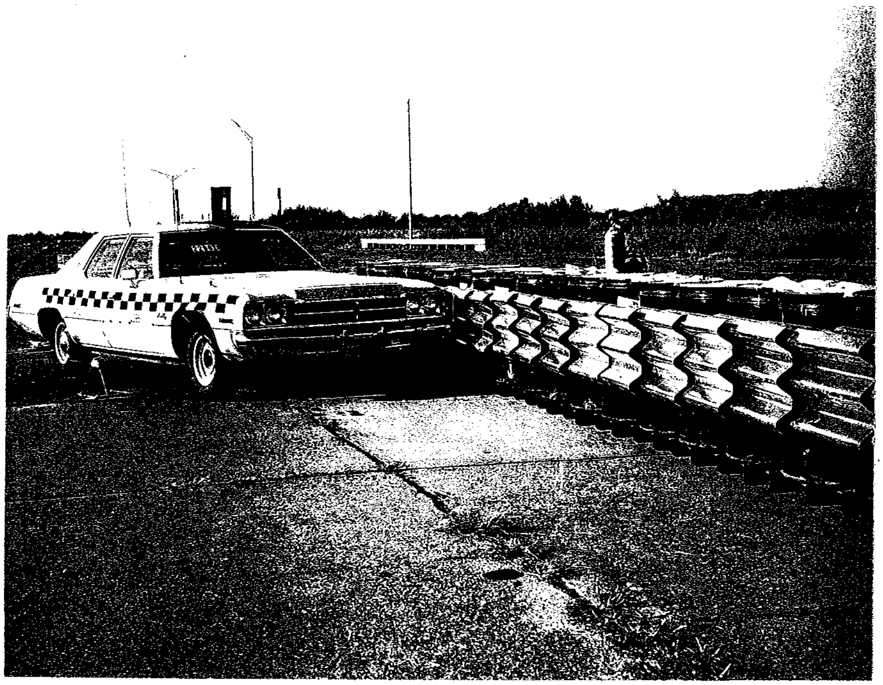
The test vehicle and installation prior to test 1 are shown in Figure 4. Figure 5 shows the test vehicle and installation after test 1. As shown in this figure, the vehicle damage was not severe for a collision of this nature. Restoration of the crash cushion required replacement of two 25 ft (7.6 m) sections of thrie beam, five drums, and two 37.5 in. (95.3 cm) thrie beam fish scales.

The test was considered a success based on the excellent safety performance and the relatively light damage incurred by the crash cushion.

Test 2

Test 2 examined the head-on impact behavior of the crash cushion. Figure 6 gives a summary of this test. In this test a 2410 lb (1094 kg) Chevrolet Vega (1976) impacted the nose of the crash cushion at zero degrees and 58.7 mph (94.4 km/h). The test vehicle was smoothly decelerated to a stop. The longitudinal occupant impact velocity was 32.3 ft/sec (9.8 m/sec) and peak 50 ms average accelerations were 11.6 g's longitudinal and 0.9 g's lateral. The occupant impact velocities and vehicle accelerations were within acceptable limits (3, 4) for this type of test. One thrie beam fish scale was detached from the third drum and skidded approximately 60 ft (18.2 m). This thrie beam plate could have been a hazard to other traffic in a highway installation.

Figure 7 shows the test vehicle and installation before test 2. As shown in Figure 8 the test vehicle was damaged lightly for a test of this nature. Figure 9 shows the crash cushion after test 2. The cushion was restored by



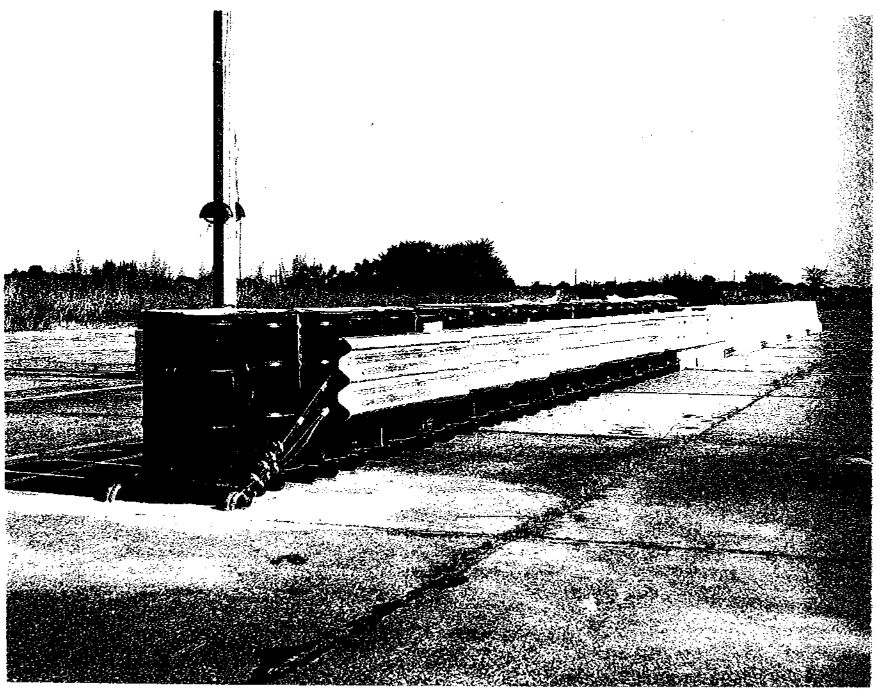


FIGURE 4. TEST VEHICLE AND INSTALLATION PRIOR TO TEST 1.

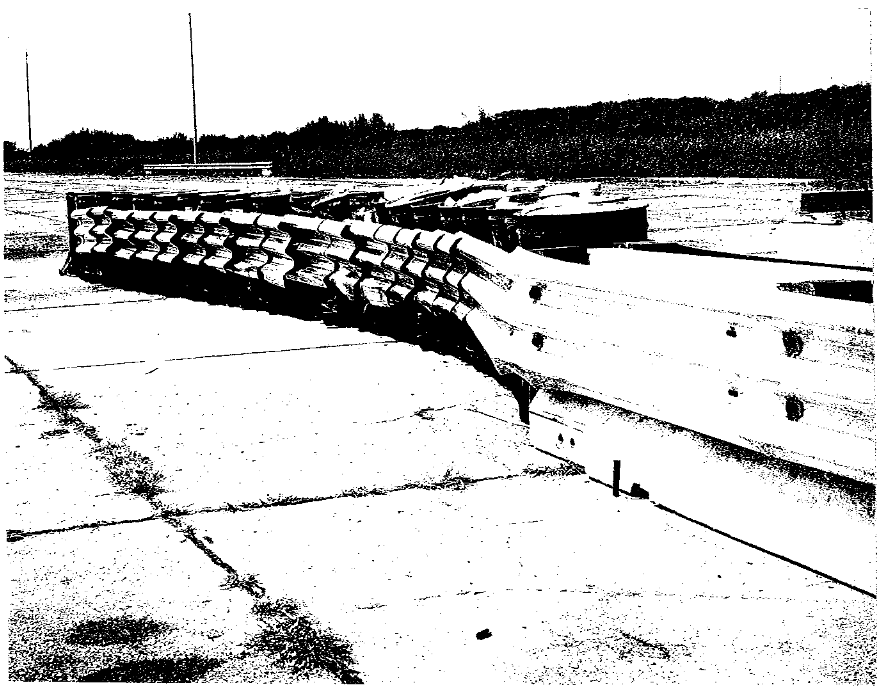
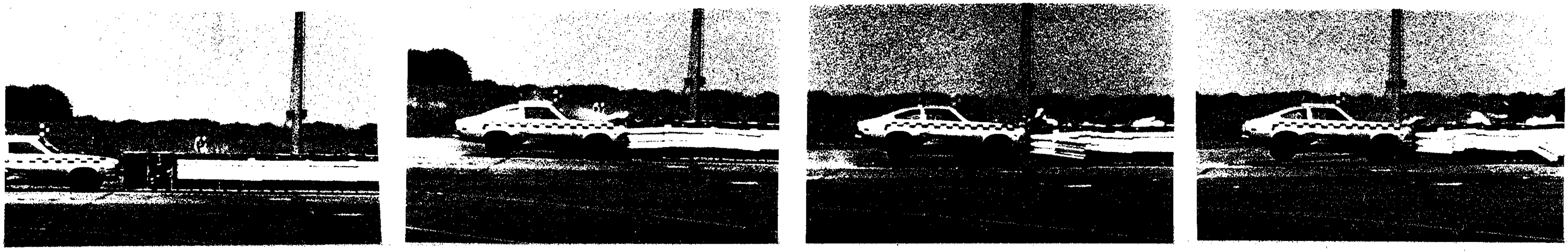
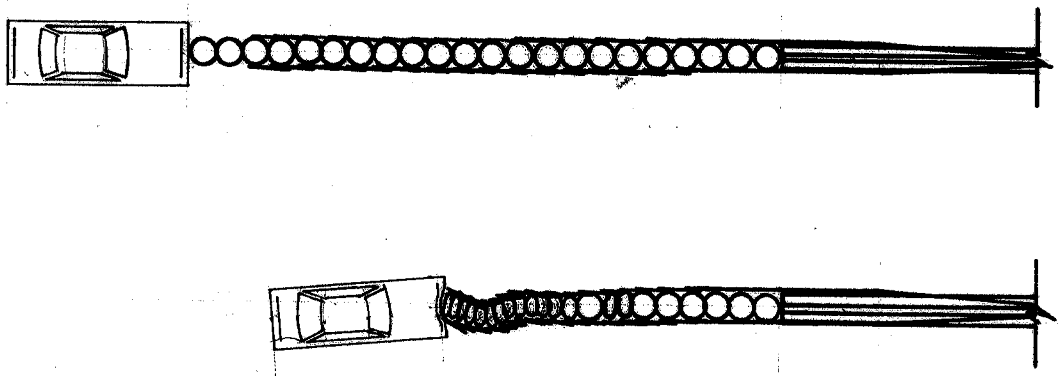


FIGURE 5. TEST VEHICLE AND INSTALLATION AFTER TEST 1.



0.000 Sec. 0.133 Sec. 0.331 Sec. 0.598 Sec.



Test No.	2296-2
Date	8/27/81
Installation	
Drawing No.	2262-1,2
Length, ft (m)	104 (31.7)
Maximum Deformations, ft (m)	
Longitudinal	15.3 (4.7)
Lateral	----
Vehicle Model	1976 Chevrolet Vega
Vehicle Mass, lb (kg)	2410 (1094)
Impact Conditions	
Speed, mph (kph)	58.7 (94.5)
Angle, deg	0
Vehicle Stopping Distance, ft (m)	15.3 (4.7)

Occupant Impact Velocity, ft/s (m/s)	
Longitudinal	32.3 (9.8)
Lateral	----
Vehicle Accelerations, g's	
Occupant Ride Down	
Longitudinal	7.5
Lateral	----
Peak 50 ms. avg	
Longitudinal	11.6
Lateral	0.9
Average Over Stopping Distance	7.5
Vehicle Damage Classification	
TAD	12-FD-2
VDI	12FDEW3

FIGURE 6. SUMMARY OF TEST 2.

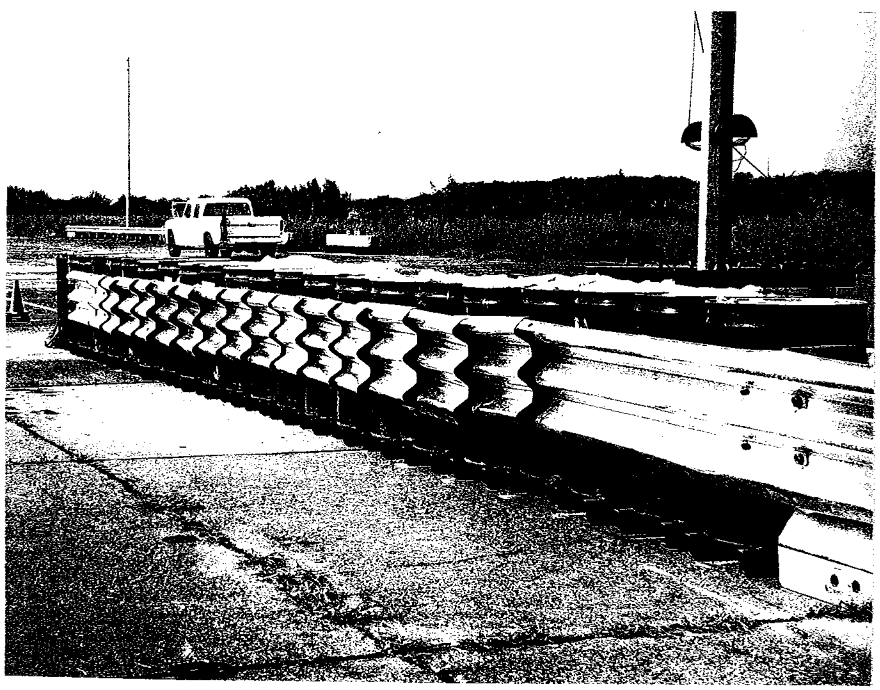


FIGURE 7. TEST VEHICLE AND INSTALLATION
BEFORE TEST 2.

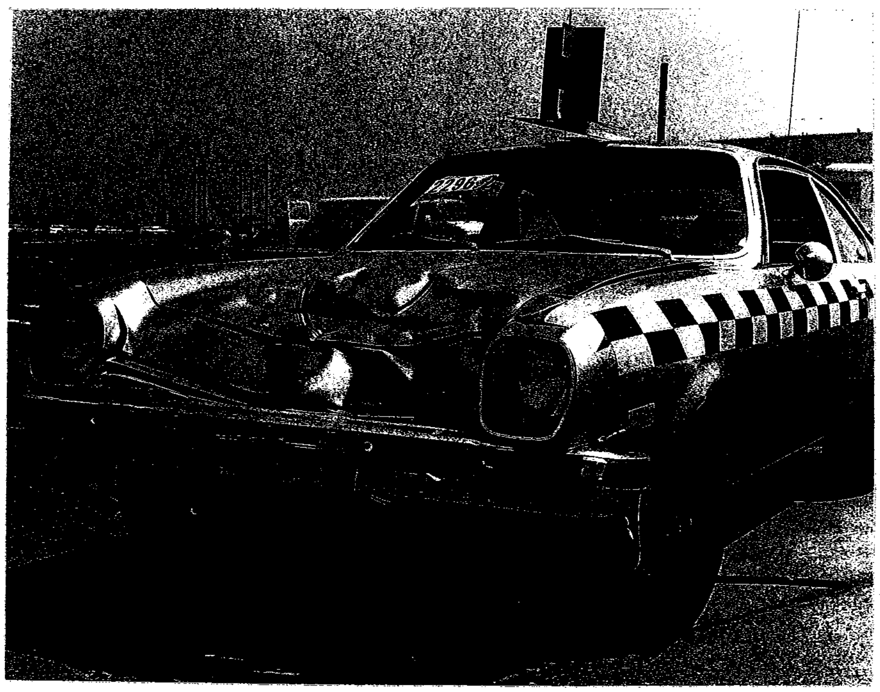


FIGURE 8. TEST VEHICLE AFTER TEST 2.

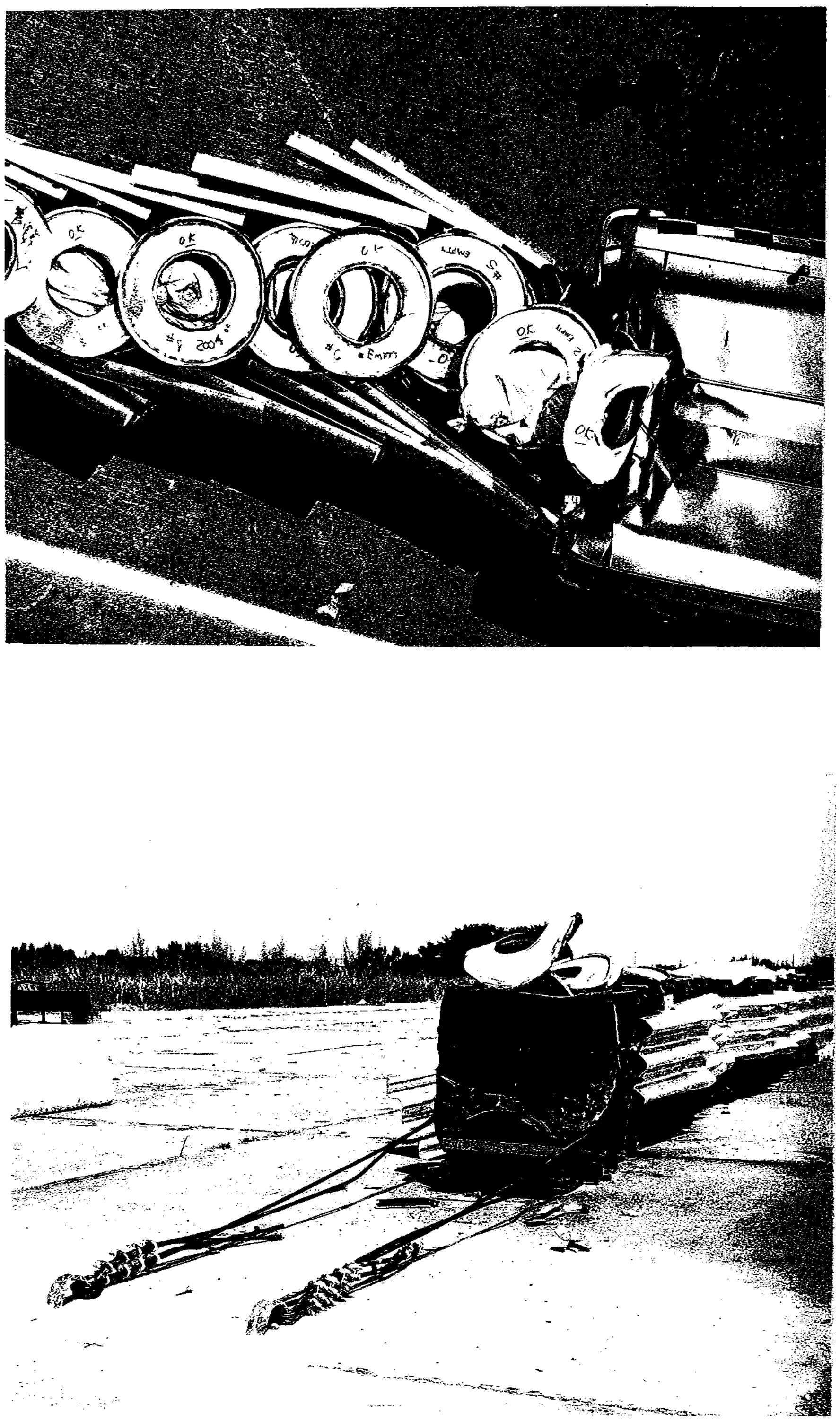


FIGURE 9. TEST INSTALLATION AFTER TEST 2.

replacement of 18 barrels. All other materials were salvageable. This test was considered very successful.

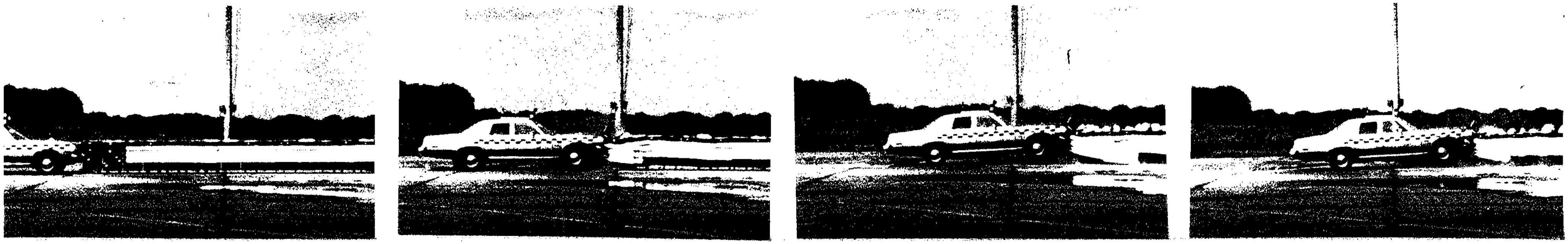
Test 3

Test 3 evaluated the head-on impact behavior of the cushion with a large vehicle. Test 3 is summarized in Figure 10. For this test a 4500 lb (2043 kg) Plymouth Fury (1977) impacted the nose of the cushion head-on at 60.5 mph (97.4 km/h). The test vehicle was smoothly decelerated to a stop over a distance of 20.9 ft (5.4 m). The front of the test vehicle pitched up less than 5 degrees and did not yaw significantly during the test. Peak 50 ms average accelerations for the vehicle were 8.4 g's longitudinal and 0.7 g's lateral. These values are below the recommended limits of 12 g's longitudinal and 6 g's lateral (4). The longitudinal impact velocity was 28.0 ft/sec (8.5 m/sec) which is well below the recommended limit of 40 ft/sec (12.2 m/sec) (3). A thrie beam fish scale again became detached from the third drum and skidded approximately 135 ft (41 m).

Figure 11 shows the test vehicle and installation before test 3. The test vehicle, shown in Figure 12, experienced very light damage for a test of this nature. Figure 13 shows the crash cushion after test 3. The cushion was heavily damaged, as would be expected from this test. However, the only materials requiring replacement were 19 drums. This test was very successful with the exception of the thrie beam plate that became detached from barrel 3.

Test 4

Analysis of high-speed films from test 2 revealed that the leading thrie beam fish scale on the upstream side of the cushion was impacted by the test vehicle's bumper before the drum to which the fish scale was attached was impacted. Researchers concluded that if the leading fish scale could be bent around the drum, and more bolts could be placed in it, this fish scale would



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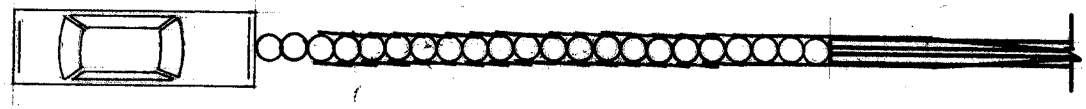
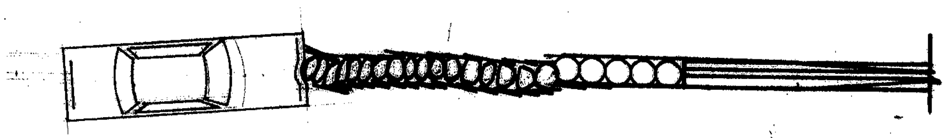




Test No.	2296-3
Date	9/1/81
Installation	
Drawing No.	2262-1,2
Length, ft (m)	104 (31.7)
Maximum Deformations, ft (m)	
Longitudinal	20.9 (6.4)
Lateral	----
Vehicle Model	1977 Plymouth
Vehicle Mass, lb (kg)	4500 (2040)
Impact Conditions	
Speed, mph (kph)	60.5 (97.4)
Angle, deg	0
Vehicle Stopping Distance, ft (m)	20.9 (6.4)

Occupant Impact Velocity, ft/s (m/s)	
Longitudinal	28.0 (8.5)
Lateral	----
Vehicle Accelerations, g's	
Occupant Ride Down	
Longitudinal	9.4
Lateral	0.2
Peak 50 ms avg	
Longitudinal	8.4
Lateral	0.7
Average Over Stopping Distance	5.8
Vehicle Damage Classification	
TAD	12-FD-2
VDI	12FDMW2

FIGURE 10. SUMMARY OF TEST 3.

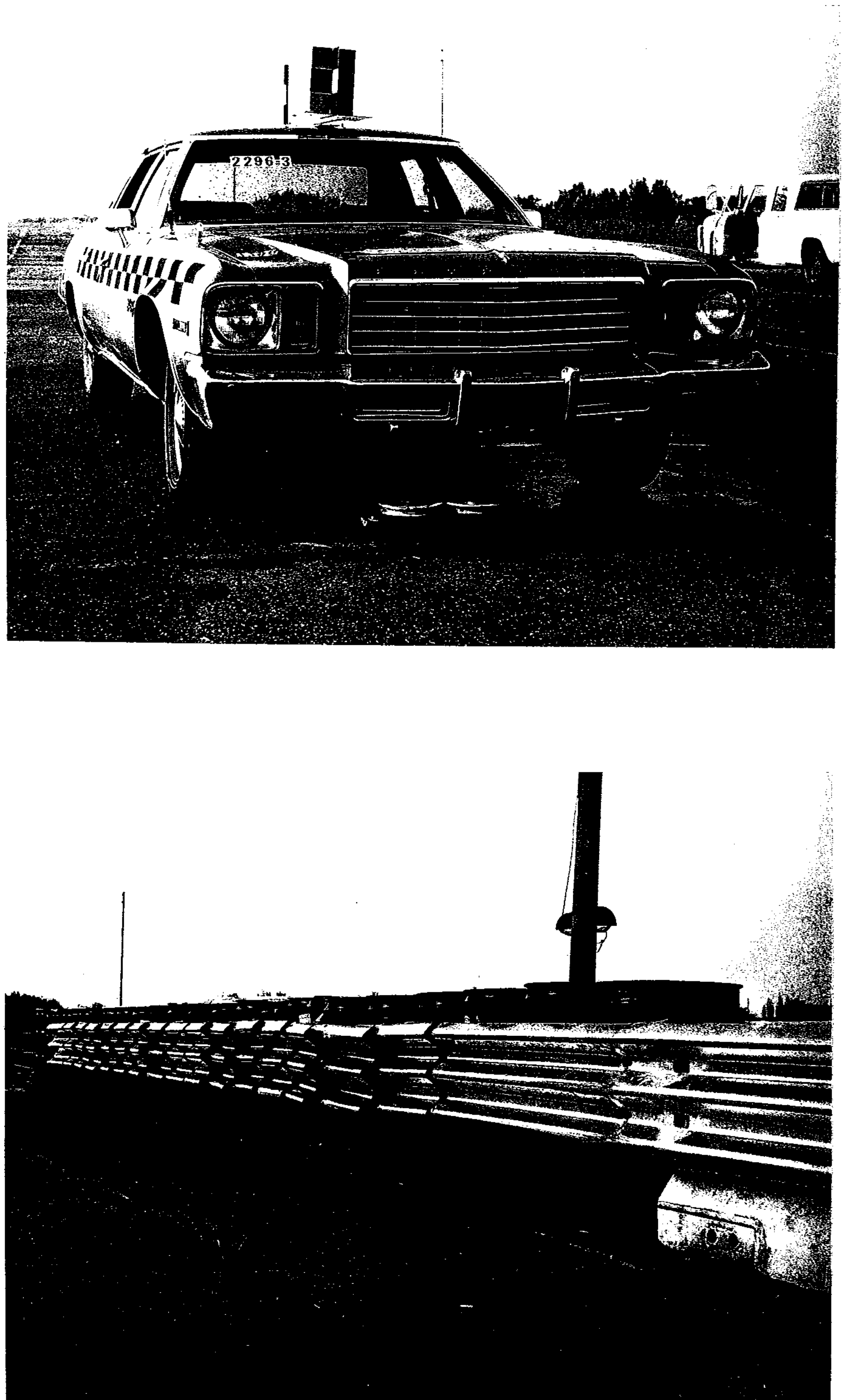


FIGURE 11. TEST VEHICLE AND INSTALLATION PRIOR TO TEST 3.

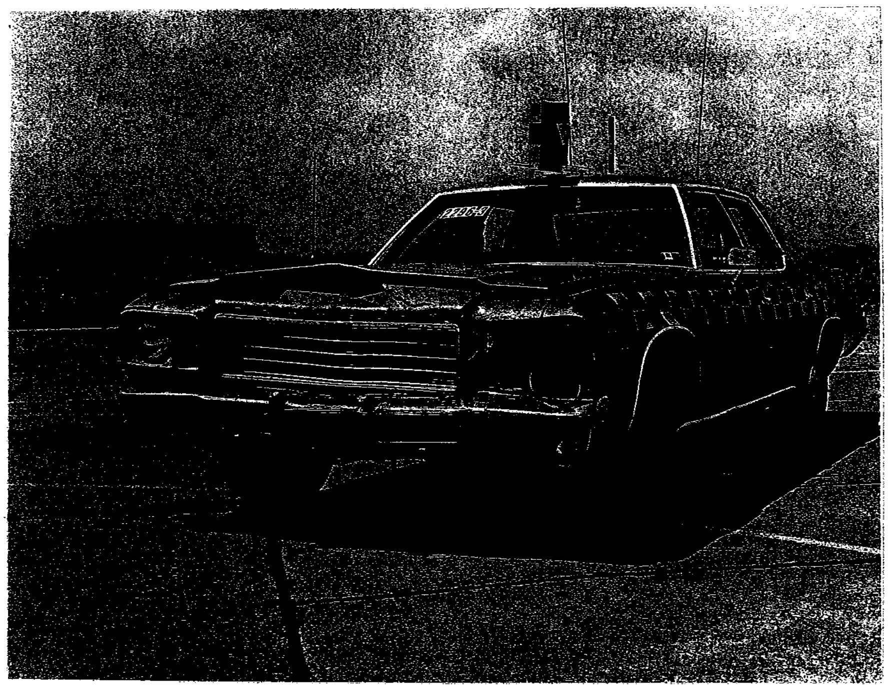


FIGURE 12. TEST VEHICLE AFTER TEST 3.

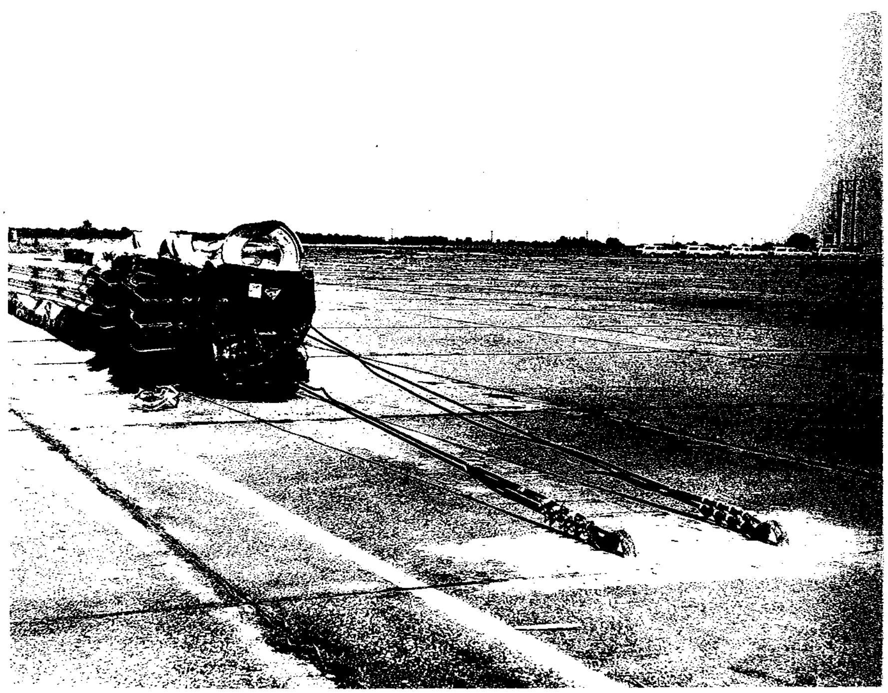
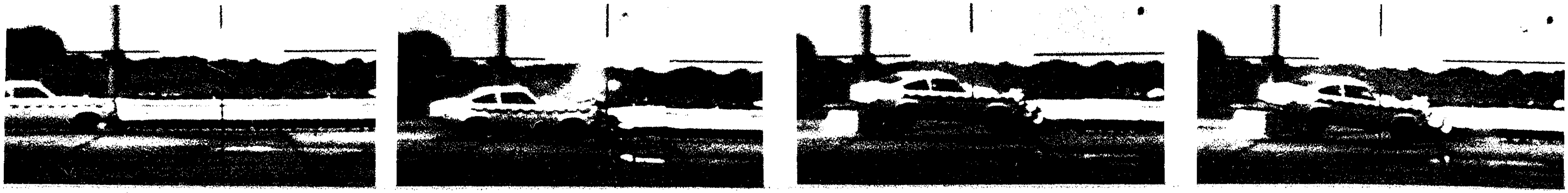


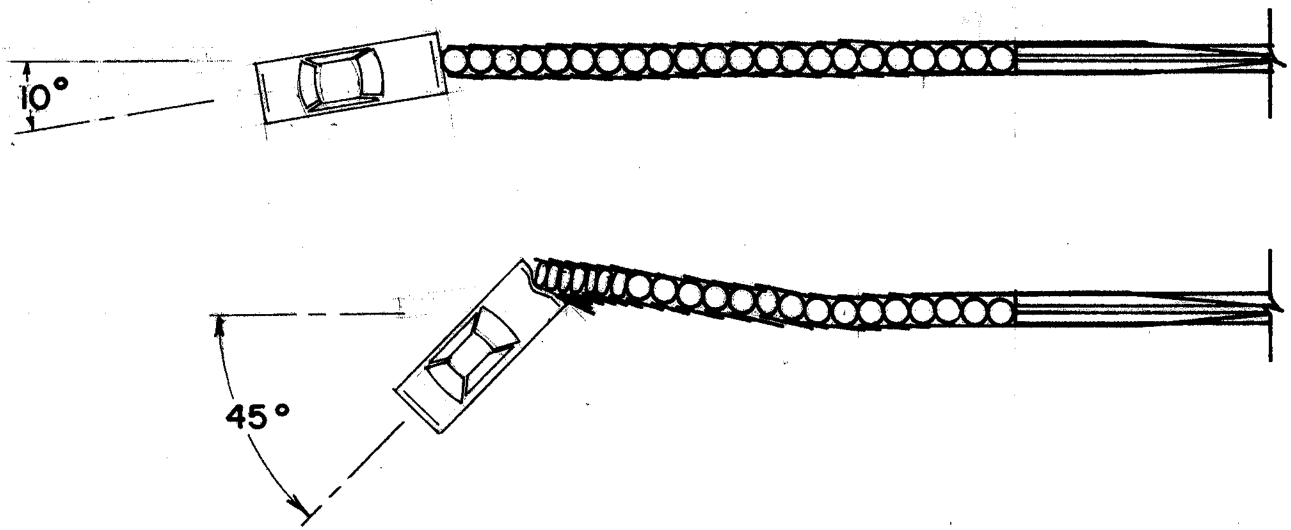
FIGURE 13. TEST INSTALLATION AFTER TEST 3.

not be dislodged during the head-on impacts. Therefore, two additional thrie beam fish scales were added to the upstream side of the crash cushion prior to test 4. One of these thrie beam plates, a standard thrie beam end shoe, was attached to the leading drum and bent around it. In addition, three bolts were used to attach the end shoe to the drum.

Test 4 evaluated the crash cushion for unsymmetrical loading at the nose. This test is summarized in Figure 14. For this test a 2335 lb (1060 kg) Chevrolet Vega (1975) impacted the nose of the crash cushion at 10 degrees and 59.7 mph (96.1 km/h). Upon impact the left front side of the test vehicle pocketed on the nose of the cushion. The vehicle then yawed approximately 45 degrees as it was smoothly decelerated to rest. The longitudinal occupant impact velocity was 38.9 ft/sec (11.9 m/sec) which is below the maximum recommended value of 40 ft/sec (12.2 m/sec) (3). The test vehicle and installation before test 4 are shown in Figure 15. The test vehicle was damaged only moderately as shown in Figure 16. Figure 17 shows the damage to the crash cushion. Note that no thrie beam fish scales became dislodged during this test. Restoration of the crash cushion involved replacement of 14 barrels. This test was considered a success.



0.000 Sec. 0.122 Sec. 0.426 Sec. 0.528 Sec.



Test No.	2296-4
Date	9/8/81
Installation	
Drawing No.	2252-1,2
Length, ft (m)	104 (31.7)
Maximum Deformations, ft (m)	
Longitudinal	11.4 (3.5)
Lateral	1.2
Vehicle Model	1976 Chevrolet Vega
Vehicle Mass, lb (kg)	2335 (1060)
Impact Conditions	
Speed, mph (kph)	59.7 (96.0)
Angle, deg	
Vehicle Stopping Distance, ft (m)	10

Occupant Impact Velocity, ft/s (m/s)	
Longitudinal	38.9 (11.9)
Lateral	----
Vehicle Accelerations, g's	
Occupant Ride Down	
Longitudinal	10.0
Lateral	----
Peak 50 ms avg	
Longitudinal	12.9
Lateral	2.0
Average Over Stopping Distance	10.5
Vehicle Damage Classification	
TAD	1-FL-4
VDI	01FDEW5

FIGURE 14. SUMMARY OF TEST 4.

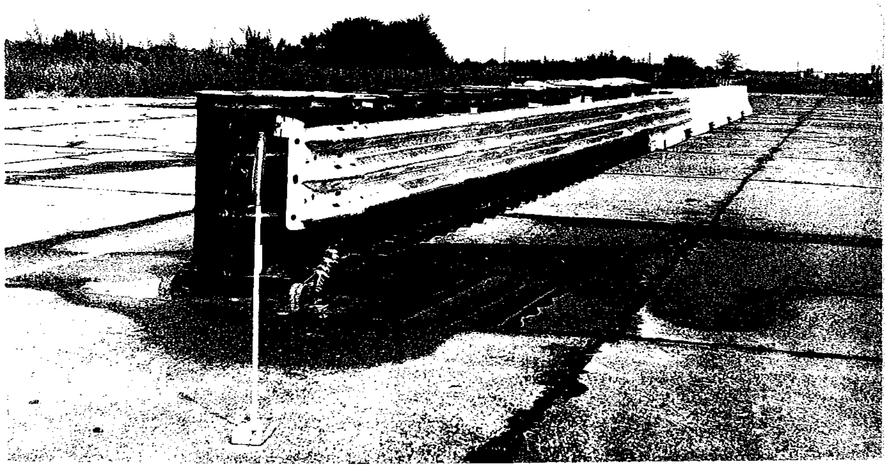


FIGURE 15. TEST VEHICLE AND INSTALLATION
BEFORE TEST 4.

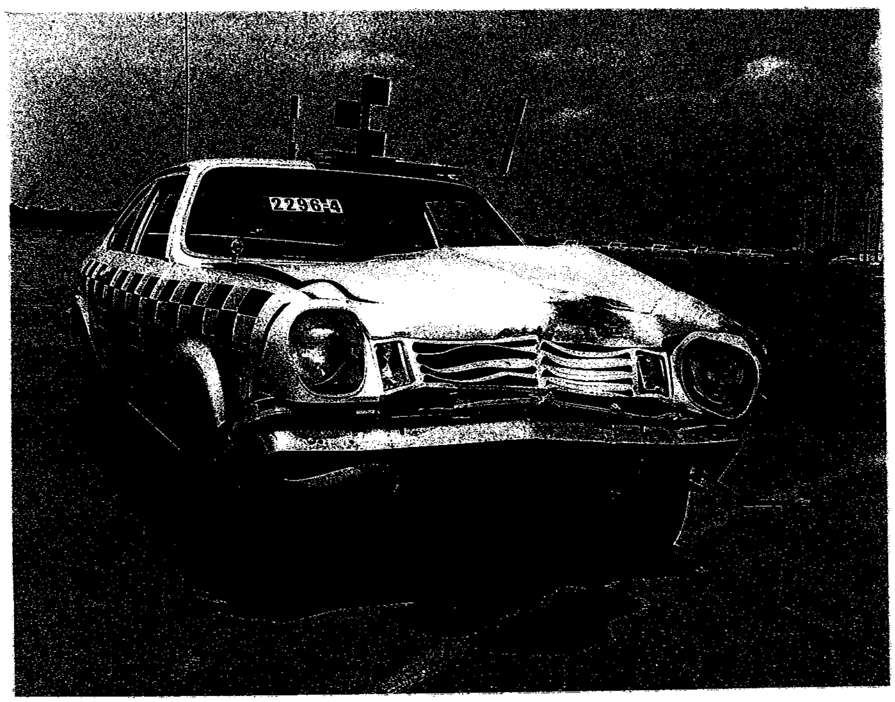


FIGURE 16. TEST VEHICLE AFTER TEST 4.

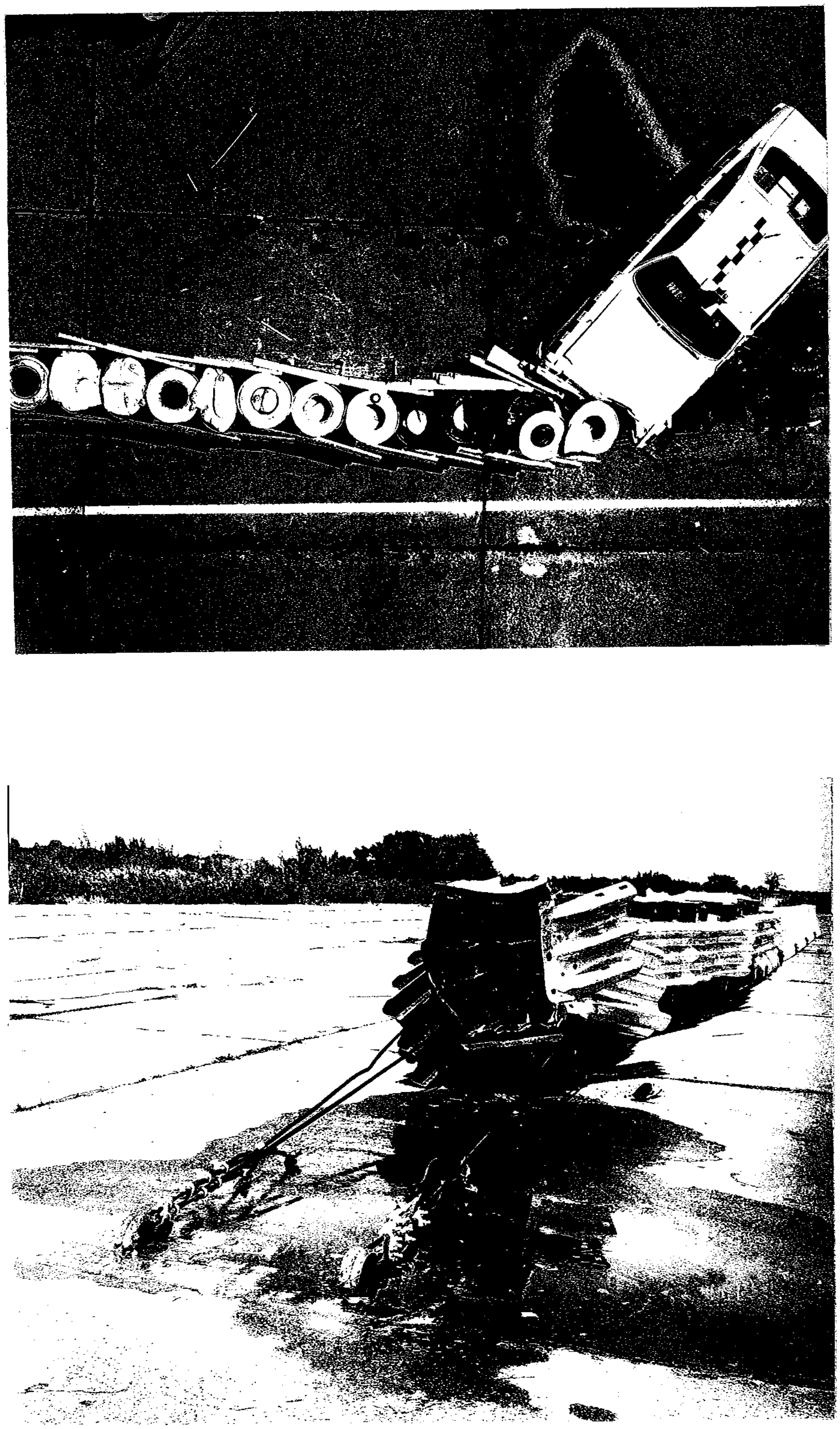


FIGURE 17. TEST INSTALLATION AFTER TEST 4.

CRASH CUSHION COSTS

Material costs and labor requirements for crash cushion fabrication and installation are shown in Table 3. Material costs were obtained through telephone bids and invoices for materials purchased during crash cushion construction. Labor requirements for fabrication were estimated from published productivity standards for industrial operations (5). Labor requirements for crash cushion installation were estimated from observations of installation of the tested appurtenance. Material and labor requirements for the pavement cable anchor were not included in Table 3 since anchors used in the field would differ significantly from that used in the test installation.

As shown in Table 3, total material costs for the narrow hazard crash cushion are approximately \$1,842.00. Similar costs for commercial crash cushions are approximately \$8,500.00. Also shown in this table is that total labor requirements for fabrication and installation of this crash cushion are less than 95 man-hours. If labor cost is \$15.00 per man-hour, total costs for the crash cushion would be approximately \$3,252.00. Thus, the initial cost of the narrow hazard crash cushion is approximately one-third of the cost of commercial crash cushions.

Estimates of repair costs for the test conducted are shown in Table 4. The average cost of repairing the barrier after the four tests was approximately \$650.00. In view of the severity of the test conditions, this repair cost must be considered low. Therefore repair costs for the crash cushion should be competitive with repair costs of other systems currently in use.

TABLE 3. CRASH CUSHION INSTALLATION COSTS

MATERIALS	TTI COST ($)
Steel Drums	66.00
Thrie Beam	694.00
Thrie Beam End Shoes	135.00
C4 x 5.4 Steel Channels	179.00
5/8" Steel Cable	161.00
Sand Bags and Sand	360.00
Miscellaneous	247.00
TOTAL	$1,842.00

LABOR REQUIREMENTS	MAN-HOURS
Shop Fabrication	55.0
Site Installation	39.0
TOTAL	94.0

Labor Cost @ $15.00/man-hr	$1,410.00
TOTAL CRASH CUSHION COST	$3,252.00

TABLE 4. CRASH CUSHION REPAIR COSTS

REPLACEMENT OF DAMAGED DRUMS	
Expendable Material Replacement	$7.10/drum
Shop Fabrication Labor (includes material salvage)	1.3 man-hr/drum
REPAIR OF END TREATMENT	
Test 1	
Material Replacement	$375.25
Labor	14.50 man-hr
TOTAL COST @ $15/MAN-HR	$592.75
Test 2	
Material Replacement	$127.80
Labor	38.9 man-hr
TOTAL COST @ $15/MAN-HR	$711.30
Test 3	
Material Replacement	$134.90
Labor	41.0 man-hr
TOTAL COST @ $15/MAN-HR	$749.90
Test 4	
Material Replacement	$ 99.40
Labor	30.2 man-hr
TOTAL COST @ $15.00/MAN-HR	$552.40

SUMMARY AND CONCLUSIONS

In recent years the concrete safety shape barrier has gained widespread acceptance. A nagging problem with this barrier has been the serious hazard to traffic posed by the end of the CSSB when it must be terminated within the "clear zone". There are currently no inexpensive end treatments available for the CSSB that are crashworthy for permanent installations and are suitable for use in narrow medians. Therefore a crash cushion has been developed to meet the following design criteria:

1. impact performance standards as outlined in NCHRP Report 230 dated March 1981;
2. suitable for use in narrow medians and for roadside applications;
3. relatively inexpensive to install and maintain; and
4. constructed of readily available materials.

The crash cushion, described in Figures 1 and 2, consists of a single row of steel drums with thrie beam plates and steel cables on each side. For head-on impacts, empty drums provide a yielding mechanism and sand-filled drums aid in smoothly decelerating an errant vehicle. Steel cables and inertia of sand-filled drums provide redirective capability for the cushion. The narrow hazard crash cushion is only slightly wider than the concrete safety shape barrier and can be used in narrow medians as well as on the roadside.

All materials used in the construction of this crash cushion are available commercially, and the components of the cushion can be shop-fabricated and field-assembled. Thus the installation and maintenance costs of this crash cushion should be significantly less than the commercial crash cushions currently employed to protect the end of the CSSB.

Successful crash tests as required by NCHRP Report 230 (3) have been conducted to verify the crashworthiness of the crash cushion. In the first test a large vehicle was smoothly redirected. In tests 2 and 3 large and small test vehicles impacted the crash cushion head-on and were smoothly decelerated to a stop. For these tests, all occupant risk values were below recommended levels (3).

The final test involved a small car impacting the nose of the device at 10 degrees. For this test the vehicle yawed approximately 45 degrees as it was smoothly decelerated to a stop. The longitudinal occupant impact velocity for this test was 39 ft/sec which is within maximum acceptable limits (4).

This crash cushion can be placed in narrow medians that could not be previously treated. The reduced cost associated with this cushion will allow placement of a safety treatment to become cost effective in more sites and allow the construction of more crash cushions than was previously possible. Therefore the narrow hazard crash cushion should improve the level of highway safety.

APPENDIX A

DATA ACQUISITION SYSTEMS

Instrumentation

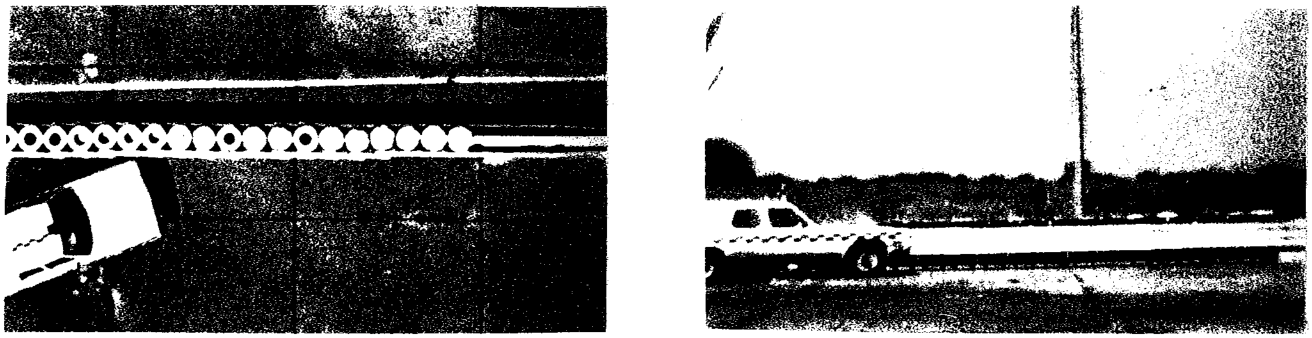
Test vehicles were equipped with triaxial accelerometers mounted near the center of gravity. Yaw, pitch, and roll were sensed by on-board gyroscopic instruments. The analog signals were telemetered to a base station for recording on magnetic tape and display on real-time strip chart. Provision was made for transmission of calibration signals before and after the test, and an accurate time reference signal was simultaneously recorded with the data.

Tape switches near the impact area were actuated by the vehicle to indicate elapsed time over a known distance to provide a quick check of impact speed, and the initial contact also produced an "event" mark on the data record to establish the instant of impact.

High-speed motion pictures were obtained from various locations, including overhead, to document the events and provide a time-displacement history. Film and electronic data were synchronized through a visual/electronic event signal at initial contact.

APPENDIX B

SEQUENTIAL PHOTOGRAPHS FROM HIGH-SPEED FILM



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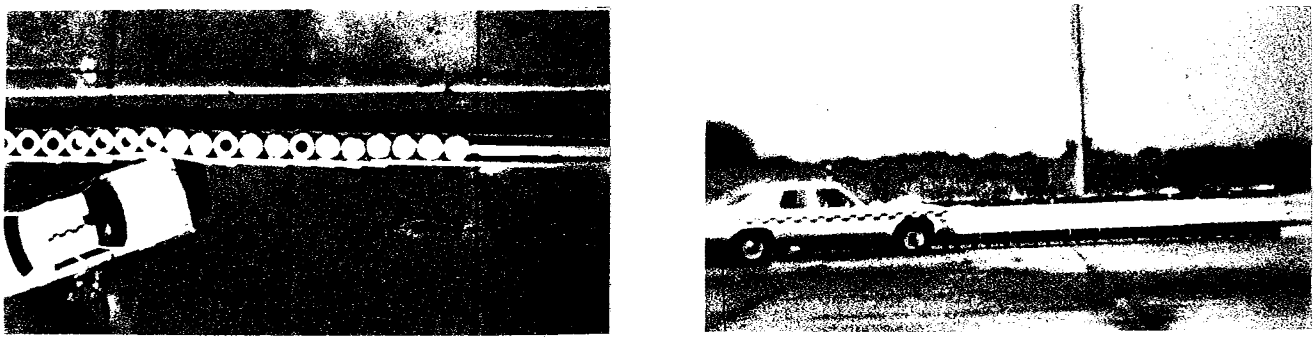

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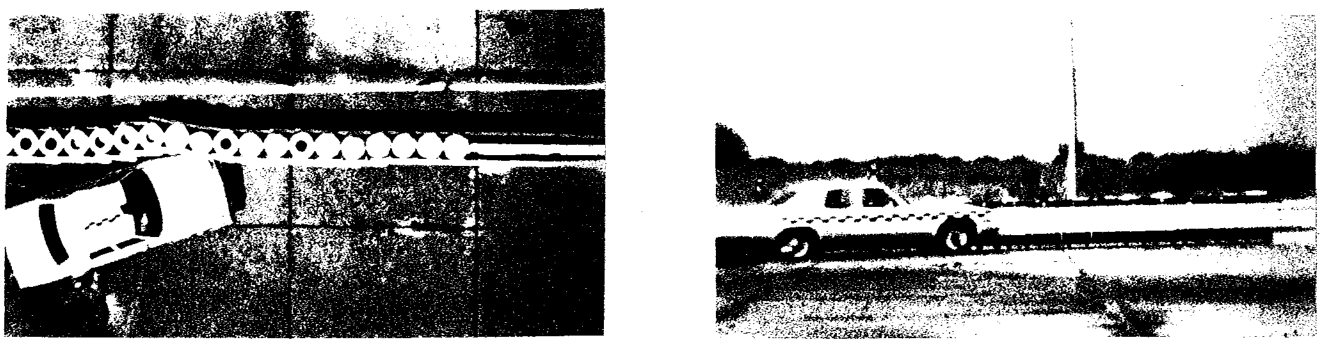

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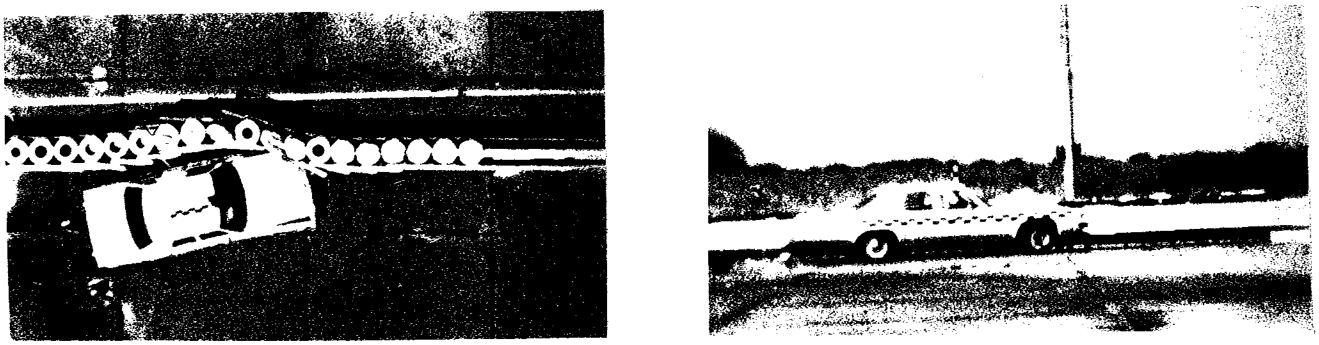
0.117 sec

FIGURE 18. SEQUENTIAL PHOTOGRAPHS FOR TEST 1.



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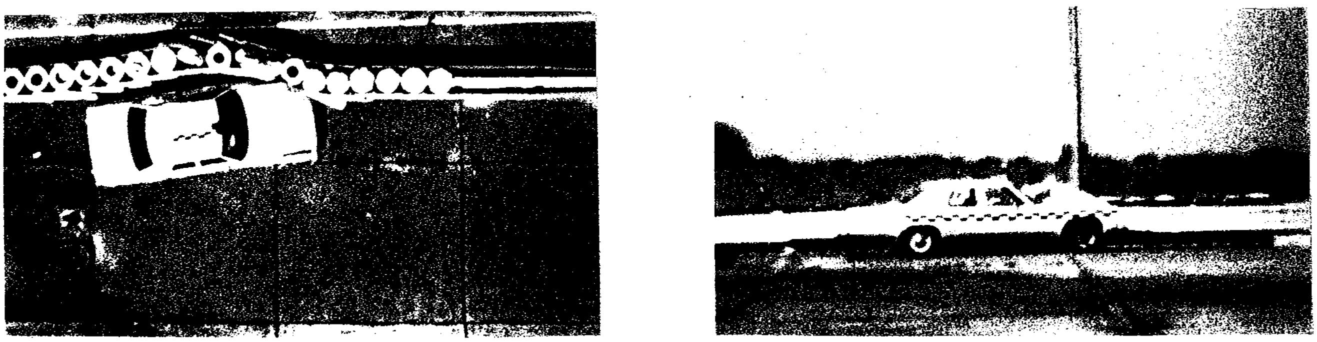

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0.272 sec

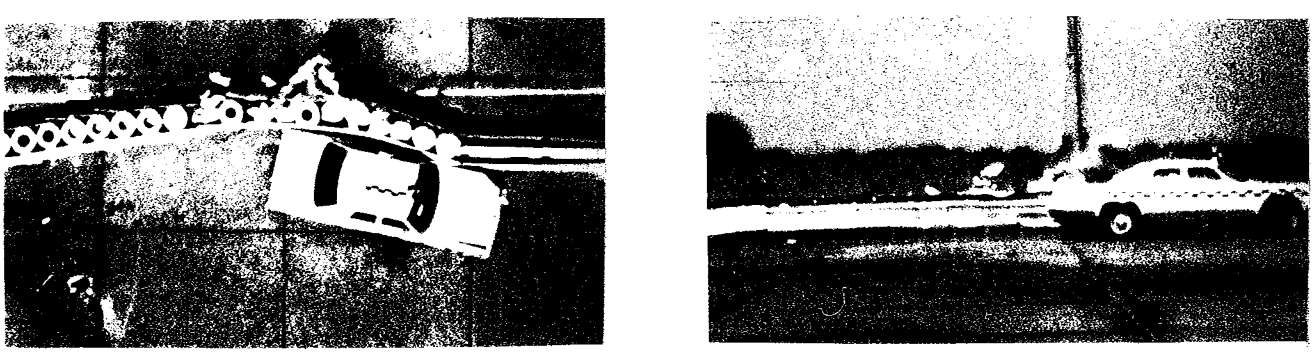

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FIGURE 18. SEQUENTIAL PHOTOGRAPHS FOR TEST 1. (con't.)

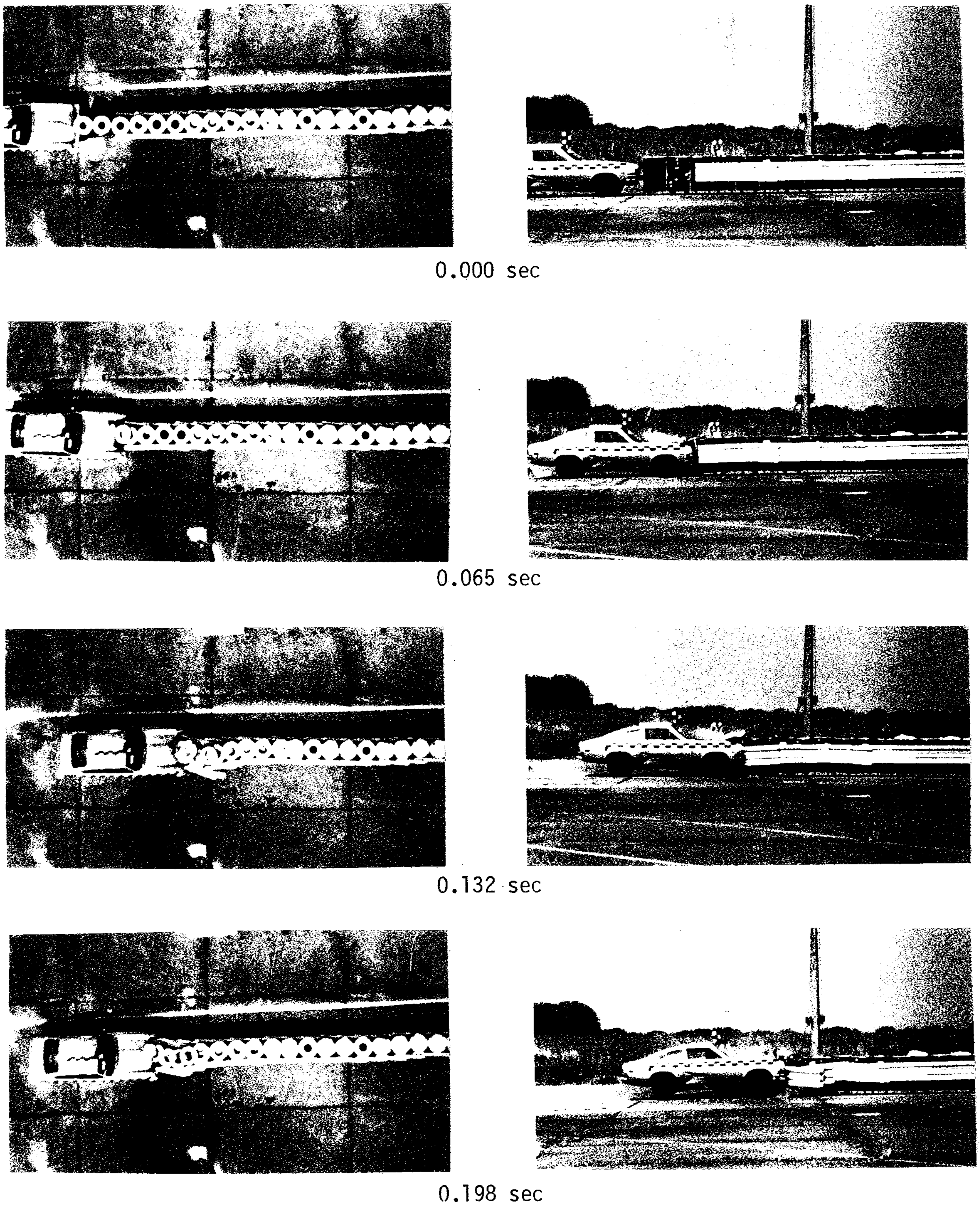
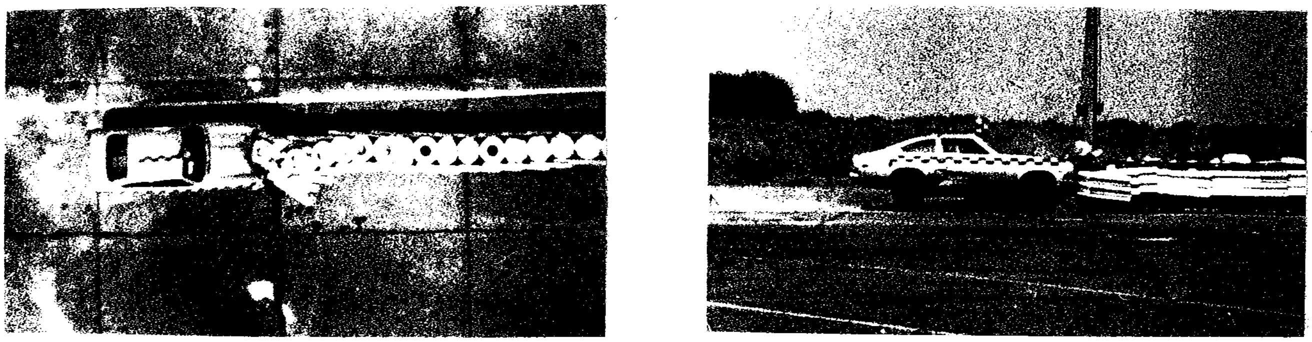


FIGURE 19. SEQUENTIAL PHOTOGRAPHS FOR TEST 2.



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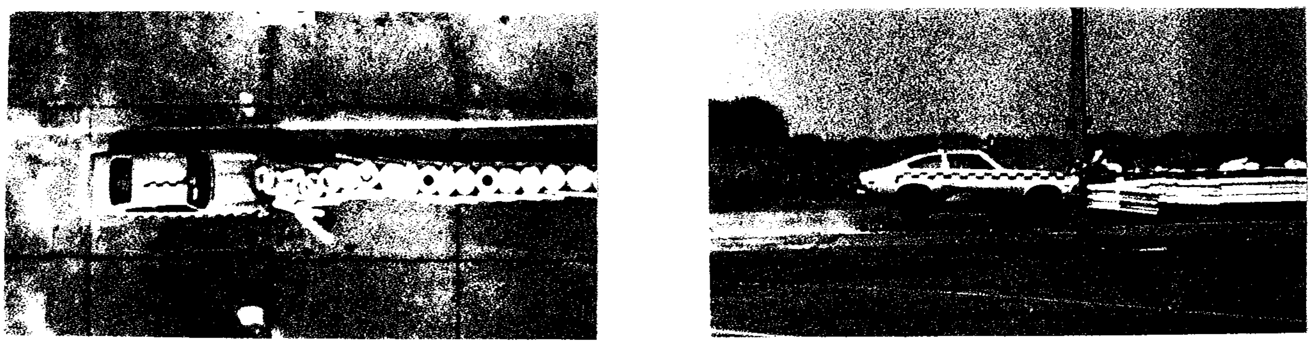

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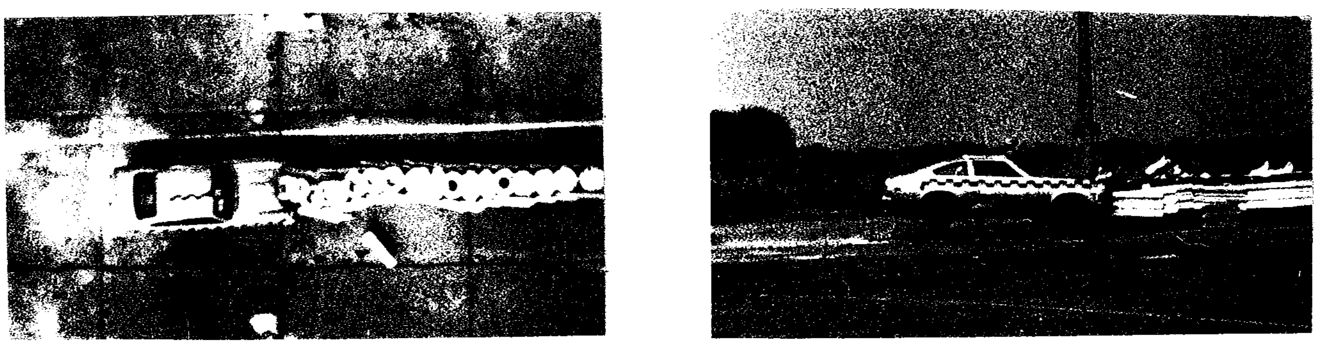

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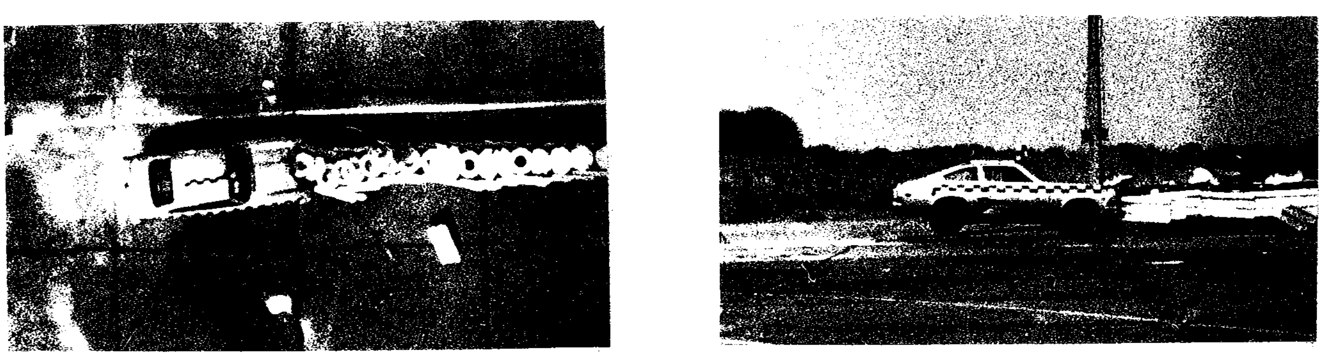

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FIGURE 19. SEQUENTIAL PHOTOGRAPHS FOR TEST 2. (con't.)

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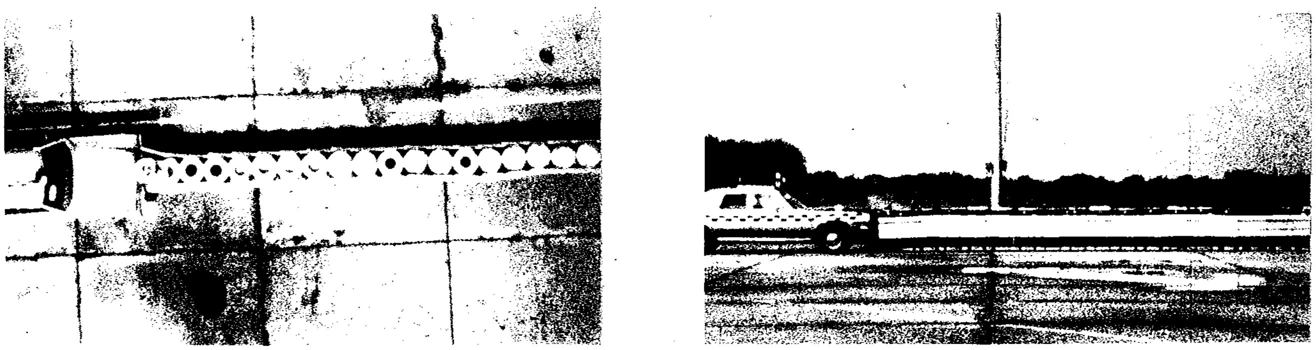

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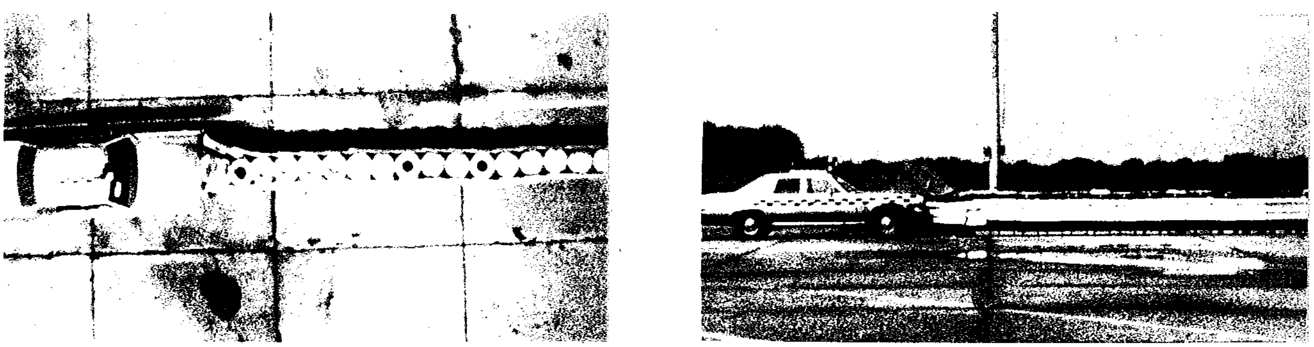

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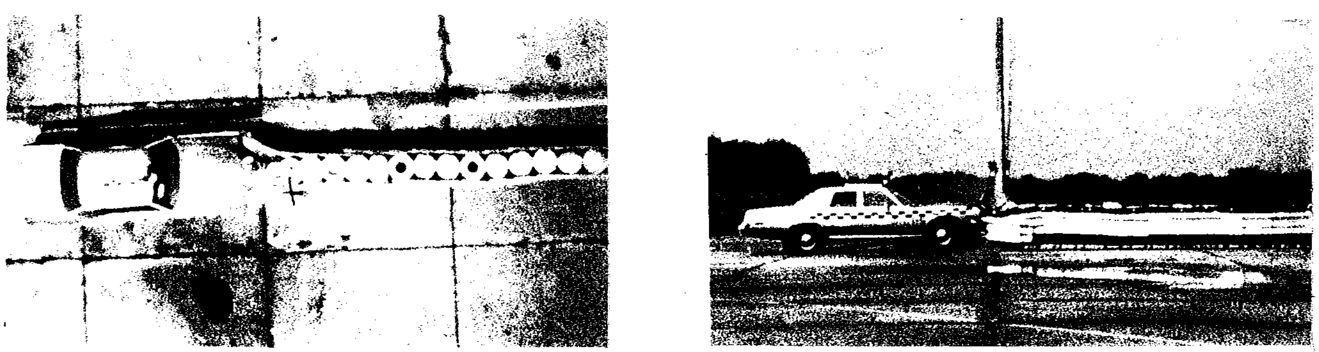

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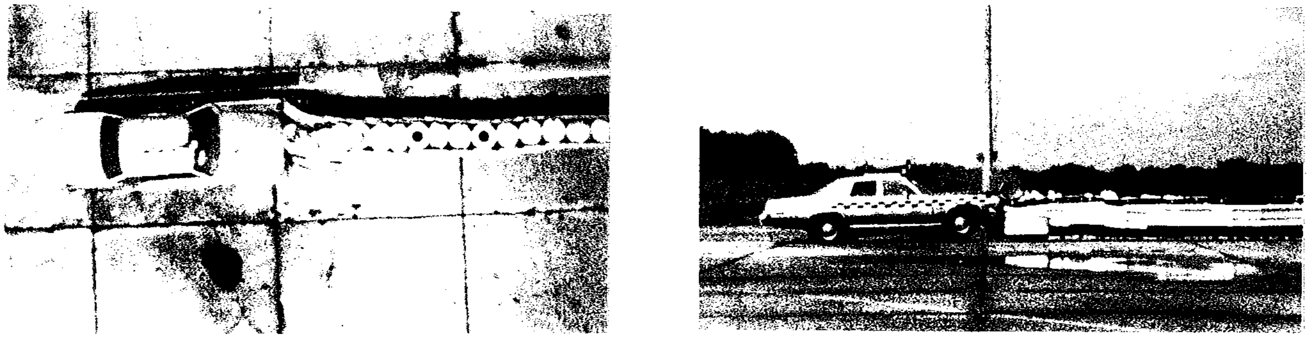
FIGURE 20. SEQUENTIAL PHOTOGRAPHS FOR TEST 3.



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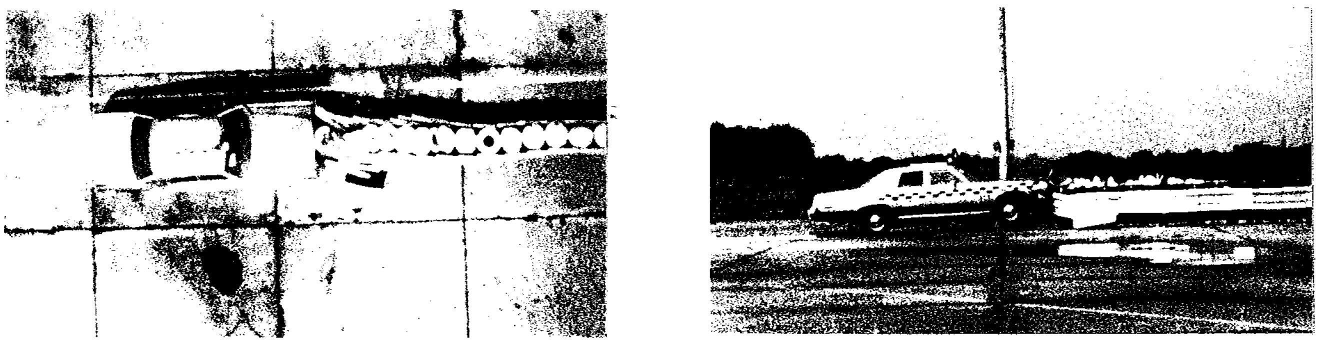

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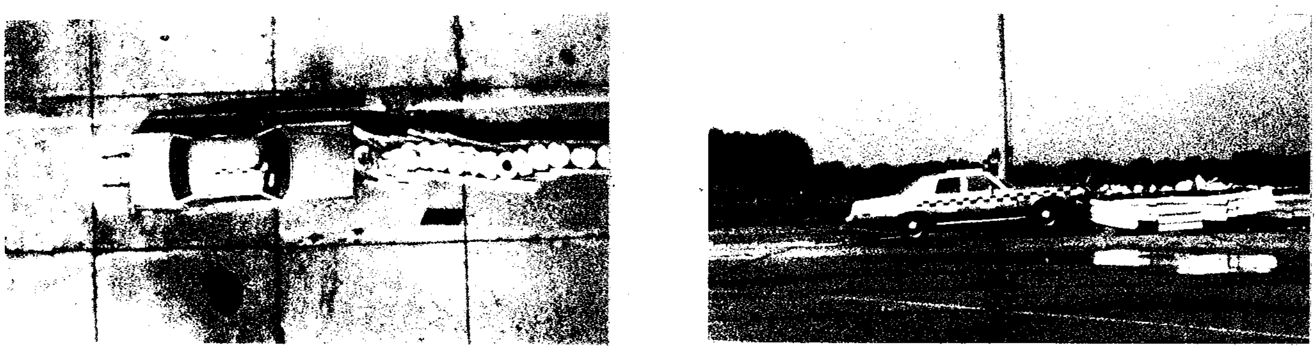

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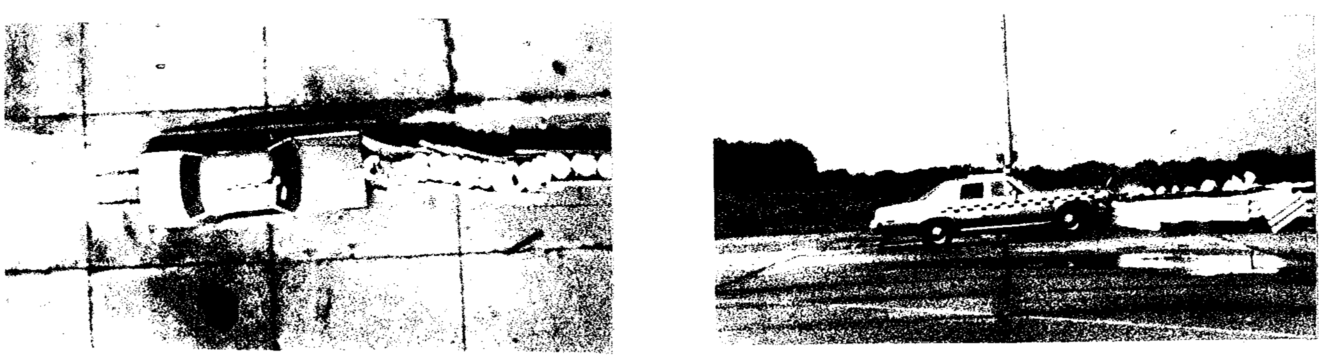

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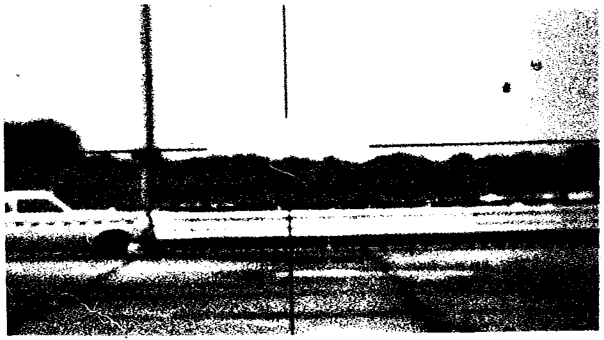
FIGURE 20. SEQUENTIAL PHOTOGRAPHS FOR TEST 3. (con't.)



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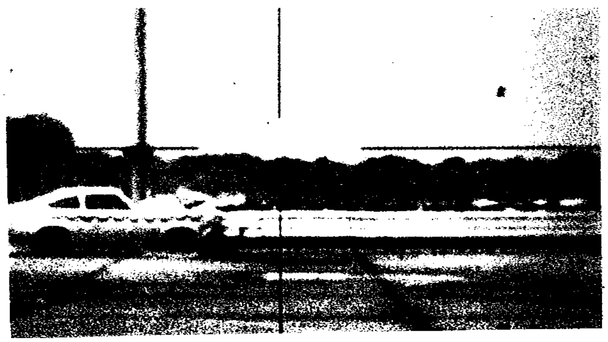

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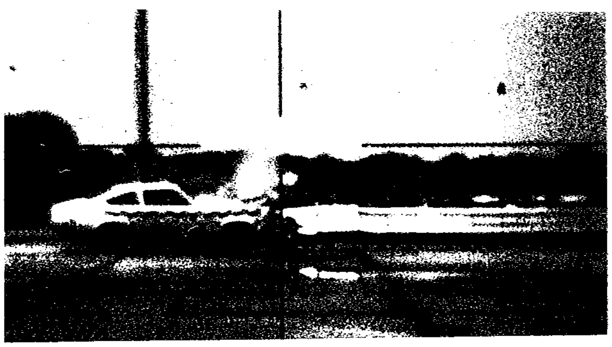

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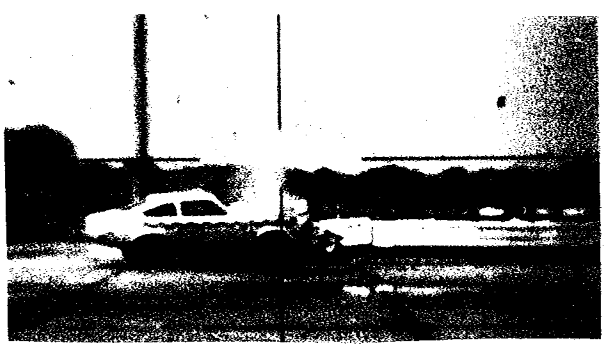

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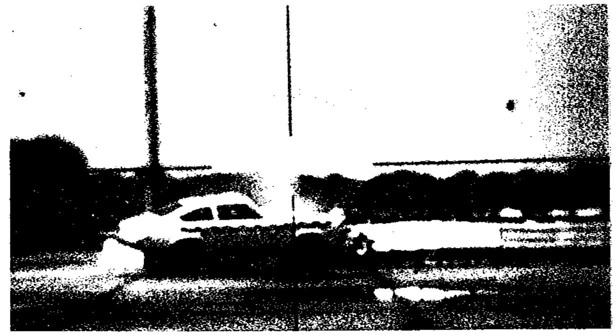

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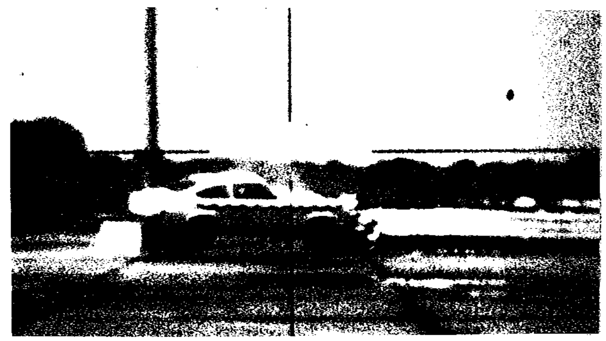

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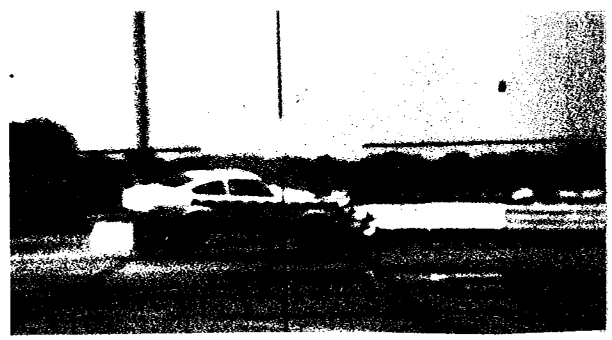

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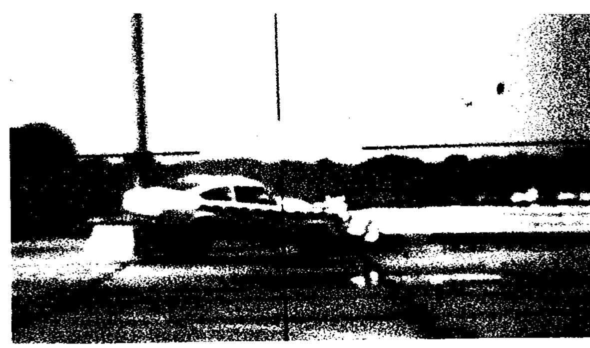

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FIGURE 21. SEQUENTIAL PHOTOGRAPHS FOR TEST 4.

APPENDIX C

ACCELEROMETER TRACES

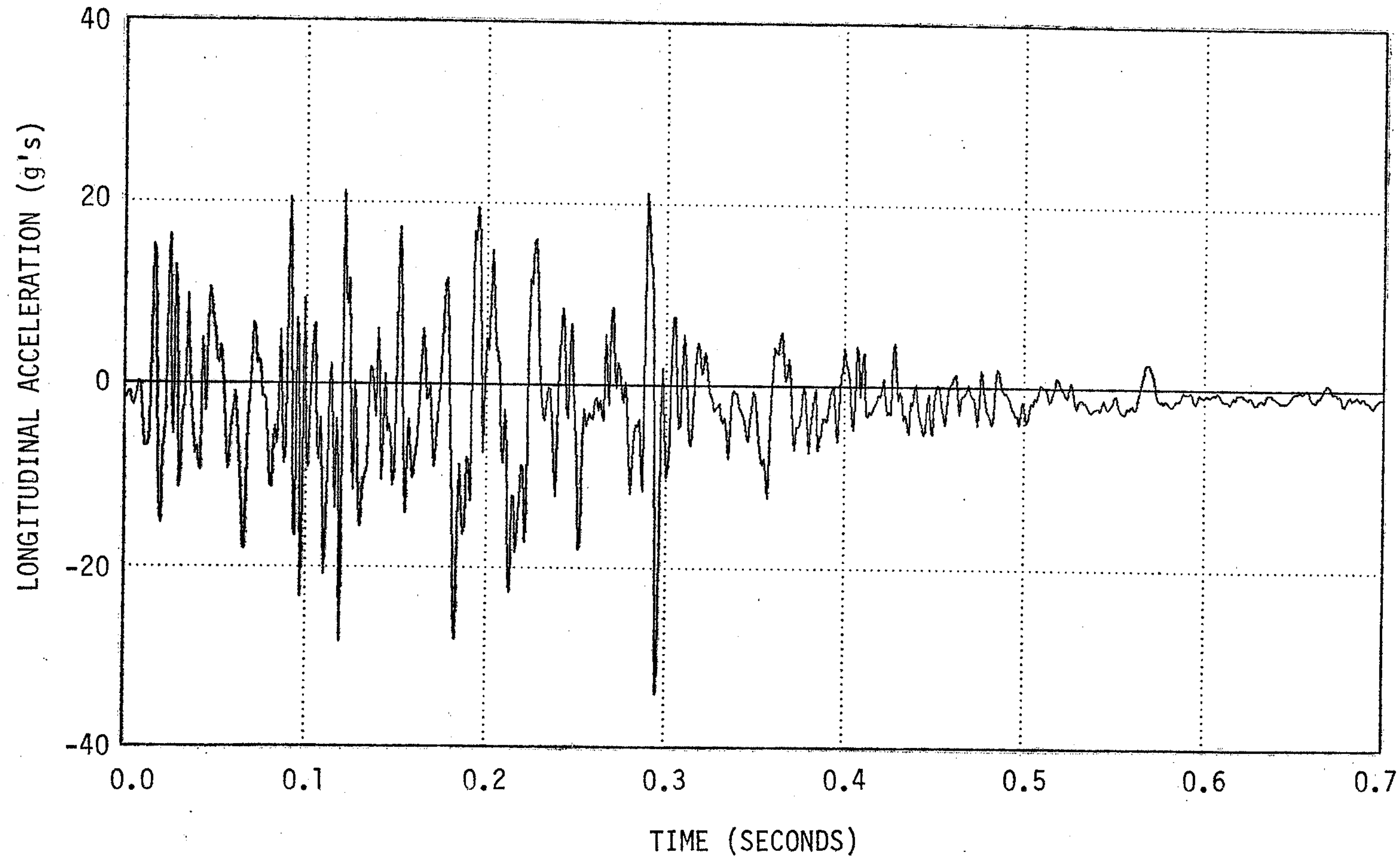

FIGURE 22. VEHICLE LONGITUDINAL ACCELEROMETER TRACE FOR TEST 1.

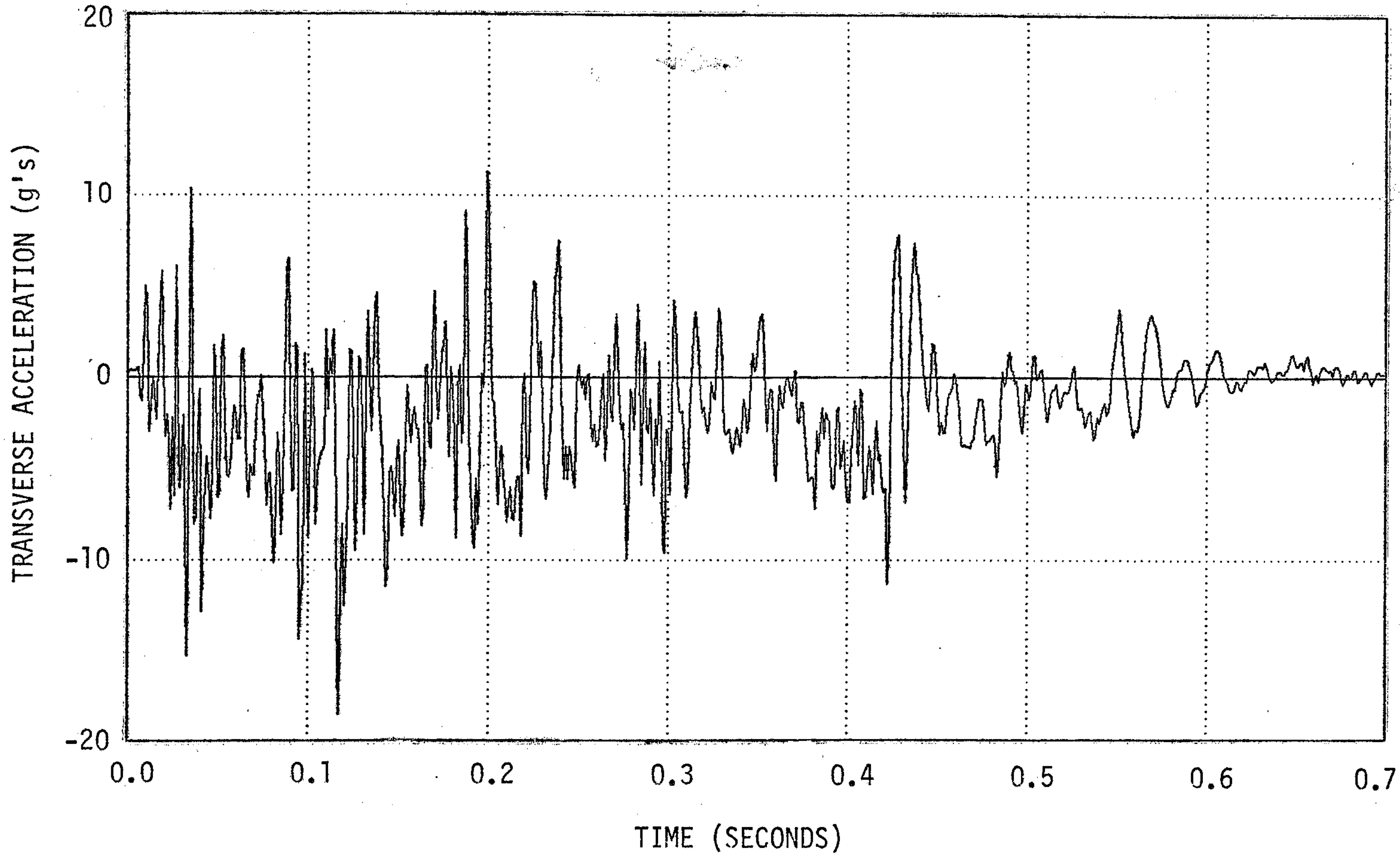

FIGURE 23. VEHICLE TRANSVERSE ACCELEROMETER TRACE FOR TEST 1.

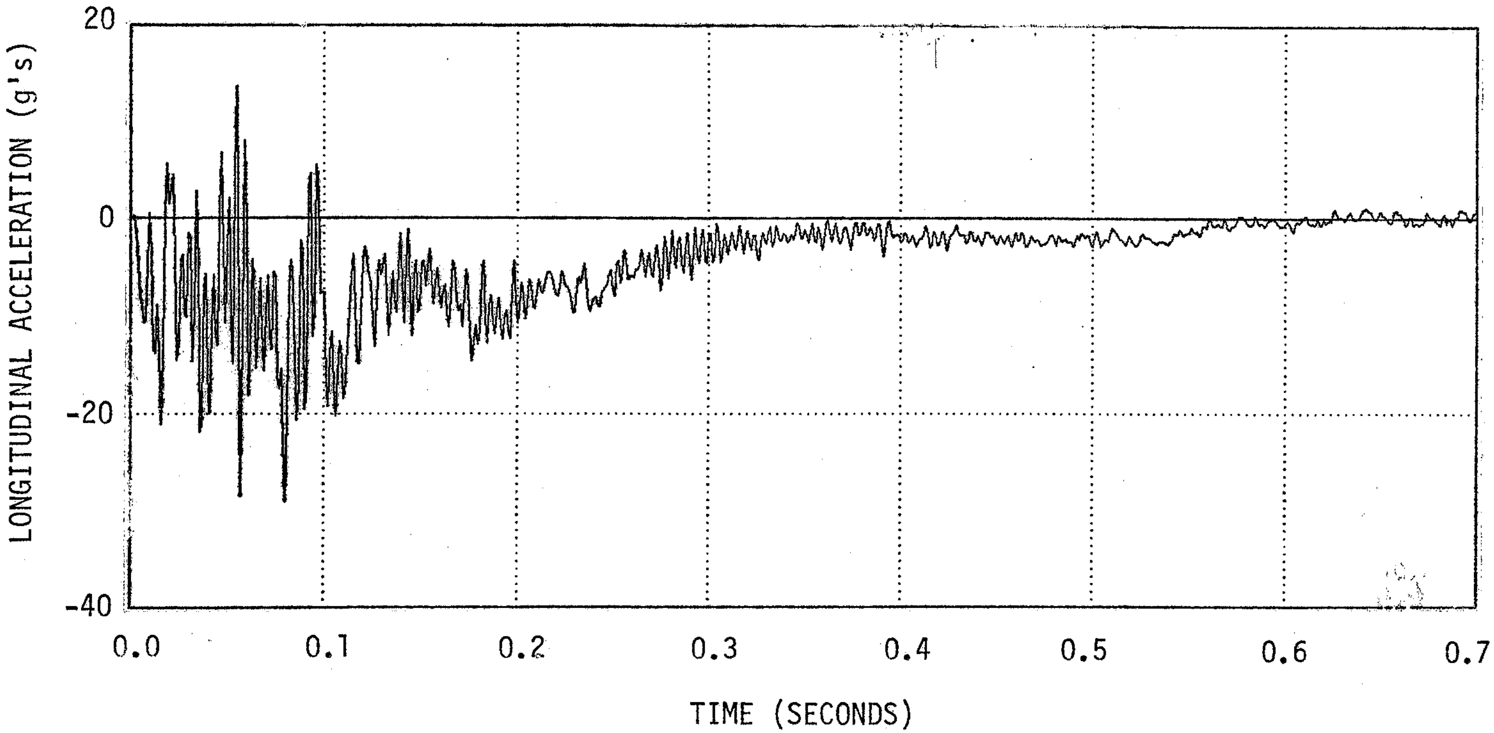

FIGURE 24. VEHICLE LONGITUDINAL ACCELEROMETER TRACE FOR TEST 2.

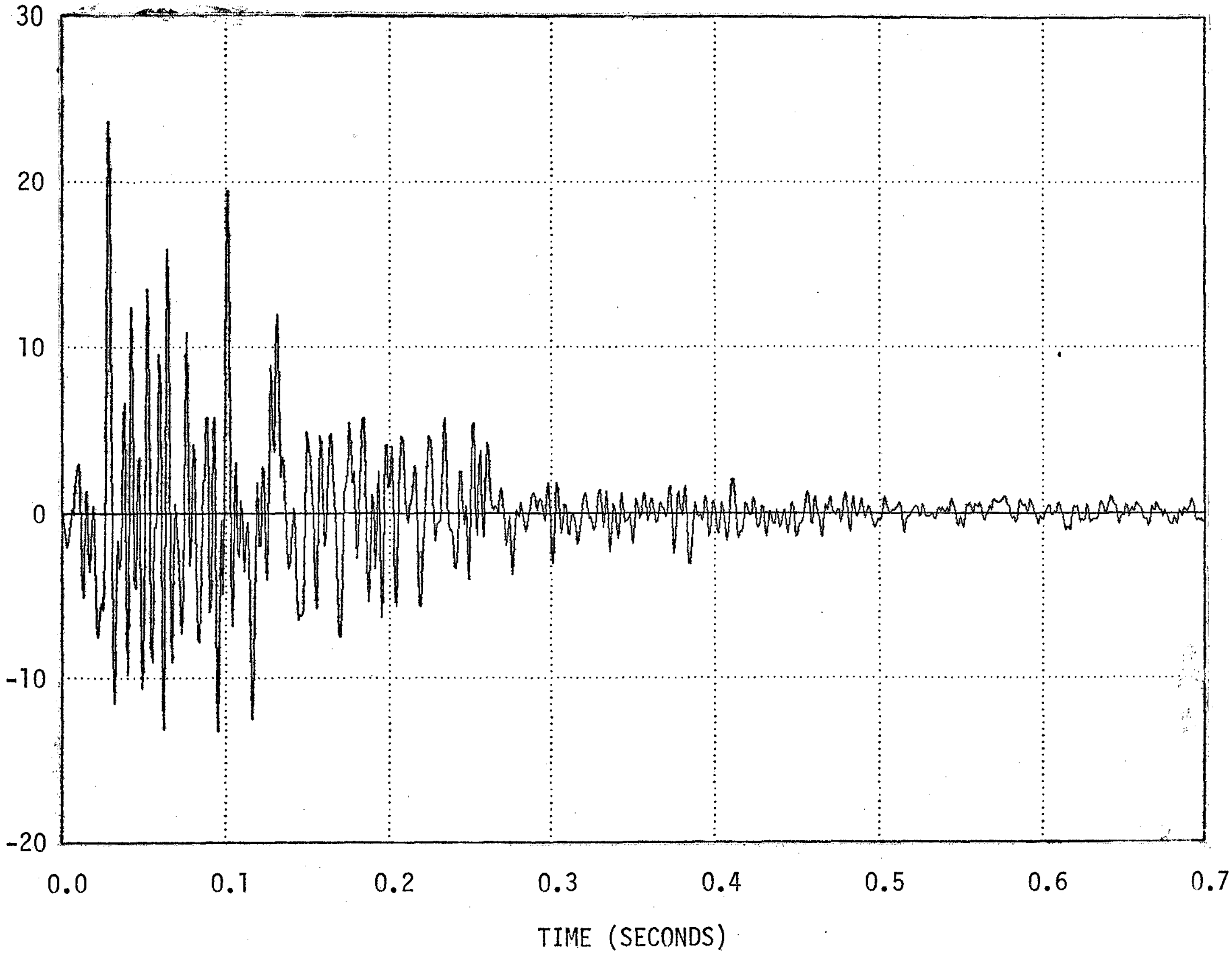

FIGURE 25. VEHICLE TRANSVERSE ACCELEROMETER TRACE FOR TEST 2.

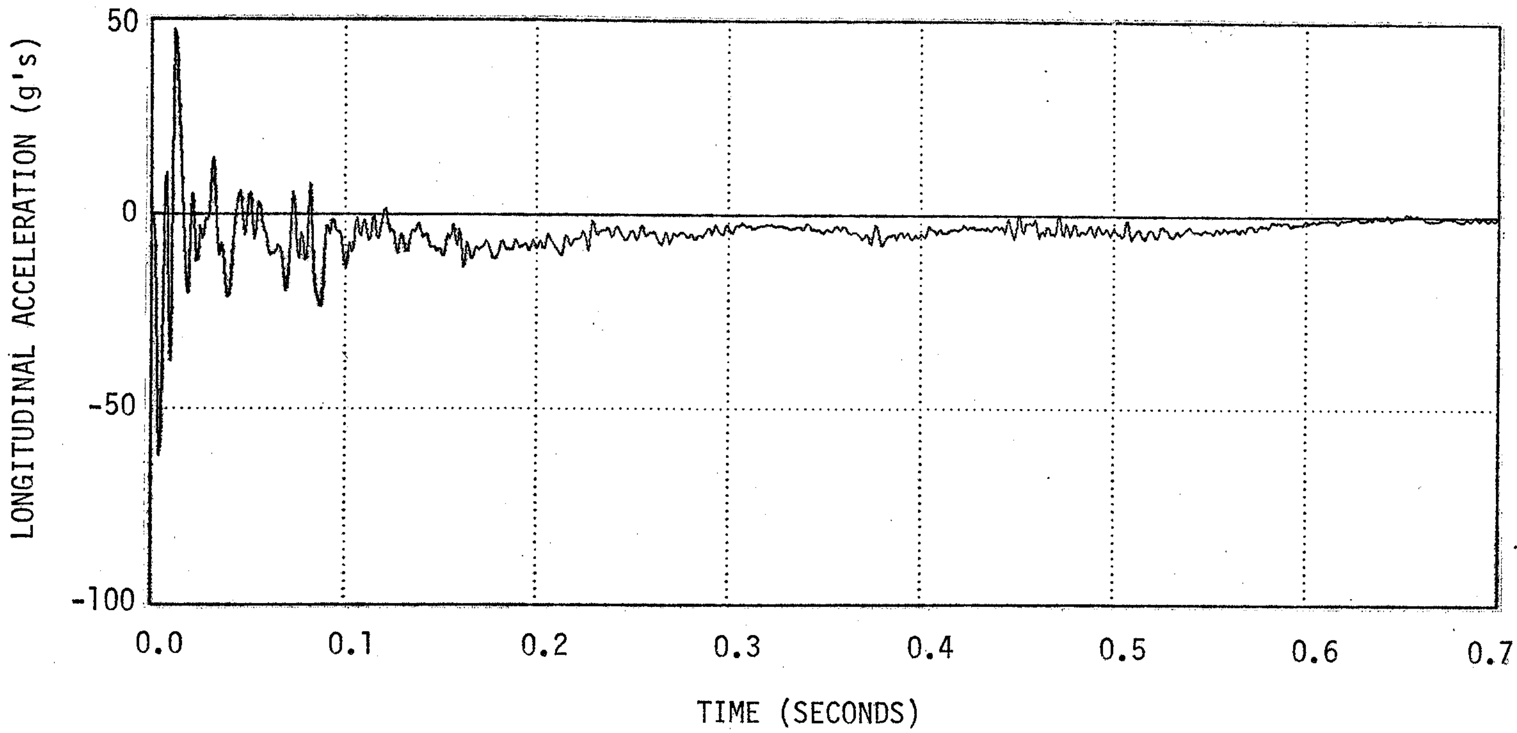

FIGURE 26. VEHICLE LONGITUDINAL ACCELEROMETER TRACE FOR TEST 3.

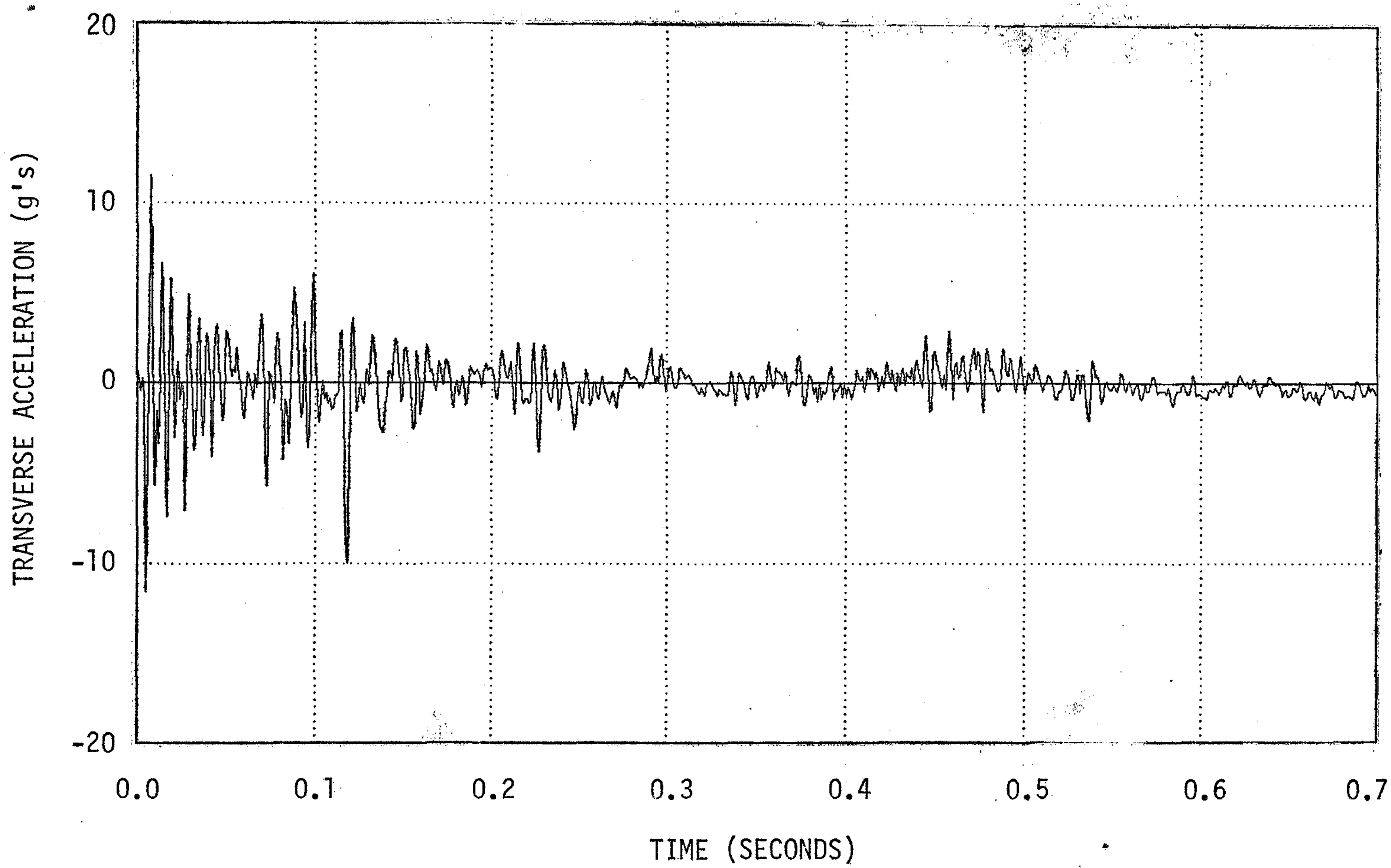

FIGURE 27. VEHICLE TRANSVERSE ACCELEROMETER TRACE FOR TEST 3.

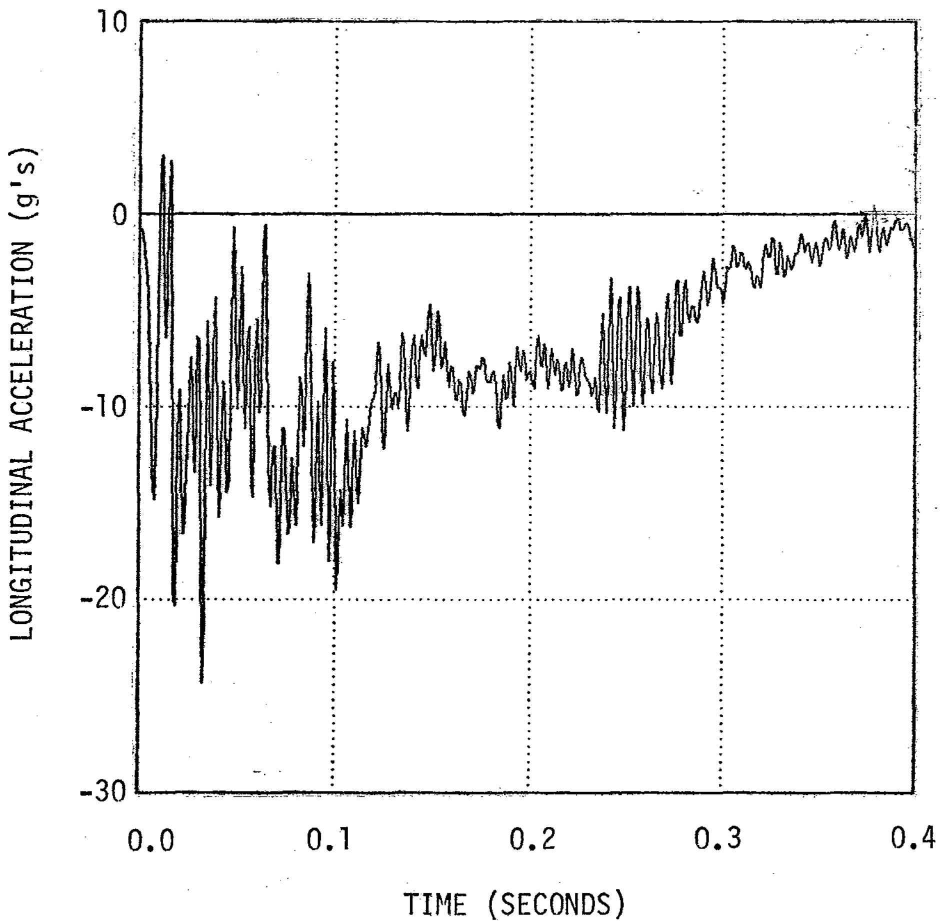

FIGURE 28. VEHICLE LONGITUDINAL ACCELEROMETER TRACE FOR TEST 4.

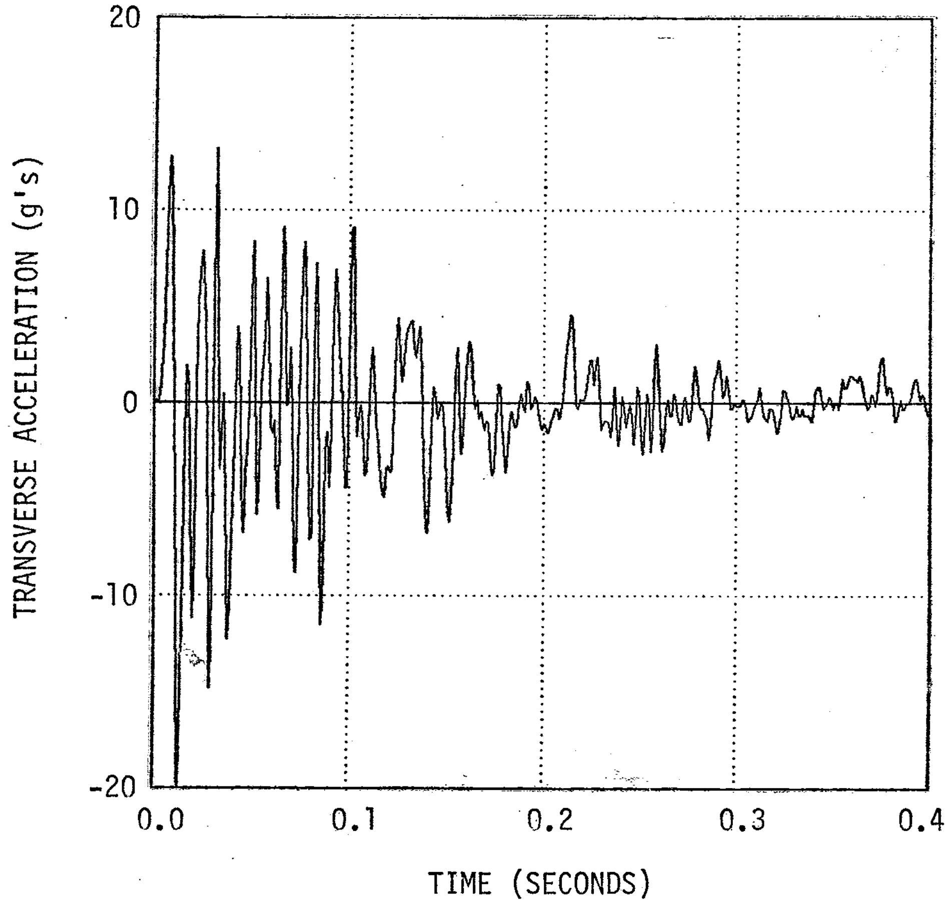

FIGURE 29. VEHICLE TRANSVERSE ACCELEROMETER TRACE FOR TEST 4.

REFERENCES

1. Sicking, Dean L. and Hayes E. Ross, Jr., "An End Treatment for Concrete Barriers Used in Work Zones," Research Report 2262-2, Texas Transportation Institute, Texas A&M University, August 1982.

2. Hirsch, T. J. and Ivey, D. L., "Vehicle Impact Attenuation by Modular Crash Cushion", Research Report No. 146-1, Texas Transportation Institute, Texas A&M University, June 1969.

3. Michie, Jarvis D., "Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances," National Cooperative Highway Research Program Report 230, March 1981.

4. "Recommended Procedures for Vehicle Crash Testing of Highway Appurtenances," Transportation Research Circular No. 191, Transportation Research Board, February 1978.

5. "Means Building Construction Cost Data," Robert Snow Means Co. Inc., Construction Consultants and Publishers, 100 Construction Plaza, Kingston, Mass. 02364.