DYNAMIC TESTS OF AN ENERGY-ABSORBING BARRIER EMPLOYING WATER-FILLED CELLS

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The results of four full-scale vehicle-impact tests into energy-absorbing barriers using water-filled plastic cells and cartridges are reported. This barrier absorbs the energy of an impacting vehicle through the movement of water horizontally as the barrier is shortened and vertically through orifices as the flexible water cells and cartridges are compressed. The recorded vehicle passenger-compartment decelerations indicated that, although unrestrained occupants would sustain moderate to severe injuries, in most cases, during 60-mph collisions with this barrier design, fully restrained (seat belt and shoulder harness) occupants would sustain little or no injuries during the majority of 60-mph impacts into the nose or side of the barrier. In addition, the barrier did not generate unstable vehicle behavior and, in conjunction with the bridge approach guardrail backstop, effectively redirected a vehicle impacting from the side. The overall barrier performance showed significant improvement over the concrete wedge-shaped deflectors currently in use in California on off-ramp gores.

•ACCIDENTS where vehicles ran off the road accounted for approximately 50 percent of the fatalities on the California freeway system during 1967 and 1968. More than 50 percent of the fatalities resulting from this type of accident involved collisions with fixed objects such as bridge abutments, bridge rail end posts, and large sign supports. Consequently, the California Division of Highways is now striving to provide a 30-ft wide recovery area alongside the traveled way free of unprotected fixed objects.

Providing protection for those fixed objects that cannot be removed or made "breakaway" has often been very difficult. One of the problems for which no satisfactory solution has been developed is providing protection from hazardous fixed objects located in the gore area at freeway off-ramps. Thus, the California Division of Highways has been involved in a research program for the last 2 years to develop energy-absorbing barriers for use in gore areas.

During 1967, 40 full-scale vehicle-impact tests of barriers incorporating water-filled cells were conducted and reported by Brigham Young University researchers (1). Based on the results of these tests and a few earlier unpublished tests by the original developer of this concept (John Rich Enterprises of Sacramento), the California Division of Highways undertook in 1968 a series of eight full-scale impact tests of barriers incorporating the water-filled cell concept. The results of the four tests of the second-generation barrier are reported here. The results of the four tests on the much less satisfactory first-generation barrier can be found elsewhere (2).

The California Division of Highways has also tested two other types of energy-absorbing barriers. The barriers utilized (a) 55-gal steel drums and (b) plastic drums containing sand. The results of the three tests of barriers using steel drums can be found elsewhere (3). The tests of the barrier using sand will be reported during the spring of 1971.

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OBJECTIVES

The primary objectives of this research were as follows:

1. Test the ability of a barrier incorporating water-filled plastic cells to decelerate a 4,700-lb vehicle impacting at speeds up to 60 mph such that (a) the maximum average 40-millisecond (msec) deceleration sustained by the vehicle passenger compartment is no more than 12 g, and (b) the vehicle does not ramp, roll, or spin out in a manner that will result in additional damage to it, injury to its occupants, or hazards to oncoming traffic because of its final position.
2. Generate barrier modifications dictated by the barrier behavior during the tests to decrease the decelerations sustained by the vehicle, minimize the amount of barrier debris created during a collision, and minimize the on-site repairs that would be required to return the barrier to service.

DESCRIPTION OF TEST PROCEDURE

All four tests were conducted on a section of runway at an airport near Lincoln, California. The vehicles used for this series of tests were 1968 Dodge sedans weighing about 4,700 lb, including dummies and instrumentation, that impacted the barrier on the nose and side at speeds near 60 mph. Control of the vehicles was accomplished by a remote operator following 200 ft behind the test vehicle in a car equipped with a tone transmission system. A "trip line" placed in the vehicle path cut off the ignition just prior to impact. A study by Nordlin, Woodstrom, and Hackett (4) contains a description of this control equipment.

The test barriers were 19 ft 6 in. long and incorporated rows of flexible water-filled plastic cartridges placed between plywood panels oriented perpendicular to the barrier axis. Fiberglass-coated plywood diaphragms were used for every fourth panel. Overlapping fiberglass-coated plywood fender panels were attached to each end of each diaphragm so that they would telescope during head-on impacts but redirect a vehicle if oblique-angle impacts occurred. Lateral restraint was provided by two $^7/_8$-in. diameter main cables plus two $^3/_8$-in. diameter secondary cables.

All the tests were recorded with high-speed (250 to 400 frames per second), motor-driven Photosonic cameras that were manually actuated from a central control console. These cameras were located on both sides of the barrier and on a 30-ft light standard directly above the point of impact. Another Photosonic camera was located in the vehicle passenger compartment to film the movement of the dummies. This camera was started by means of a pin-actuated switch mounted on the rear bumper of the test vehicle.

A motor-driven Hulcher camera with a speed of approximately 20 frames per second was located on scaffolding and provided documentary coverage of the tests. High-speed and normal-speed cameras were hand-panned through impact. Still photographs, slides, and documentary movies of the test barrier and vehicle were also taken.

TEST RESULTS

The barrier used and its modifications are described in the following sections for each of the four tests reported. The primary variables were the impact speeds of the vehicles and the angles and locations of impact into the barrier. Table 1 gives these impact conditions.

TABLE 1

TEST PARAMETERS

Test No.	Impact Speed (mph)	Location on Barrier of Impact	Angle With Barrier Axis of Impact
215	57.5	Nose	Head-on
216	61.8	Nose	Head-on
217	57.0	Side[a]	9 deg
218	59.2	Nose	8 deg

[a]13 ft behind the nose.

The decelerations included in the descriptions of each test are averages of the highest average decelerations sustained by the vehicle passenger compartment or the dummy over a 50-msec period unless otherwise noted. These measurements were taken using Statham strain-gage accelerometers mounted on the vehicle floor and on the back of the dummy. The deceleration curves are given in another study by the authors (2). A discussion of the processing and interpretation of these types of data is included elsewhere (3).

The effect of the measured vehicular decelerations was interpreted using the tolerance limits given in Table 2. Injury severity predictions are related only to the direction of deceleration that appears to be most critical (i.e., no vectorial addition of deceleration was accomplished). A discussion of deceleration tolerances and the reasoning behind the choice of these values is given elsewhere (4). These limits define what would be, in the opinion of the authors, a survivable environment under almost all circumstances.

TABLE 2
DECELERATION LIMITS

Occupant Restraint	Lateral	Longitudinal	Total
Unrestrained	3	5	6
Seat belt	5	10	12
Seat belt and shoulder harness	15	25	25

Note: Measured in g in passenger compartment—highest 50 msec average.

Test 215

Barrier Description—The overall dimensions of the test barrier used in test 215 were a 19-ft 6-in. length, a 3-ft width at the nose, and a 7-ft width at the back of the barrier (Fig. 1). The basic module of the barrier consisted of four rows of cells contained by $1\frac{1}{2}$-in. fiberglass-coated plywood diaphragms; there were eight modules in the barrier plus a cluster of cells at the nose. Between diaphragms, the rows of cells were separated by a $\frac{1}{2}$-in. interior panel of Duraply plywood. There were three to five water-filled cartridges in each row (Fig. 2). Along the sides of the barrier, fender panels of $1\frac{1}{4}$ in. fiberglass-coated plywood were hinged to each diaphragm at the noseward side of the panel (Fig. 3). The length of these fender panels was such that they overlapped. Thus, backward movement (compression) of the barrier was not hindered. The back sides of the fender panels were attached with springs to the next rearward diaphragm. Fiberglass was used to provide not only additional strength but also a low-friction surface between the fender panels and the impacting vehicle. These fender panels were developed for the purpose of redirecting vehicles that impacted the side of the barrier without permitting pocketing into the barrier.

The cartridges used in the eight modules (126 total) were made of a thin vinyl-coated nylon fabric and were 24, 30, and 36 in. long (Figs. 3 and 4). Their outside diameter was $5\frac{1}{2}$ in. These cartridges were slipped through $\frac{1}{4}$-in. thick vinyl supporting rings that were fastened to the interior panels or diaphragms. The water-filled cells used in the nose of the barrier (18 total) were 6 in. in diameter, 41 in. long, and consisted of $\frac{1}{4}$-in. thick vinyl walls.

The nose cells and the cartridges both had solid vinyl evaporation caps permanently attached with aluminum pop rivets. All the cartridges were filled with water, but only 6 of the 18 nose cells contained water.

Figure 1.

Figure 2.

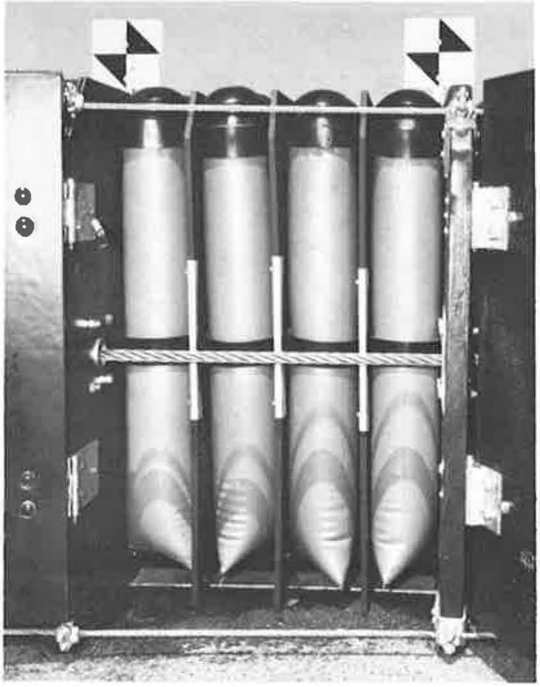

Figure 3.

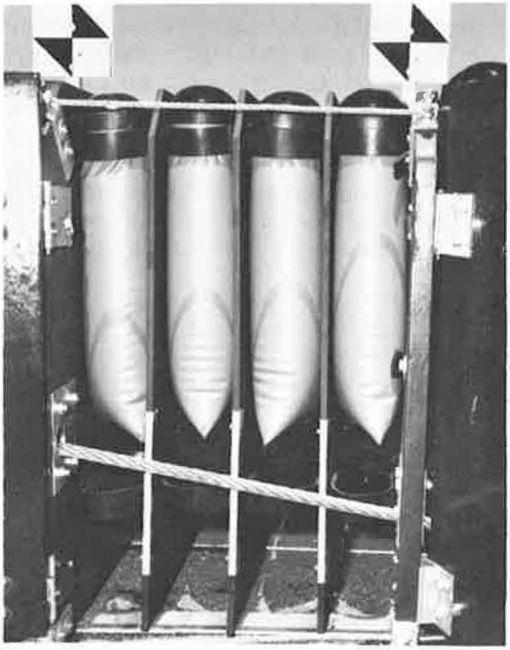

Figure 4.

The third module back from the nose of the barrier contained no cells or cartridges. The developers advised the use of this empty, or void, space for better dynamic response of the barrier (6). The theoretical effect of the void bay is shown in Figure 20 of the Appendix.

Wire ropes were used to stabilize the entire barrier. Two parallel ⅞-in. preformed galvanized 6 by 19 wire ropes with independent wire cores extended from steel plates attached to a concrete anchor block in front of the barrier nose back through fabricated steel guides in the diaphragms to the backup bridge rail at the rear of the barrier. These cables were designed to give the barrier lateral and vertical stability and limit pocketing during side-angle impacts. Two secondary cables of ⅜-in. wire rope were used to stabilize the barrier nose during a side-angle impact (Fig. 5). They were attached to the anchor block and the first diaphragm; each cable anchor attachment included a pin that would shear when subjected to a 4,000-lb load. After the barrier had been

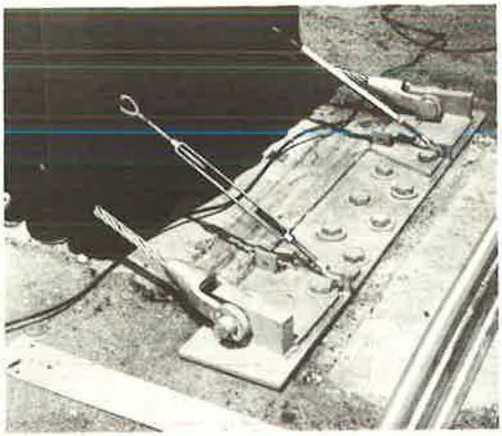

Figure 5.

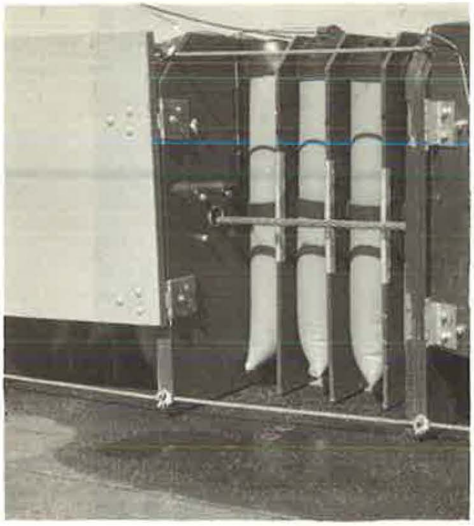

Figure 6.

compressed due to an impact, 3/8-in. wire ropes were used to stretch out the barrier and reposition it. These wire ropes were attached to the upper and lower corners of each end of each diaphragm (Fig. 6).

Diaphragms 6 and 7 contained two 1/4-in. steel plates in addition to the 1 1/2-in. fiberglass-coated plywood. Diaphragm 8 consisted of two 1/4-in. steel panels and one 12-gage steel sheet. This additional weight was also suggested by the developer to improve the barrier's dynamic response (6).

The test barrier required a rigid backup structure. Thus, a bridge approach guardrail nose structure typical of a gore installation was constructed. In addition, a fabricated steel plate backup panel was attached to the nose of the bridge rail to provide a large bearing area for the barrier during impact (Fig. 7). (See Figs. 21 and 22 in the Appendix for additional barrier details.)

Results of Test 215—Figure 23 in the Appendix shows a summary of the test results. The 1968 Dodge impacted the barrier head-on at a speed of 57.5 mph. As rearward displacement of the barrier began, the fender panels rotated downward so that their lower rear corners penetrated into the asphalt concrete runway and restricted barrier compression. This, plus an 18-in. vehicle offset at impact, resulted in a lifting, rolling motion being imparted to the test vehicle. The vehicle traversed a 360-deg roll off to the right side of the barrier and came to rest several feet behind and to the right of the barrier (Fig. 8). Front-end crush varied from 0 to 20 in.; maximum crush was on the left side (Appendix Fig. 24). The top caved in, the windshield was broken, the left-

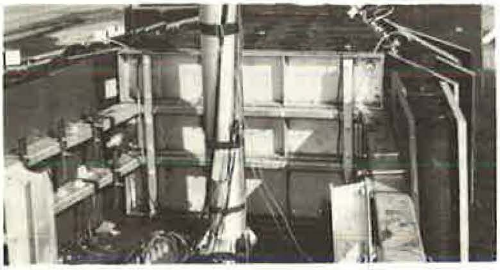

Figure 7.

Figure 8.

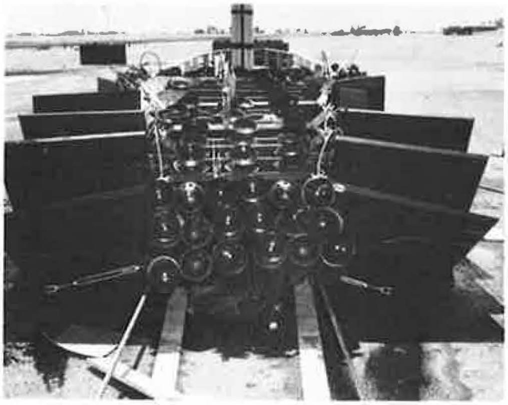

Figure 9.

rear wheel was bent, the left-rear door was jammed, and there were scrapes over much of the surface of the vehicle.

The barrier itself remained intact (Fig. 9). However, some damage was sustained as many of the fender panels were scarred, and most were damaged on the rear-bottom corners where they were thrust into the ground as the barrier was compressed (Fig. 10). The edges of several diaphragms were broken or showed delamination of the plywood; hinges between fender panels and diaphragms were bent or broken in several locations. Damage was less severe toward the rear of the barrier. There was no damage to the steel backup structure. Static barrier displacement was 9.3 ft.

Data From Instrumentation—An instrumentation system on loan from the Federal Highway Administration was used for test 215 and the succeeding tests (7). This system (the Wyle system) consisted of seven channels of FM telemetry for use on the barrier. The system included seven accelerometers and two seat-belt force transducers and all the necessary signal-conditioning equipment for their use. The dynamic data from these transducers were recorded on a 14-channel analog magnetic tape recorder.

In addition to the FHWA system, there were six channels of data transmitted through a Visicorder oscillograph. However, this did not produce usable results. The data included results from load cells on the two ⅞-in. cables and four pressure transducers in selected cartridges. (See Figs. 25 and 26 in the Appendix for the locations of the instrumentation.)

The maximum compressive stress in the bridge approach guardrail tubular members was 4,500 psi. Maximum seat-belt load for the dummy driver was 513 lb; maximum load on the dummy's chest was 470 lb.

The peak vehicular decelerations were 10 to 12 g in the longitudinal direction. The highest 50-msec average vehicle deceleration (longitudinal) was 7.0 g (average of two accelerometers). Thus, in most cases unrestrained vehicle occupants would have sustained minor to moderate injuries under this longitudinal deceleration; restrained occupants would probably have sustained little or no injuries. The peak longitudinal deceleration for the dummy was more than 25 g; the lateral and vertical decelerations were 10 to 12 g. These decelerations were sustained for relatively short 5-msec periods.

Figure 10.

Test 216

Barrier Description—In test 216, the barrier used for test 215 was modified by cutting off the lower 6 in. of all the fender panels and cutting the lower rear corner of the panels on a diagonal to eliminate penetration of these trailing corners into the runway, as had occurred during test 215 (Figs. 11 and 12). Also, metallic shoes (or skids) were added to the lower edge of interior panels, heavier hinges were used to attach the fender panels to the diaphragms, and all the evaporation flaps were removed to lessen, at least to some extent, the lateral discharge of the water and danger of loss of telemetry signal.

Figure 11.

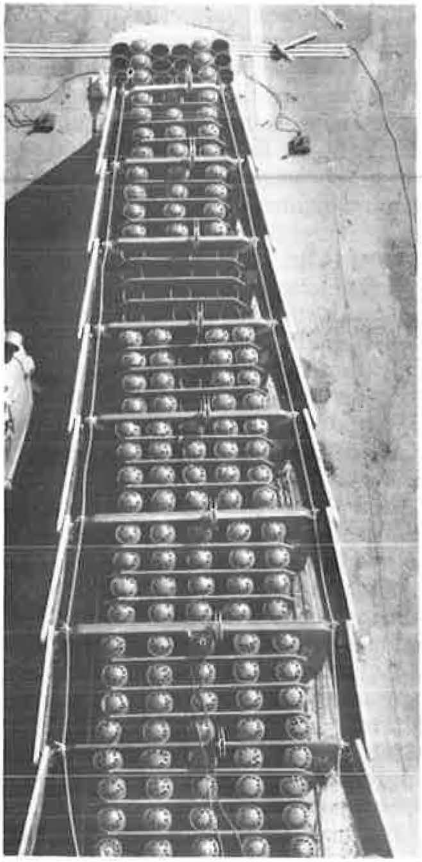

Figure 12.

Results of Test 216—Figure 27 in the Appendix contains a summary of the test results. A 4,690-lb 1968 Dodge impacted the barrier head-on at a speed of 61.8 mph. Deceleration of the impacting vehicle was relatively smooth and the vehicle remained stable. Vehicle rise was a little more than 1 ft.

The maximum crush of the vehicle forestructure was 20 in.; it occurred at the center of the vehicle (Fig. 13; Appendix Fig. 24). Buckling of the car body was indicated by a crimp in the roof over the door post on both sides of the car. The engine deflected the firewall back 1 to 2 in. Steering wheel deformation was 1¼ in. The steering column collapsed 2.9 in.

Fender panels on the left side of the first three modules were scarred. The bottoms or top inserts or both were blown out of 16 cartridges. The barrier moved straight back with negligible lateral movement or buckling. Maximum vehicular displacement of the barrier was 16.3 ft, but the at-rest displacement of the barrier nose was only 10.7 ft (Fig. 14).

Figure 13.

Figure 14.

Data From Instrumentation—Instrumentation was nearly identical to that used for test 215 (Appendix Figs. 25 and 26).

The maximum pressure transducer reading from the cartridges was 110 psi. The maximum loads on the two ⅞-in. wire ropes were 14,750 lb on the left and 18,750 lb on the right. The bridge-approach guardrail experienced compressive stresses from 3,060 psi on the bottom left to 12,200 psi on the top left. Seat-belt loads up to 533 lb were measured for the dummy driver along with a maximum chest load of 530 lb.

The vehicle longitudinal deceleration included three distinct 5 to 10 msec peaks. The highest 50-msec average vehicle deceleration (longitudinal) was 9.8 g. Thus, moderate to severe injuries would be sustained by unrestrained vehicle occupants in most cases. Little or no injury would be sustained by restrained vehicle occupants. These magnitudes and the general shape of the curve are in excellent agreement with those reported by the Texas Transportation Institute for a 64-mph, head-on impact of a 4,650-lb vehicle (8).

The longitudinal dummy trace had a shape very similar to that for the vehicle except that the peaks were higher (above 14 g for 5 to 10 msec). The first dummy peak occurred about 25 msec after the first vehicle peak, but the later peaks occurred at about the same time, presumably after the dummy was positioned against the seat belt or vehicle interior. The lateral vehicle trace was somewhat erratic; however, it appears as though the peaks coincide with the longitudinal vehicle peaks. The vertical dummy trace was similar in shape to the longitudinal dummy trace but with mostly lower peaks (8 to 12 g). This reflects the probability that the main motion of the dummy had strong components in both the vertical and longitudinal direction as it was decelerated along a diagonal path.

Test 217

Results of Test—The barrier used in test 217 was the same as that used for test 216. Figure 28 in the Appendix shows a summary of the test results. A 4,760-lb 1968 Dodge impacted along the side of the barrier 13 ft behind the barrier nose at a speed of 57.0 mph and an angle of 9 deg. After the vehicle struck the barrier, it was slightly redirected by the barrier fender panels. However, significant redirection was not achieved until the solid resistance of the bridge approach guardrail was utilized. There was virtually no rise of the vehicle forestructure. The right-front side of the car was severely crushed; there was no crush on the left side (Fig. 15; Appendix Fig. 24). The right-front door was jammed and the right doorpost was partially torn loose at the roof connection. The right side of the hood cracked the windshield. Near the end of the collision, the right-rear quarter panel of the car slapped the barrier. This damaged the right-rear fender and the right end of the rear bumper. A crimp in the roof over the doorposts was sustained on both sides of the car; the radiator was buckled back toward the engine on the right side. The steering wheel had a slight deformation, but the steering column did not collapse.

Figure 15.

Several fender panels were torn off the barrier on the left side, mainly because of hinge failures. Two panels were thrown 8 ft beyond the final position of the car and two panels were lodged in the crushed front end of the car. The five cells on the left side of the bridge approach guardrail were all torn off and scattered along the path of the car. Shear pins in the secondary cables sheared off. Permanent displacement of the barrier nose was 1.5 ft (Figs. 16 and 17).

Data From Instrumentation—The instrumentation consisted of the FHWA system plus six extra channels recorded directly on the Visicorder oscillograph. (See Figs. 29 and 30 in the Appendix for the type and location of this instrumentation.)

Figure 16.

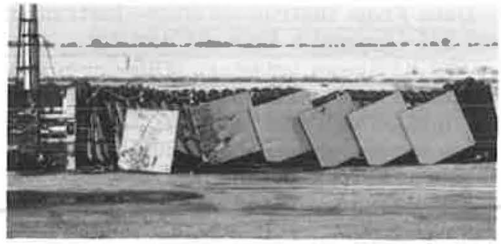

Figure 17.

The maximum pressure transducer reading was 50 psi. The maximum loads on the two $^7/_8$-in. cables were 14,300 lb on the left and 11,500 lb on the right. The bridge approach guardrails sustained compressive stresses from 3,540 psi on the top right to 9,850 psi on the bottom left.

Two accelerometer traces were produced in test 217 for both the longitudinal and lateral motions of the vehicle (4 total) and were filtered at 100 Hz. The two longitudinal traces were very similar with thin peaks above 15 g. The highest 50-msec average passenger-compartment deceleration was 8.4 g (average of two accelerometers). The two lateral traces were also similar. The highest 50-msec passenger-compartment average (average of two accelerometers) was 5.2 g. Thus, unrestrained vehicular occupants would have sustained moderate to severe injuries in most cases. If restraints were used, no more than moderate injury would usually occur. The lateral traces were similar in shape to the longitudinal ones. The highest peaks (9 g for 5 msec) occurred on all four traces at about 190 msec after impact. At 430 msec after impact, all four records showed evidence of a deceleration pulse caused by the rear of the car slapping the barrier.

The filtered traces for the longitudinal and lateral dummy motions appeared to be distorted by the noise; they showed large, somewhat erratic peaks.

Test 218

Test Results—The barrier used in test 218 was the same as that used for tests 216 and 217. Figure 31 in the Appendix shows a summary of the test results. A 4,760-lb 1968 Dodge impacted the nose of the barrier at an angle of 8 deg and a speed of 59.2 mph. The vehicle struck the barrier, rotated until it was nearly on line with the barrier axis, and continued to a stop in a manner similar to that of Test 216 (62-mph head-on impact). The crush in the vehicle forestructure formed an arc (plan view) with least crush at the fenders. Maximum crush at the center was 20 in. (Fig. 18; Appendix Fig. 24). Once again, a crimp was noted in the roof over the door posts on both sides of the car. The left-front door was jammed, and the radiator buckled back around the engine. Vehicle rise was 1 ft 4 in.

Figure 18.

Maximum vehicular penetration was 15.3 ft, and permanent displacement of the barrier nose was 11.7 ft. There were delamination and splitting of some of the interior panels and diaphragms, bent and broken hinges, and gouging of some of the fender panels. However, no parts became detached from the barrier (Fig. 19).

Data From Instrumentation—The FHWA instrumentation system was used in addi-

Figure 19.

tion to nine channels of information that were transmitted through a hardwire system to a second magnetic tape recorder (Appendix Figs. 29 and 30).

The maximum pressure transducer reading from the cells was 64.0 psi. The maximum loads on the two ⅞-in. cables were 20,900 lb on the left and 5,450 lb on the right. The bridge approach guardrails sustained compressive stresses from 4,800 psi on the bottom left to 12,000 psi on the top right. The maximum chest load on the dummy was 175 lb.

The longitudinal deceleration sustained by the vehicle included three distinct peaks greater than 13 g (5-msec duration). The average 50-msec passenger compartment deceleration (three accelerometers) was 10.2 g. This magnitude of deceleration would cause moderate to severe injuries in most cases if the vehicle occupants were not fully restrained. The fact that the vehicle impacted the nose of the barrier at an angle did not appear to cause large lateral decelerations.

Accelerometer records were obtained for the motion of the chest of the driver dummy in the longitudinal, lateral, and vertical directions. Only the longitudinal record was transmitted by hardwire. It had a shape very similar to the longitudinal vehicle records, with two peaks exceeding 12 g for as much as 30 msec. The first dummy peak lagged the vehicle peak by about 40 msec; the other two peaks lagged about 20 msec.

The lateral dummy record of motion showed a thin 20-g spike (5-msec duration), three or four other thin spikes with magnitudes of 8 to 10 g (also 5-msec duration), and low values elsewhere. The peaks occurred at the same time as the longitudinal dummy peaks, but the shape of the two curves was totally dissimilar. The vertical dummy record of deceleration was similar to that for longitudinal motion, except that the first, vertical peak was opposite in direction to the second and third vertical peaks. There was one thin (5-msec duration) 23-g spike; the second and third peaks (also 5 msec) were about 13 g. If the second and third longitudinal and vertical peaks are resolved vectorially, the resultant is about 18 to 19 g for each peak.

CONCLUSIONS

The following conclusions are based on an analysis of the results of the full-scale impact tests conducted during this test series:

1. The passenger-compartment decelerations measured indicate that passengers will have a good chance of sustaining little or no injury during high-speed collisions if fully restrained (with seat belt and shoulder harness). However, even unrestrained occupants will have a much better chance of surviving an impact with the barrier than they would if colliding with a fixed object. This is particularly true at impact speeds less than 60 mph.
2. The post-collision trajectory of impacting vehicles will be acceptable in most cases. The final position of the vehicle may, however, be hazardous to adjacent traffic after oblique-angle impacts.
3. During test 217, the vehicle was effectively redirected when it struck near the rear of the barrier; however, redirection appeared to be due more to the action of the bridge railing than to the fendering ability of the energy-absorbing barrier. Despite this observation, the fendering system is recommended on the basis of several unpublished tests by the developer in which test vehicles weighing around 4,500 lb and traveling 50 to 60 mph impacted the side and the nose of the barrier at angles of 10 to 20 degrees with the barrier axis and were effectively redirected.
4. The effort and number of barrier components required to place the barrier back in service will be minimal after the head-on and nearly head-on tests in most cases.

A significantly greater effort may be required to repair the barrier after the oblique-angle collision with the side of the barrier because of the amount of debris that is created during this type of collision.

5. Minor drawbacks to this barrier system include the problems that might arise in protecting water in the cells from leakage, vandalism, and freezing. Also, the barrier is more complex than most other highway barriers and, as such, would require skilled construction and maintenance personnel as well as a relatively large number of maintenance components compared with most other highway barriers.

6. Because most of the test objectives were successfully met using a moderately heavy passenger vehicle impacting at relatively high speeds, this barrier should perform with reasonable effectiveness under the range of conditions that constitute the majority of gore-area impacts.

ACKNOWLEDGMENT

This work was accomplished in cooperation with the Federal Highway Administration. The opinions, findings, and conclusions expressed are those of the authors and not necessarily those of the Federal Highway Administration.

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Appendix

DETAILS OF BARRIER DESIGN AND PERFORMANCE

The following figures contain pertinent data and photographs of the impact tests discussed in this report.

THEORETICAL DECELERATION – VEHICLE
9-BAY HI-DRO CUSHION BARRIER

VEHICLE WEIGHT 4720 LBS
IMPACT VELOCITY 60 MPH

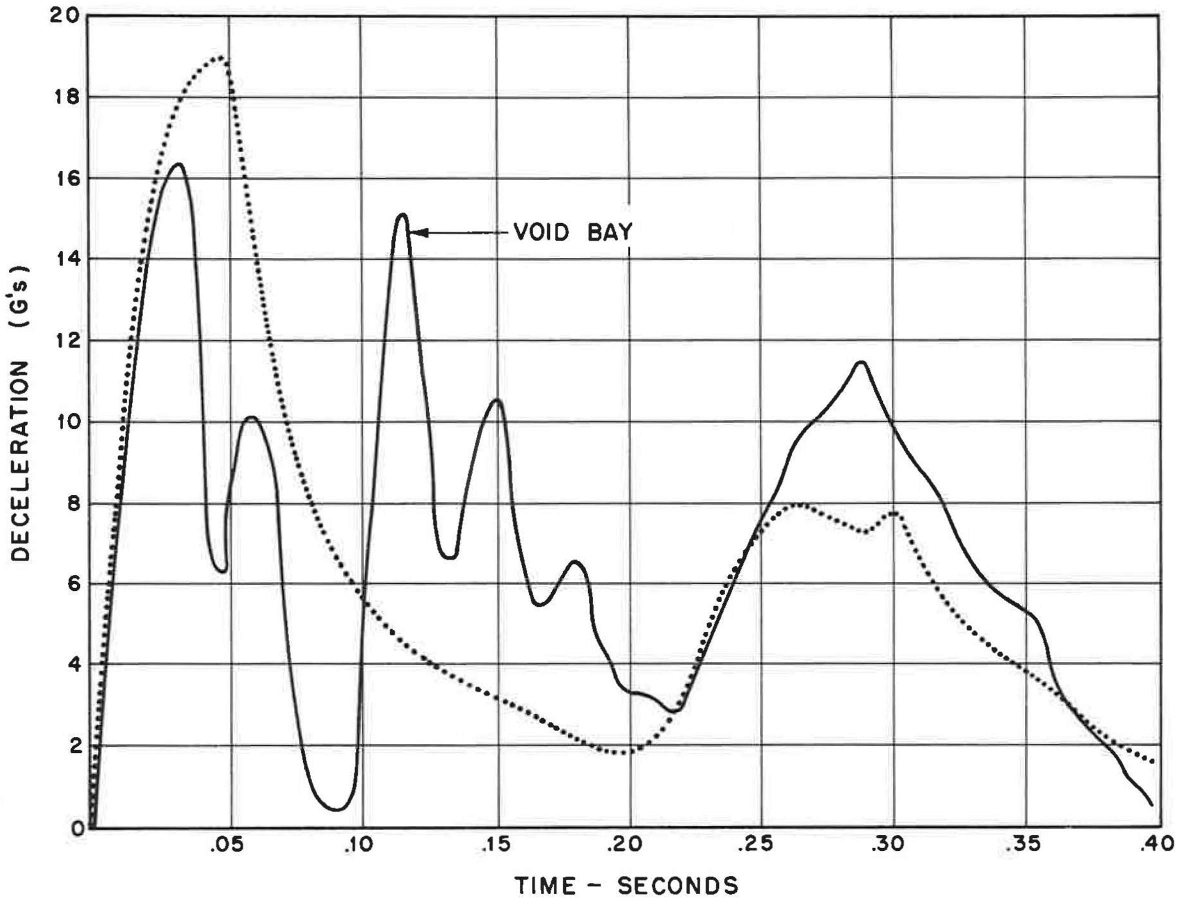
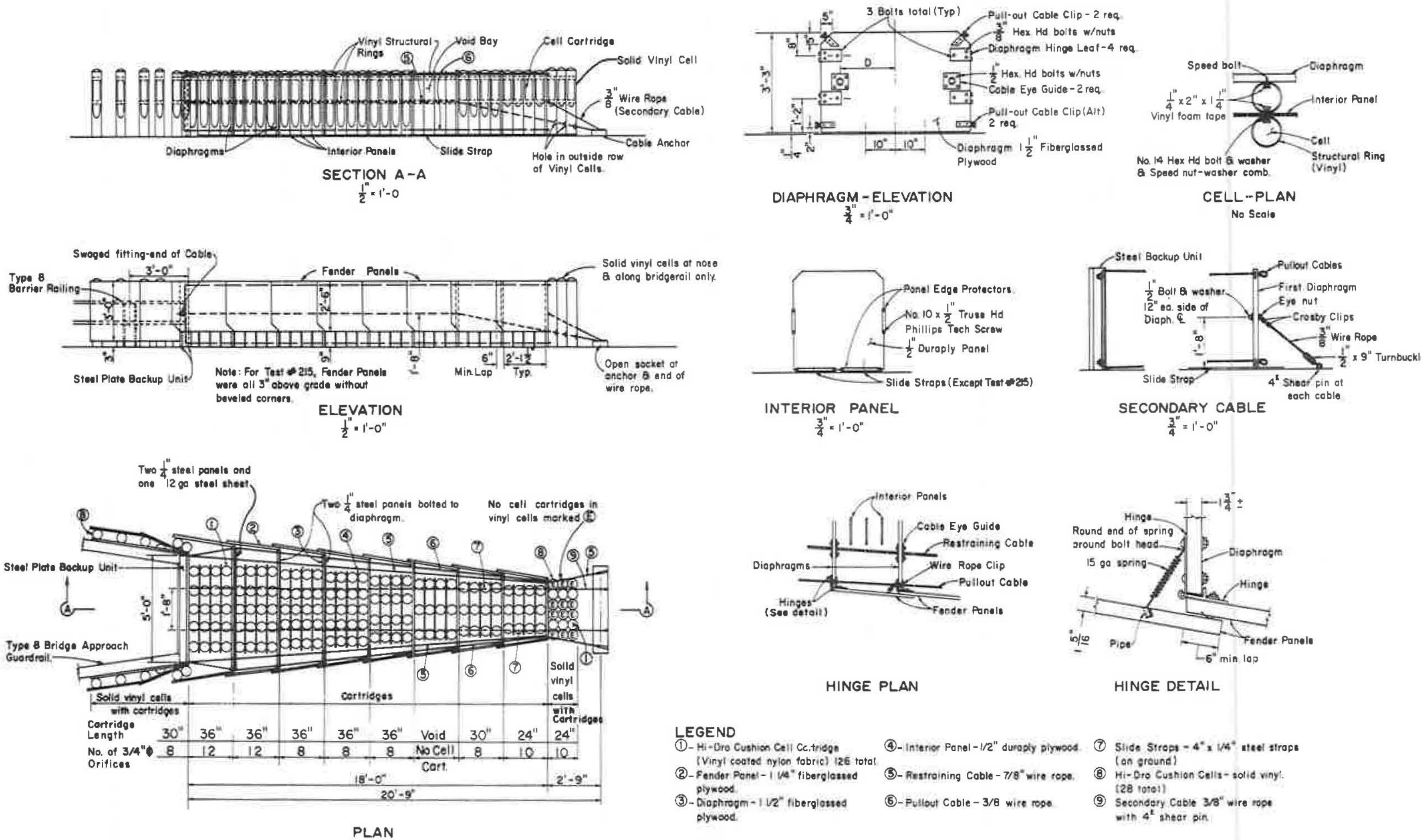
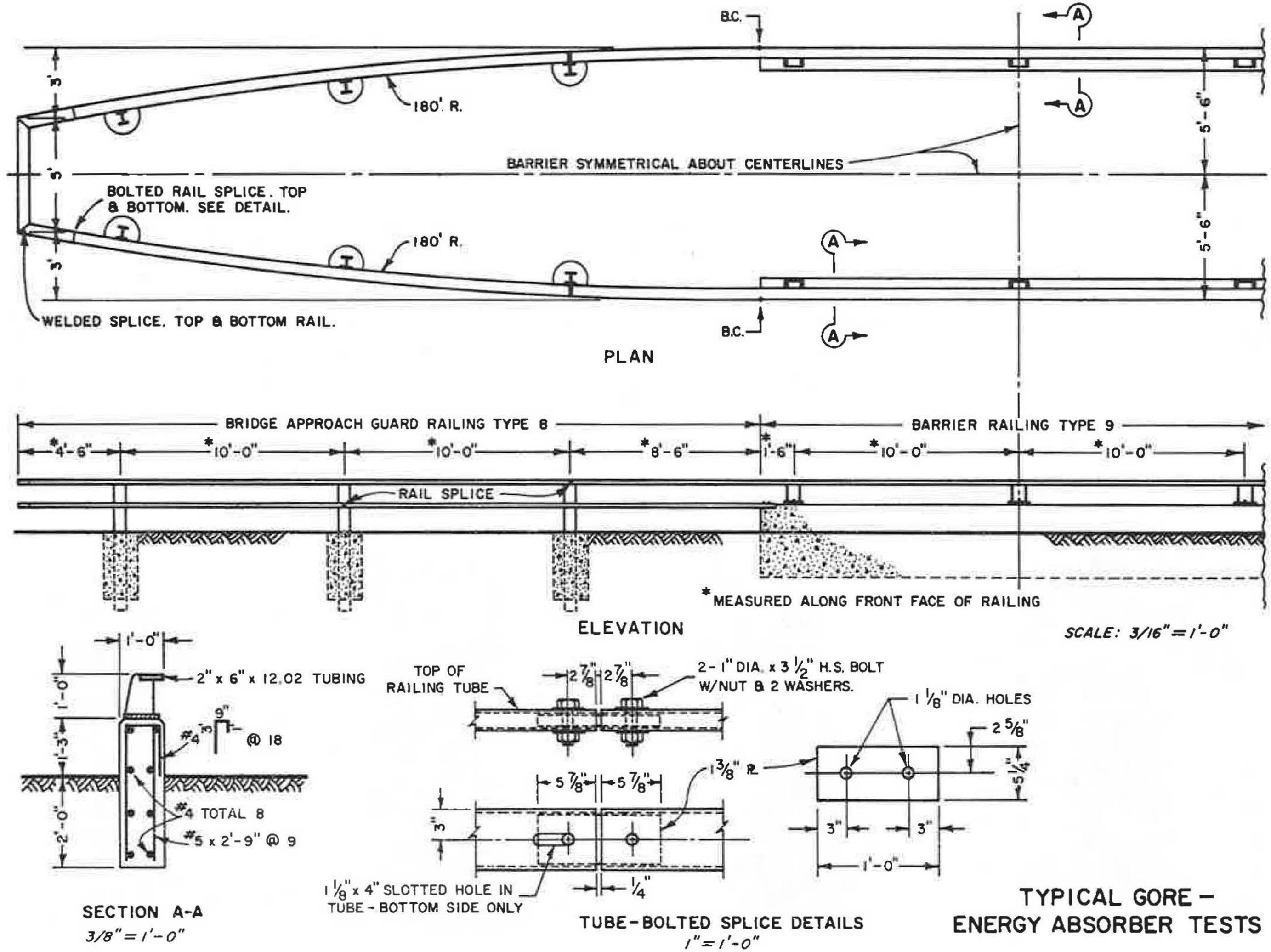


Figure 20.



BARRIER DETAILS - TEST NO. 215-218

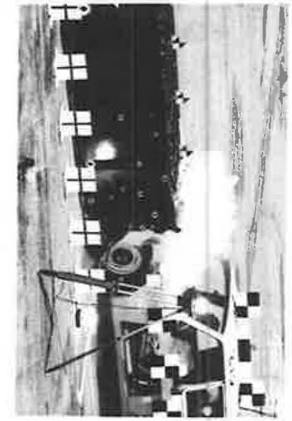
Figure 21.



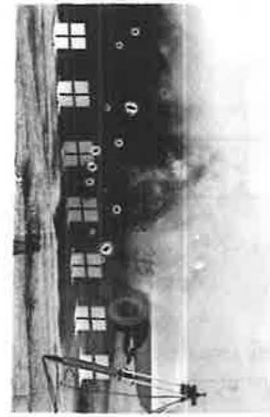
B.C.
180' R.
BARRIER SYMMETRICAL ABOUT CENTERLINES
BOLTED RAIL SPLICE. TOP & BOTTOM. SEE DETAIL.
WELDED SPLICE. TOP & BOTTOM RAIL.
PLAN
BRIDGE APPROACH GUARD RAILING TYPE 8
BARRIER RAILING TYPE 9
RAIL SPLICE
*MEASURED ALONG FRONT FACE OF RAILING
ELEVATION
SCALE: 3/16" = 1'-0"
2" x 6" x 12.02 TUBING
#4 TOTAL 8
#5 x 2'-9" @ 9
SECTION A-A
3/8" = 1'-0"
TOP OF RAILING TUBE
2-1" DIA. x 3 1/2" H.S. BOLT W/NUT & 2 WASHERS.
1 1/8" DIA. HOLES
1 1/8" x 4" SLOTTED HOLE IN TUBE - BOTTOM SIDE ONLY
TUBE-BOLTED SPLICE DETAILS
1" = 1'-0"
TYPICAL GORE - ENERGY ABSORBER TESTS

Figure 22.

Impact + 0.03 Sec.



I + 0.22 Sec.



+ 0.44 Sec.

I + 2.58 Sec.

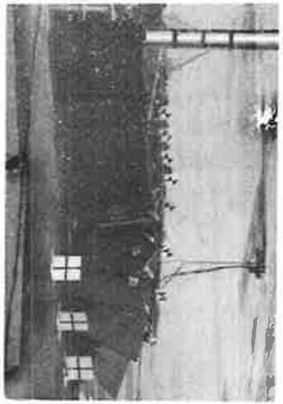


Figure 23.

Barrier Depth	19.5 Ft.	Test No.	215
No. of Water-Filled Cells	126	Date	7-16-69
Permanent Displacement of Barrier Nose	9.3 Ft.	Vehicle	1968 Dodge
Deceleration Distance-Passenger Compartment	-	Vehicle Weight	4690 Lbs.[1]
Maximum Vehicular Deformation	20 In.	(W/Dummy and Instrumentation)	
Passenger Compartment Deceleration	7.0 G's	Impact Velocity	57.5 mph
(Highest 50 ms avg. - accelerometer)	(long.)	Impact Angle	Head-on
Vehicle Average Deceleration-Calculated	Rolled	Dummy Restraint	Lap belt

[1] Left front door removed.

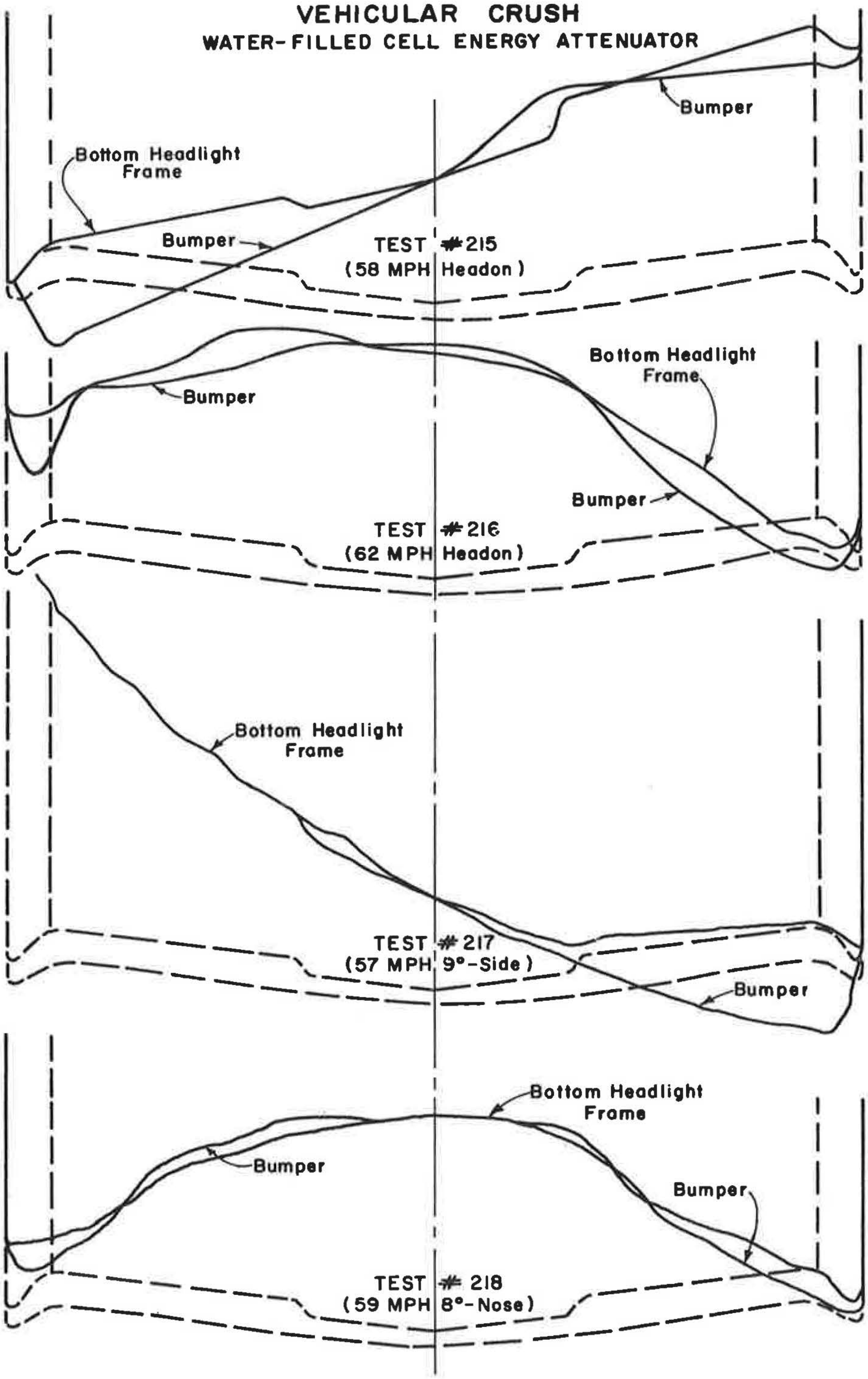
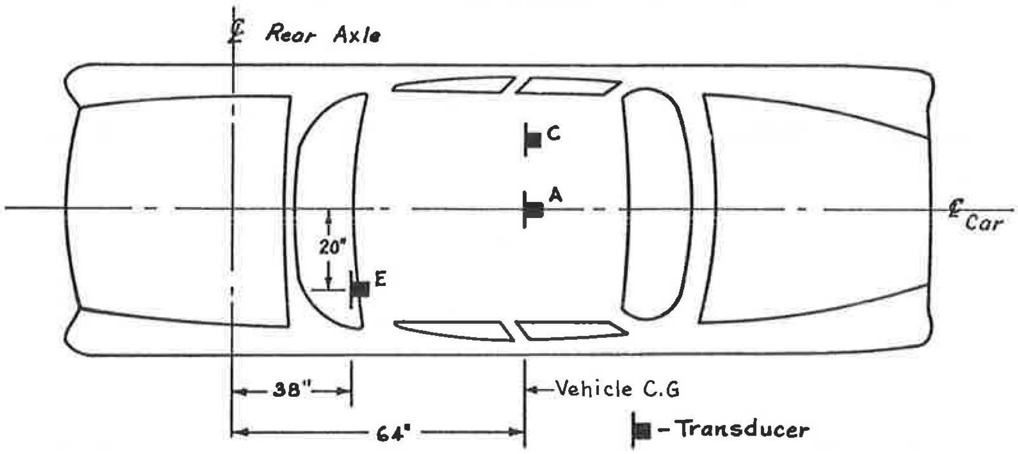

VEHICULAR CRUSH
WATER-FILLED CELL ENERGY ATTENUATOR
Bottom Headlight Frame
Bumper
Bumper
TEST #215
(58 MPH Headon)
Bumper
Bottom Headlight Frame
Bumper
TEST #216
(62 MPH Headon)
Bottom Headlight Frame
TEST #217
(57 MPH 9°-Side)
Bumper
Bottom Headlight Frame
Bumper
Bumper
TEST #218
(59 MPH 8°-Nose)

Figure 24.

CALIFORNIA DIVISION OF HIGHWAYS

VEHICLE INSTRUMENTATION

WATER-FILLED CELL ENERGY ATTENUATOR TESTS



Tests #215 & 216

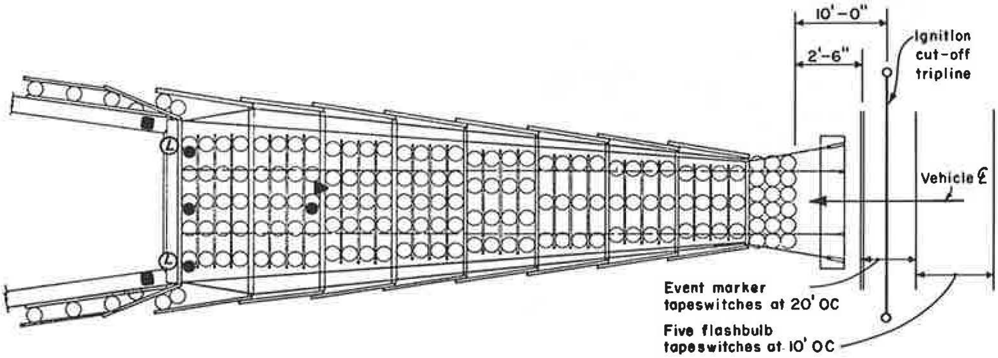
CHANNEL NO.	LOCATION[1]	DESCRIPTION
1	A	100 "G" longitudinal accelerometer
2	E	100 "G" longitudinal accelerometer
3	C	50 "G" longitudinal accelerometer
4	C	50 "G" lateral accelerometer
5	C	50 "G" vertical accelerometer
6	C	Force meter in dummy's chest
7	C	Lap belt tension transducer

Notes:

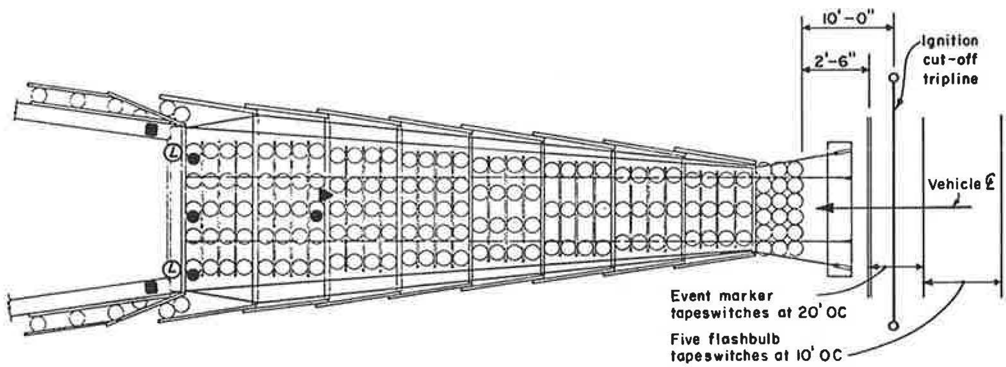
[1] A and E on vehicle floor; C on back of dummy's chest cavity.

Figure 25.

BARRIER INSTRUMENTATION
TESTS 215 & 216



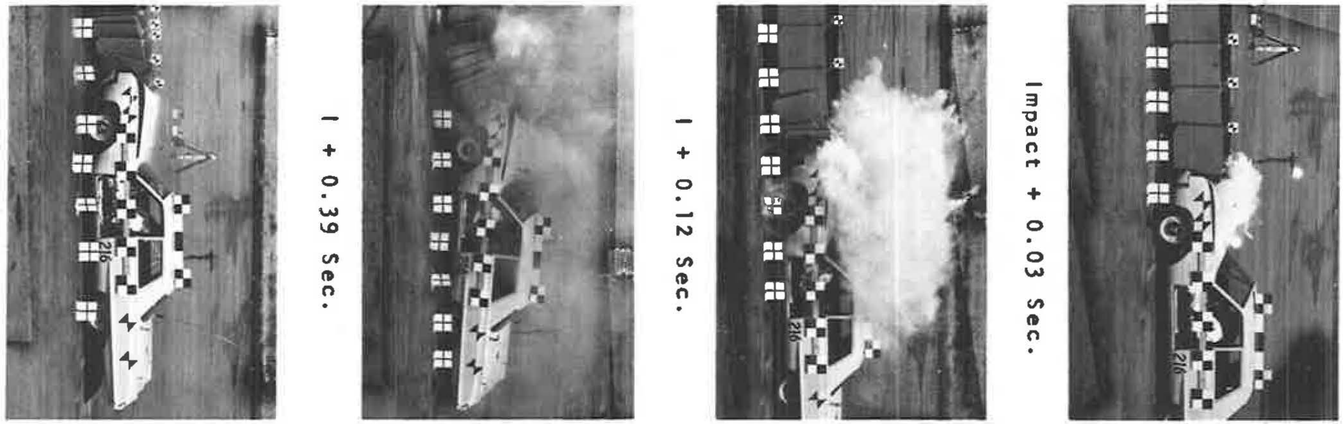
TEST 215



TEST 216

LEGEND:
- ■ = Strain gage – on top of top and bottom bridgerails (Total 4)
- ● = Pressure transducer in water cells.
- Ⓛ = Load cell on main cables
- ▶ = Accelerometer.

Figure 26.

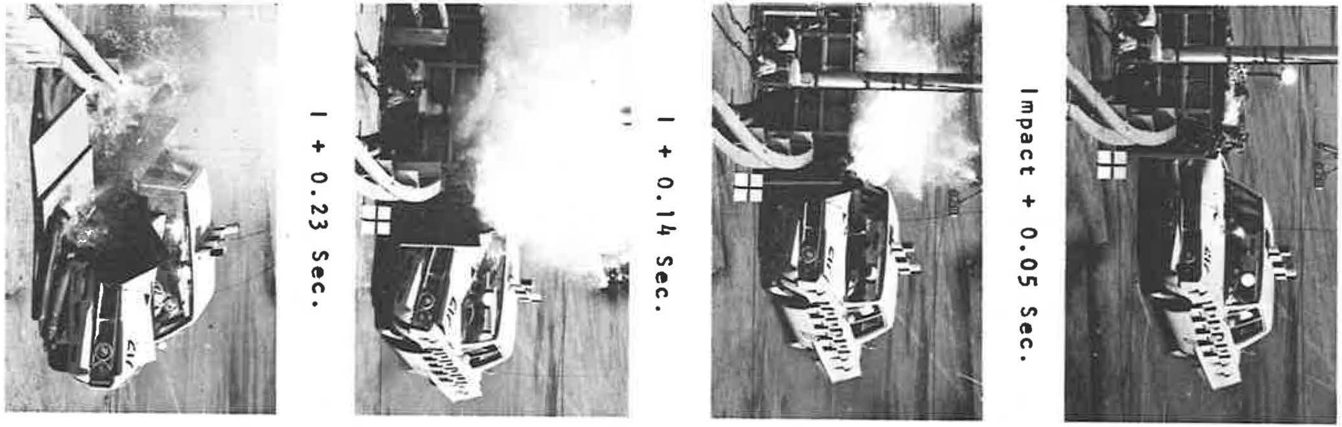


Impact + 0.03 Sec. I + 0.12 Sec. I + 0.39 Sec. I + 2.73 Sec.

Figure 27.

Barrier Depth	19.5 Ft.	Test No.	216
No. of Water-Filled Cells	126	Date	9-3-69
Permanent Displacement of Barrier Nose	10.7 Ft.	Vehicle	1968 Dodge
Deceleration Distance-Passenger Compartment	18.0 Ft.	Vehicle Weight	4690 Lbs.[1]
Maximum Vehicular Deformation	20 In.	(W/Dummy and Instrumentation)	
Passenger Compartment Deceleration	9.8 G's	Impact Velocity	61.8 mph
(Highest 50 ms avg. - accelerometer)	(long.)	Impact Angle	Head-on
Vehicle Average Deceleration-Calculated	7.1 G's	Dummy Restraint	Lap belt

[1] Left front door removed.



Impact + 0.05 Sec.

I + 0.14 Sec.

I + 0.23 Sec.

I + 0.62 Sec.

Figure 28.

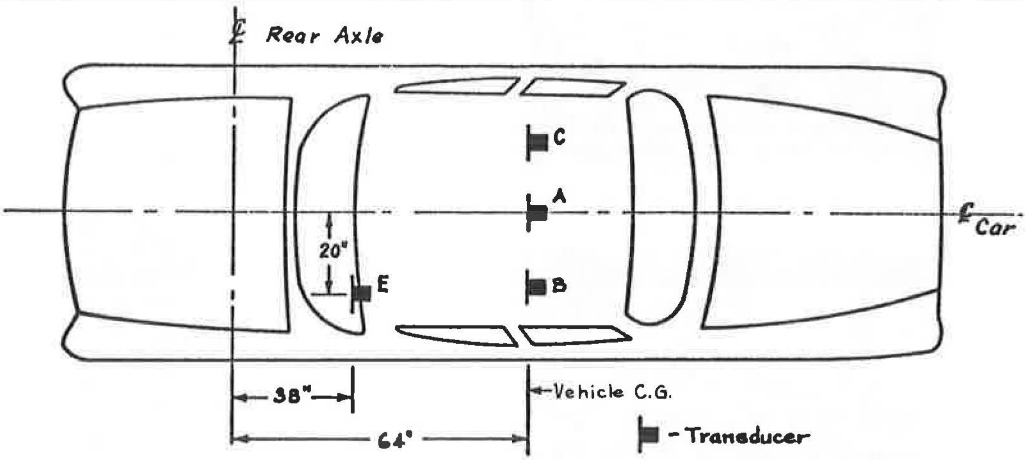
Barrier Depth	19.5 Ft.
No. of Water-Filled Cells	126
Permanent Displacement of Barrier Nose	1.5 Ft.
Deceleration Distance-Passenger Compartment	-
Maximum Vehicular Deformation	-
Passenger Compartment Deceleration (Highest 50 ms avg. - accelerometer)	8.4 G's (long.)
Vehicle Average Deceleration-Calculated	Redirected

Test No.	217
Date	9-25-69
Vehicle	1968 Dodge
Vehicle Weight (W/Dummy and Instrumentation)	4760 Lbs.
Impact Velocity	57.0 mph
Impact Angle	9° (side)
Dummy Restraint	Lap belt

CALIFORNIA DIVISION OF HIGHWAYS

VEHICLE INSTRUMENTATION

WATER-FILLED CELL ENERGY ATTENUATOR TESTS



Test #217

CHANNEL NO.	LOCATION[1]	DESCRIPTION[2]
1	A	100 "G" longitudinal accelerometer (T)
2	A	100 "G" lateral accelerometer (T)
3	E	100 "G" longitudinal accelerometer (T)
4	E	50 "G" lateral accelerometer (T)
5	C	50 "G" longitudinal accelerometer (T)
6	C	50 "G" lateral accelerometer (T)
7	C	50 "G" vertical accelerometer (T)

Test #218

CHANNEL NO.	LOCATION[1]	DESCRIPTION[2]
1	A	100 "G" longitudinal accelerometer (T)
2	A	100 "G" lateral accelerometer (T)
3	E	100 "G" longitudinal accelerometer (T)
4	E	50 "G" lateral accelerometer (T)
5	C	50 "G" vertical accelerometer (T)
6	C	Force meter (in dummy's chest cavity)
7	C	50 "G" lateral accelerometer (T)
G	E	50 "G" lateral accelerometer (U)
H	B	50 "G" longitudinal accelerometer (U)
I	E	100 "G" longitudinal accelerometer (U)

Notes:

[1] A and E on vehicle floor; C on back of dummy's chest cavity, B in dummy's chest cavity.

[2] (T) = telementry, (U) = umbilical cord.

Figure 29.

BARRIER INSTRUMENTATION
TESTS 217 & 218

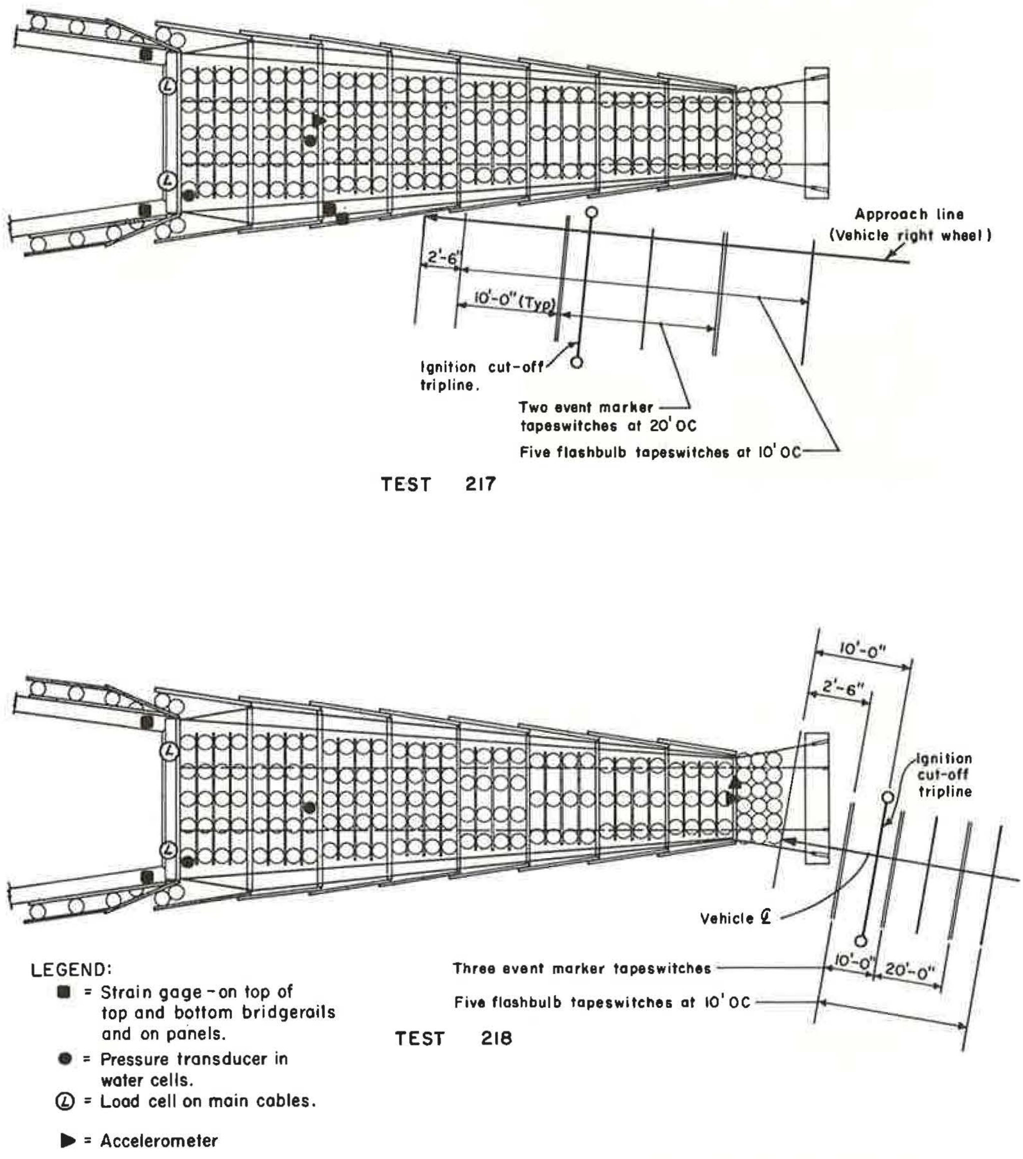
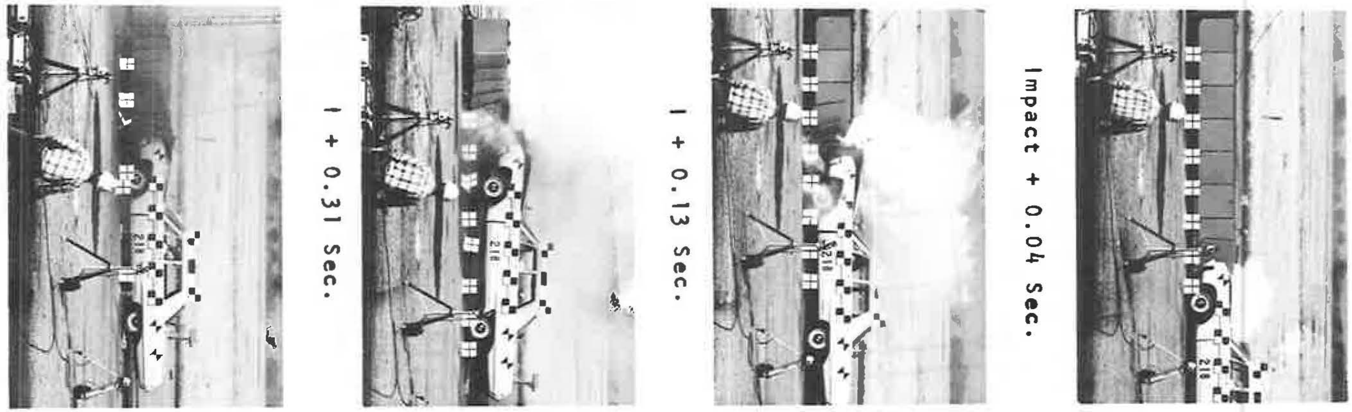


Figure 30.



Impact + 0.04 Sec.

I + 0.13 Sec.

I + 0.31 Sec.

I + 1.30 Sec.

Figure 31.

Barrier Depth	19.5 Ft.	Test No.	218
No. of Water-Filled Cells	126	Date	11-12-69
Permanent Displacement of Barrier Nose	11.7 Ft.	Vehicle	1968 Dodge
Deceleration Distance-Passenger Compartment	16.9 Ft.	Vehicle Weight	4760 Lbs.
Maximum Vehicular Deformation	20 In.	(W/Dummy and Instrumentation)	
Passenger Compartment Deceleration	10.2 G's	Impact Velocity	59.2 mph
(Highest 50 ms avg. - accelerometer)	(long.)	Impact Angle	8° (nose)
Vehicle Average Deceleration-Calculated	6.9 G's	Dummy Restraint	Lap belt