DYNAMIC TESTS OF AN ENERGY-ABSORBING BARRIER EMPLOYING SAND-FILLED PLASTIC BARRELS

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The results of three full-scale tests of vehicles impacting energy-absorbing barriers employing sand-filled frangible plastic barrels are reported. The barriers were designed for placement in front of fixed objects located in freeway gores. They were composed of an array of 15 to 17 barrels 36 in. in diameter by 30 and 36 in. high. The barriers were 21 and 25 ft long and tapered from a 9-ft width at the rear to a 3-ft width at the nose. The barrels were not attached to the ground. Sedans weighing approximately 4,700 lb impacted the nose of the barrier head on at a speed of approximately 60 mph and at a 15-deg angle. A small sedan weighting about 1,900 lb also impacted the nose of the barrier head on at 59 mph. The barrier was judged acceptable in the areas of cost, ease of construction and maintenance, aesthetics, simplicity, and versatility and is recommended for use in operational trial installations.

•DURING 1967 and 1968, approximately 25 percent of all California freeway fatalities occurred when vehicles ran off the road and collided with fixed objects. Consequently, the California Division of Highways is endeavoring to provide a 30-ft-wide recovery area, clear of fixed objects, adjacent to the traveled lanes. Wherever possible, fixed objects that cannot be removed from this recovery area are modified and made "breakaway." However, one of the most difficult problem areas has been the gores of freeway off-ramps that contain large signposts, bridge rail end posts, and other rigid structures. Various types of energy-absorbing barriers have been proposed for installation in front of or around these fixed objects to cushion vehicular impacts. The California Division of Highways has previously conducted full-scale crash tests of two of these barriers, one composed of water-filled plastic cells and the other composed of empty, 55-gallon steel oil drums (1, 2).

This report discusses three recent dynamic tests of a third barrier composed of an array of sand-filled frangible plastic barrels placed between the traveled way and the fixed object. The barrier was developed by John Fitch and is manufactured by Fibco, Inc., of Hartford, Connecticut. During 1967, more than 30 crash tests were conducted of impact attenuators that utilize sand supported by various types of material. This series of tests was supported by a few interested firms, and engineering assistance was provided by the New York State Department of Transportation. The tests proved the feasibility of using the concept of momentum transfer from the impacting vehicle to the sand but the need for a more sophisticated system for containing the sand became evident. A weatherproof, cylindrical, plastic barrel was developed that would provide lateral support for the sand but would shatter relatively easily when struck by a vehicle. The barrel was made of a high-density polyethylene produced by using a structural foam process.

In April 1969, Fitch conducted another series of six tests. This phase of his testing was supported by Connecticut under the auspices of a National Highway Safety Board project grant. The tests were conducted at speeds of 40 to 50 mph using vehicles weigh-

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ing 1,700, 3,000, 3,500, and 3,900 lb. The test barriers were 14½ to 25 ft long. A human driver was used in two tests. The barrels were placed in an open area with no fixed object behind the barrier. In all of the tests, except those using a 1,700-lb car, the stopping distance exceeded the barrier length. Reports of the tests indicated that the test vehicles were decelerated in an effective, stable manner; however, there was no instrumentation to measure peak g on the vehicle. The amount of debris that was generated as the barrier decelerated an impacting vehicle was unsatisfactory.

Subsequent to these tests, Fitch barriers had been installed at locations in several states. A few collisions with these barriers had been recorded with generally favorable performance. Thus, the sand inertial barrier concept appeared promising because of its apparent effectiveness in adequately decelerating impacting vehicles, adaptability to varied site conditions, simplicity, and relatively low first cost. However, due to the limited number of formally documented tests that had been conducted, a series of 60-mph tests using instrumented, relatively heavy and light vehicles was deemed necessary to more acurately evaluate the barrier's effectiveness.

OBJECTIVE

The objective of this research was to conduct instrumented vehicular impact tests of energy-absorbing barriers composed of sand-filled plastic barrels and, based on the results of these tests, determine the degree to which these barriers would minimize the hazards created by gore separation structures and other fixed objects. The following criteria were used to evaluate the barrier design:

1. The impact severity for the occupants of errant vehicles involved in head-on collisions into fixed objects located in gores must be reduced to a survivable level at impact velocities of 60 mph and less;
2. The barrier components should not be susceptible to dislodgement or ejection onto the traveled way when an impact occurs;
3. First cost and maintenance costs should be economically feasible; and
4. On-site repair time should be minimal because of the safety hazards to maintenance personnel and adjacent traffic when field repairs are in progress.

TEST PROCEDURE

All three tests were conducted on a section of runway at the Lincoln Municipal Airport located near Lincoln, California.

Test Vehicles

The full-sized vehicles used in these tests were 1968 Dodge sedans that, including the dummies and instrumentation, weighed approximately 4,700 lb. The vehicles were controlled by a remote operator following 200 ft behind the test vehicle in a control car equipped with a tone transmission system. A trip line in the path of the test car was used to cut off its ignition 10 ft prior to impact. The brakes were not applied before or during impact. A more complete description of the remote-control equipment is contained elsewhere (4).

A 1957 Volkswagen (VW) was steered and braked by remote control from a follow car as in the other two tests; however, because it was incapable of accelerating to 60 mph under its own power within the confines of the test site, a cable tow system was devised to pull the VW into the barrier. A detailed description of this system is included in the original report (5).

Test Dummies

Two anthropometric dummies were placed in the vehicle. A 165-lb dummy (50th percentile male) occupied the driver's seat and was secured by a conventional lap belt. A 210-lb dummy (95th percentile male) occupied the passenger side of the front seat for one of the tests (Appendix, Fig. 20).

Photographic Coverage

All of the tests were recorded with high-speed (250 to 400 frames per second) Photosonic motor-driven cameras that were manually actuated from a central control console. These cameras were located on the ground on both sides of the barrier, on a 30-ft-high light standard positioned directly above the barrier, and in the rear 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. A ground-mounted high-speed camera and a normal-speed camera were hand panned through impact. Still photos, slides, and documentary movies were also taken.

Data Acquisition and Processing

Four accelerometers were mounted on both the driver dummy and the vehicle, and one seat-belt transducer was used on the driver dummy's lap belt. The accelerometers were all of the unbonded linear strain-gauge type (Appendix, Fig. 20). Signals from three strain gauges on the bridge approach guardrail were also transmitted by cable to the tape recorder for Test 241 (Appendix, Fig. 21).

For Test 241, a Krohn-Hite filter was used to obtain data filtered at a rate of 100 Hz. These filtered traces were easier to compare and to use for data reduction than were the unfiltered traces. They also gave a better overall record of the motion of the dummy and vehicle. The high-frequency spikes on the unfiltered records were assumed to be relatively insignificant as related to the overall motion of the vehicle.

After the data from Test 241 had been filtered, there was a malfunction of the Krohn-Hite filter. A Brush brown dot galvanometer with a frequency response of 22 Hz was used instead to obtain an effective filtration rate of 176 Hz for Tests 242 and 243. However, this filtration rate proved to be too unwieldy for numerical work, and a "hand-filtered" line was superimposed on it. This eliminated the high-frequency spikes and permitted the computation of the maximum deceleration values given in the test results. Copies of the filtered records of impact data for all the tests are contained elsewhere (5).

DESCRIPTION OF TEST BARRIER

The test barrier for Test 241 was composed of an array of frangible plastic barrels containing varied amounts of sand and was placed in front of a California Type 8 Bridge Approach Guardrail (BAGR) (Fig. 1 and Appendix, Figs. 22 and 23). Deceleration of the impacting vehicle was obtained through a transfer of momentum from the vehicle to the sand. The foamed plastic used for the barrels was frangible so that the sand was relatively unconfined when the modules were subjected to an impact-type load. Thus the barrier design was based on the conservation of momentum with adjustments so that standard barrel sizes could be used. The overall barrier length for the first test was approximately 21 ft. An additional 1-ft gap was left between the rear of the barrier and the nose of the BAGR to provide some additional deceleration distance and to minimize the accumulation of sand against the BAGR (which might provide a ramp for the vehicle).

Barrier Module

Several components were used to construct each barrel (Fig. 2). Frangible, high-density polyethylene plastic was used as the barrel material and a thin flexible plastic was used for the lids. A round plastic disc was available to place at the bottom of the barrel on soft ground; however, it was unnecessary for the barriers at this test site. An interlocking group of seven polystyrene (plastic) boards served as a core to support the sand at the proper height in the barrel. The core was covered with a thin, hard, circular, high-impact polystyrene disc. A flexible clear-plastic circular seal with upturned edges was seated on top of the disc to prevent the sand from spilling down to the ground. The sand was poured into the barrel to obtain the desired weight, and then a lid was riveted to the barrel in three or four places. Core heights available from the manufacturer permitted nominal sand weights (based on a sand density of 100 pcf) of 200, 400, 700, and 1,400 lb; a full barrel (with no core) contained 2,100 lb of sand. The barrels holding 1,400 and 2,100 lb of sand were 3 ft in diameter and 3 ft high; all other barrels were 3 ft in diameter and $2\frac{1}{2}$ ft high.

Barrier Design

The initial barrier (Test 241) was constructed using barrels containing 400 lb of sand at the nose and 2,100 lb of sand at the rear (Figs. 3 and 4 and Appendix, Fig. 22). This mass distribution was designed to obtain a relatively uniform rate of deceleration during impacts. The tapered barrier was 3 ft wide (one barrel) at the nose and 9 ft wide (three barrels) at the rear.

Simulated shoulder lines were placed 10 ft from the left side of the barrier and 4 ft from the right side as measured at the last row of barrels. These dimensions represented a four-lane freeway with a two-lane off-ramp as per the California Division of Highways' planning manual. The simulated gore area was 23 ft wide at this point. Instructions and observations on the installation and assembly of the test barriers are given elsewhere (5).

TEST RESULTS

Test 241

Test Vehicle—A 1968 Dodge sedan weighing 4,690 lb (including dummies) was used in this test. A 165-lb dummy occupied the driver's seat, and a 210-lb dummy occupied the passenger side of the front seat. Both dummies were secured by lap belts. The left front door and the gas tank were removed prior to the test.

Vehicle Behavior and Damage—The test vehicle, traveling at a speed of 58 mph, impacted the barrier head on and plowed through the entire barrier (Figs. 5 and 6). The vehicle axis was 1 ft to the left of the barrier axis at the time of impact. About 3 to 4 ft in front of the bridge railing, the vehicle ramped up on barrier debris and came to rest on the bridge rail just in front of the camera tower 24 ft behind the nose of the barrier. As the vehicle came to rest, it tilted sharply in a counterclockwise direction, because the left front wheel was not supported by the bridge rail, and almost turned over (Fig. 7) before returning to its final position.

Vehicle damage was confined mainly to the front end. Maximum significant crush at the center of the vehicle forestructure was $1\frac{2}{3}$ ft. The crush was fairly uniform across the front of the vehicle but slightly less on the left side (Fig. 8 and Appendix, Fig. 24). The lower frame member, bumper, and front fenders were all severely buckled, and the radiator was shoved back against the engine. On the passenger side, the front windshield was cracked where the sun visor came down and was struck by the dummy's head. No crimp in the roof over the doorpost was observed. The doorpost on the driver's side was torn loose from its roof connection and displaced back $\frac{1}{2}$ in. Immediately after impact, the hood flew open; however, it sustained no damage because the level of the hood was higher than the $2\frac{1}{2}$-ft-high barrels at the nose of the barrier. The steering wheel deformation was $2\frac{1}{2}$ in.; the collapsible steering column was foreshortened 0.7 in. when hit by the dummy. (See Fig. 25 in the Appendix for a summary of these results.)

Barrier Damage—Most of the broken foam plastic core pieces stayed under the vehicle. Although none of the lids was broken, all of them were detached from the barrels and several were displaced a considerable distance. Broken-barrel fragments did not travel far; four barrels along the right side of the barrier were left mostly intact. They had been shoved sideways and had tipped over, spilling sand out rather than "exploding." It appeared that most of the barrier resistance came from the left two-thirds of the barrier. Other than lids, little debris flew outside the "edge of pavement" lines except for some sand that extended 4 to 6 ft into traffic lanes on each side and beside the original barrier location on the right side and 10 to 15 ft beyond it on the left side (Appendix, Fig. 26). The last one or two rows of barrels did not shatter but leaned and compressed against the bridge rail and then fractured. These barrel pieces, plus the sand that was intermixed, piled up in front of the bridge rail and provided a ramp for the car. The broken plastic core pieces were small and mixed into the sand; hence, the sand did not appear suitable for reuse without sifting. Most of these fragments remained in the debris under the vehicle; however, many pieces on top of the pile were scattered quickly by the wind. This condition could pose a psychological hazard to drivers on an adjacent traveled way as they tried to dodge these pieces and other litter near the gore area.

Figure 1.

Figure 2.

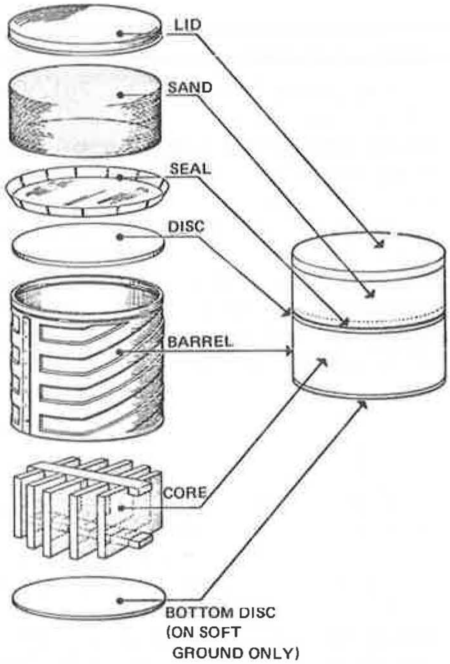


Figure 3.

Figure 4.

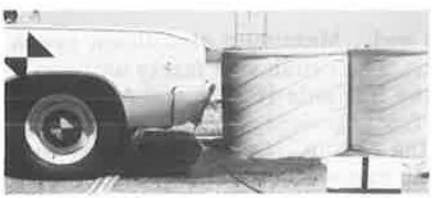


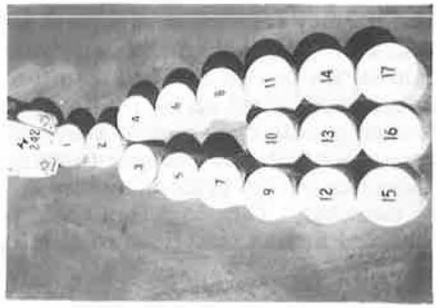
Figure 5.

Figure 6.

Figure 7.

Figure 8.

Figure 9.



Instrumentation Results—The accelerometer records were cut off about 200 msec after impact on some of the channels when equipment in the test vehicle broke loose. It appeared, however, that in many cases the main pulse of the deceleration was recorded before the interruption. Visicorder traces filtered at 100 Hz were used to derive the highest average values of deceleration. The highest 50-msec average vehicle deceleration (longitudinal) was 10.7 g (longitudinal accelerometer, Location E, Appendix, Fig. 20). The highest 50-msec average dummy (head) deceleration was 25.2 g (longitudinal and vertical accelerometers, Location A, Appendix, Fig. 20).

A maximum lap-belt load of 990 lb was recorded with the seat-belt-force transducer. Thus, the total load on the dummy was well below the 5,000-lb maximum permitted by federal standards (6). The tubular steel bridge approach guardrails sustained stresses of 3,240, 3,620, and 6,120 psi—not excessive values. Records from the longitudinal and lateral accelerometers placed at the center of gravity of the vehicle (Location A, Appendix, Fig. 20) were cut off just before the main peak—about 200 msec after impact.

The Gadd Severity Index was computed using longitudinal and vertical deceleration components of motion from accelerometers in the head of the driver dummy. For the highest 50 msec, the number was computed to be 185. This is well below the critical value of 1,000.

Test 242

Barrier Description—The test barrier consisted of 17 plastic barrels filled with varied amounts of sand ranging from 200 lb at the nose of the barrier to 1,400 lb at the rear (Appendix, Fig. 22, and Figs. 9 and 10). The black tape on the barrels shows the bottom level of sand in the rear barrels and top and bottom levels in the front barrels. The preceding weights are nominal for an assumed sand density of 100 pcf. Because it had been determined that the actual (moist) sand density for Test 241 was only 80 pcf, sand that had been run through a dryer just prior to delivery was used for Test 242. This sand had a higher density of 88 pcf (moisture content of 0.4 percent). The plastic barrel components were all identical to those used in Test 241.

The barrier was lengthened from 21 ft (Test 241) to 24 ft (nominal), and the barrel weights were decreased at the nose to provide a softer impact. Also, the rear barrels were changed from 2,100 to 1,400 lb, and the void space at the rear increased from 1 to 2 ft in an attempt to lessen the accumulation of sand and debris against the fixed object that had caused ramping in Test 241. A section of New Jersey concrete median barrier was used as the fixed object instead of the bridge rail because of the location of the ground anchors for the cable tow system used in this test.

A cotton sash cord was threaded continuously through all of the lids and was tied to the camera tower to prevent the lids from sailing onto the traveled way after impact, as had occurred during Test 241.

Test Vehicle—A 1,940-lb 1957 Volkswagen sedan was used in this test. Vehicle weight included a 165-lb dummy that was secured in the driver's seat by a lap belt, a water-filled gas tank, a spare tire (in front), and all the radio control equipment. The left door was replaced with a small steel channel brace so that the action of the dummy could be recorded by the cameras.

Vehicle Behavior and Damage—The VW hit the barrier nose head on with its axis about 9 in. to the left of the barrier centerline. The impact velocity was 59 mph. The vehicle came to rest 19 ft beyond the nose of the barrier with all its wheels on the ground (Figs. 11 and 12). During impact there was a 16-in. rise at the rear of the vehicle (measured at a target on the right rear fender). (See Fig. 27 in the Appendix for a summary of the test results.)

The front truck lid remained closed and was moderately buckled, as were the front fenders. Maximum crush at the forestructure of the VW was only 8 in. (Appendix, Fig. 24, and Fig. 13). The impact from the dummy's head caused the entire windshield to pop out. The substitution of a pulley for the standard VW steering wheel (required for radio control of the VW) prevented measurement of any steering wheel deformation.

Barrier Damage—Figure 28 in the Appendix shows the location of the barrier debris. A small number of barrel core pieces were found under the VW, but there was no other

Figure 10.

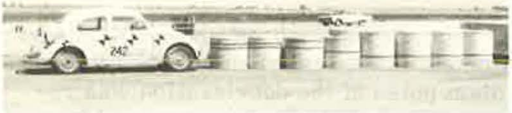


Figure 11.

Figure 12.

Figure 13.

Figure 14.

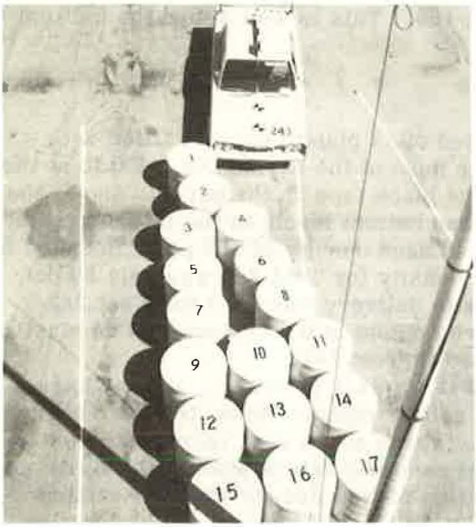


Figure 15.

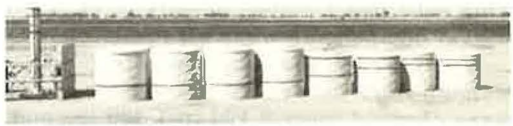


Figure 16.

Figure 17.

Figure 18.

Figure 19.

debris either under or behind it. There was no debris outside the 10-ft shoulder line, but a small amount extended 9 ft beyond the 4-ft shoulder line. There was no sand covering the front of the VW. Very little debris was found beyond the back of the barrier. The lids all remained attached to the cotton rope and were clustered near the rear of the barrier. At least nine of the barrels were totally destroyed. Four or five barrels were compressed but unbroken and could have been reused; however, some of their inner foam plastic cores were crushed. Three barrels were undamaged and undisturbed. The compressed barrels had moved forward during impact; it is not known whether they could have been dragged on the ground and repositioned without breaking the plastic barrels and cores or spilling the sand.

Instrumentation Results—Visicorder traces were used to derive the highest average values of deceleration. The highest 50-msec average vehicle deceleration (longitudinal) was 8.7 g (longitudinal and lateral accelerometers). The highest 50-msec average dummy (head) deceleration was 44.0 g (longitudinal, lateral, and vertical accelerometers).

Vehicular lateral decelerations (two accelerometers) were about 2 g maximum for 5 msec with 1-msec ringing spikes of 8 to 10 g. The seat-belt force transducer was inoperable. The Gadd Severity Index for the driver dummy's head was computed to be 1,280, significantly greater than the critical value of 1,000.

Test 243

Barrier Description—The barrier for this test had the same size, number, and configuration of barrels as was used for Test 242 (Figs. 14 through 16). As in Test 242, the sand was dried prior to delivery. It had a density of 89.2 pcf and a moisture content of 0.8 percent.

Lids were attached to the barrels with four equidistant pop-rivets according to the manufacturer's directions. Three extra rivets were added in a short row next to one of these four rivets. This row of rivets was randomly located and was not on the same side of all the barrels. It was hoped that these extra rivets would provide a hinge effect and minimize the wide scattering of lids that occurred during Test 241.

Test Vehicle—A 4,770-lb 1968 Dodge sedan was used in this test. Vehicle weight included a 165-lb dummy secured in the driver's seat by a lap belt, a water-filled gas tank, and all the radio control equipment.

Vehicle Behavior and Damage—The crash vehicle hit the nose of the barrier about a foot to the right of the planned point of impact at a speed of 57 mph and an angle of 15 deg with the barrier axis. It ramped up midway into the barrier, continued on through it, narrowly missed the right corner of the Type 8 bridge approach guardrail nose, and stopped with the rear of the vehicle even with the last row of barrels in the barrier. It came to rest with all wheels on the ground on a thin layer of sand (Figs. 17 and 18). (See Fig. 29 in the Appendix for a summary of the test results.)

Damage to the vehicle forestructure was quite severe (Fig. 19). The front end, including fenders, was uniformly crushed back against the engine. The maximum crush was 21 in. (Appendix, Fig. 24). The engine was not displaced. The lower longitudinal front frame members and the bumper were sharply buckled down to the ground and back against the front wheels. The hood was undamaged because of the relatively low height (30 in.) of the first four rows of barrels. A crimp in the roof was observed on the driver's side above the doorpost. The rest of the car was undamaged. Maximum deformation of the steering wheel was $2\frac{3}{4}$ in. The collapsible steering column was foreshortened $\frac{3}{4}$ in. by the dummy's impact.

Barrier Damage—Four barrels remained standing at the rear corner of the barrier. Of these, only two were undamaged. Large amounts of debris were scattered to the front and right front of the crash vehicle, some of which extended about 20 ft to the right of the 4-ft shoulder line and across the traffic lane (Appendix, Fig. 30). The right front corner of the vehicle projected about 3 ft into the traffic lane; the right rear was about 1 ft inside the shoulder line.

The barrel lids were thrown far ahead of the vehicle, as much as 67 to 70 ft beyond the back of the barrier; however, only 3 or 4 lids landed in the traffic lanes. One lid landed 26 ft to the left of the 10-ft shoulder line. The extra rivets on the lids did not appear to have any beneficial effect. This may have been due, in part, to the lack of a washer on the rivet inside the barrel.

A large number of broken foam core pieces were found under the crash vehicle, and many other pieces were thrown beyond the vehicle. These latter pieces were immediately blown freely about by a moderate wind and could have posed a psychological hazard if they had been blown across traffic lanes.

Instrumentation Results—The highest 50-msec average vehicle deceleration (longitudinal) was 7.9 g. The highest 50-msec dummy (head) deceleration was 34.0 g (longitudinal, lateral, and vertical accelerometers).

The seat-belt force transducer had a maximum reading of 600 lb. Vehicular lateral decelerations (two accelerometers) were about 3 g maximum for 5 msec with 1-msec spikes up to 10 g. The Gadd Severity Index was 580.

DISCUSSION

Vehicular Deceleration

The records of vehicular longitudinal deceleration for Test 242 contained four distinct pulses spaced about 50 msec apart. All were in the 10-g range with valleys of about 5 g. This pulsing occurred as the vehicle went from one row of barrels to the next. The overall shape of the deceleration data indicated that this barrier configuration (Test 242) was better than that used for Test 241 (two 700-lb barrels with three 1,400-lb barrels in the midsection of the barrier). This abrupt change in barrier mass for Test 241 coincided with a 15-g 5-msec vehicular deceleration that occurred as the vehicle passed the midsection of the barrier. For Test 242, the midsection of the barrier contained two 700-lb barrels followed by two 1,400-lb barrels and then by three 1,400-lb barrels—a smoother transition of mass that was reflected in the deceleration data.

The vehicular longitudinal decelerations for Test 243 were fairly constant at 7 to 9 g with several main pulses and were similar in magnitude and shape to those for Test 242, thus showing that the barrier configuration, which was identical for both tests, had a similar effect on cars with different weights. The deceleration pulse was decaying as the vehicle passed through the last two rows of 1,400-lb barrels; thus it appeared that these last rows had already been set in motion by the time the vehicle passed through them and, therefore, had a low decelerative effect. The vehicle had a velocity of about 14 mph as it penetrated the last row of barrels; hence, the barrier did not have enough mass and/or width to stop a 4,770-lb vehicle impacting near the nose at an angle of 15 deg and a speed of 57 mph.

The highest 50-msec average longitudinal vehicular passenger compartment decelerations measured during each test are as follows:

1. Test 241, one accelerometer, 10.7 g;
2. Test 242, two accelerometers, 8.7 g; and
3. Test 243, two accelerometers, 7.9 g.

The severity of these decelerations can be interpreted by comparing them with the recommended 200-msec deceleration tolerance limits proposed by Cornell (8). The Cornell limits, which were 5, 10, and 25 g for unrestrained, lap-belted, and fully restrained occupants, define what would be, in the opinion of the researchers, a survivable environment under almost all circumstances when applied to a 50-msec time interval. Thus the vehicular passenger compartment decelerations in the longitudinal direction were judged acceptable for restrained passengers. Only in Test 241 did the computed value slightly exceed the maximum value of 10 g for lap-belted passengers. The vehicular decelerations were also under the value of 12 g for the highest 40-msec period, another criterion that has sometimes been used to evaluate collision severity (7).

Computed values of the Gadd Severity Index indicate that in Test 242 the dummy driver might have suffered fatal head injuries. Therefore, acceptable vehicular decelerations, based on the criteria previously described, do not automatically eliminate the possibility of fatal injuries.

Gadd Severity Index

Longitudinal, lateral, and vertical components of deceleration from the dummy's head were vectorially combined at identical times after impact (at successive 0.0025-sec increments) to obtain resultant values of deceleration. Then the Gadd Severity Index (9),

$$\left({}_{t_2}\int_{t_1}^{2.5} a\, dt \right)$$

was computed over the 50-msec period with the highest average resultant values of head deceleration using 20 successive time intervals with dt = 0.0025 sec. The following Gadd Severity Index values (based on 1- to 50-msec pulse duration) were calculated for the test series.

1. Test 241, 185;
2. Test 242, 1,280; and
3. Test 243, 580.

The Gadd Severity Index of 1,280 in Test 242 indicated that even a lap-belted passenger probably would have suffered fatal head injuries if his head struck the windshield frame as violently as did the head of the dummy. This high number was not surprising in that the head of the dummy broke the windshield and forced it entirely out of the car and then dented a section near the small radius edge of the unpadded stiff metal dashboard. The steering wheel had been removed to accommodate the remote steering apparatus. If it had been in place, it might have minimized the impact severity when the dummy struck the dash; however, a front-seat passenger with no steering wheel in front of him might normally impact the dash as the dummy driver did. This reinforces the idea that the injuries sustained by the vehicle occupants in a 60-mph collision with an energy-absorbing barrier are dependent on the impact protection provided by the vehicle interior surfaces if ejection does not occur and both a lap belt and a shoulder harness are not in use. A discussion of this severity index and the tolerance of the human head to deceleration is given elsewhere (5).

Debris

In all of the tests, the foam plastic core material that supported the sand in the barrels was broken into small pieces. This material did not land in the traveled way initially, except after the angular impact in Test 243; however, the pieces were so light that the slightest breeze blew them all over the test site. If this material is used in operational barrier installations, it could pose a litter and maintenance problem after barrier impacts. In addition, this material could create a psychological hazard to nearby motorists even though it is lightweight and harmless.

The barrel lids were another source of debris. After impact, they sailed through the air for distances up to 100 ft. Most of them stayed in the gore area during the head-on impacts, but the few that landed in the traveled way posed a potential psychological hazard for nearby motorists. In Test 242, the cotton sash cord was threaded continuously through all of the lids and anchored at the rear of the barrier, which proved to be an effective method of keeping all the lids in the gore area. However, the cord gave the barrier a slightly less desirable appearance.

Broken barrel pieces and sand were mostly contained in the gore area except during the angular impact of Test 243. In Tests 241 and 243 the impact vehicles tended to ramp over the debris, especially in Test 241 where the rear of the barrier was only 12 in. from the bridge approach guardrail. The VW did not ramp up because of the sloping forestructure of the vehicle, which tended to nose under the sand in the front barrels of the barrier. The debris scattered, in the traveled way after an angular impact such as Test 243, appears to be one currently unsolved drawback of this barrier.

Barrier Dimensions

The test barriers were close to the minimum length required to provide reasonable safety for restrained passengers in vehicles impacting at a speed of 60 mph. The barrier could be increased in length to provide a softer impact; however, this would reduce possible recovery area. Site conditions would partially govern the decision regarding optimum barrier length; initial installation and long-term maintenance costs would vary with the length of the barrier.

Redirection

In all the tests, including Test 243, that involved an angular impact, the vehicle was not redirected but continued on a straight course after impacting the barrier.

Sand Density

The sand used in the barrels was sampled during barrier construction. Subsequent test results indicated that the density of the sand was significantly lower than the nominal 100-pcf unit weight assumed by the manufacturer, as can be seen in the following:

1. Test 241, 80 pcf, water content 6.7 percent;
2. Test 242, 88 pcf, water content 0.4 percent (sand had been run through a dryer just prior to delivery); and
3. Test 243, 89 pcf, water content 0.8 percent (sand had been run through a dryer just prior to delivery).

The general range of unit weights for dry, loose sand is 90 to 100 pcf, and for damp, loose sand it is 85 to 95 pcf (10). Thus, the sand used for the barriers tested fell just below the lower end of the normal weight range. Graphs that show how sand volume increases by 15 to 35 percent (maximum) for coarse to fine sand respectively and how moisture contents range from 0 to 20 percent are given elsewhere (11).

It was concluded that it would probably be too bothersome and expensive to have sand dried for operational barriers. The added weight of the dried sand would not change the effectiveness of the barrier significantly; however, it is well to realize that sand density is a variable factor and that, if sand with a density of 100 pcf was used in a barrier, the performance could differ somewhat from that reported here.

Aesthetics

This barrier presents a low, relatively uniform shape. The barrels can be ordered in bright or dark colors. Care should be taken to provide a level site so that the barrels will not lean at random angles. For these who do object to the imposition of bright cylindrical shapes on the streamlined highway profile, a cover for the entire barrier might be desirable. Any cover selected should be a weather-resistant, taut, flexible material and should not inhibit the free movement of the sand during impacts. Material wrapped around the sides would be preferable to a complete cover until full-scale tests of barriers with covered tops are conducted.

Accident Experience

Accident reports from Connecticut indicate that 15 in-service barriers were impacted 16 times (3). In 13 cases, the vehicle was driven away before accident information could be gathered. Several of these impacts were nuisance hits. However, it was reported that the barrier may have prevented an impending collision with a fixed object in many of these cases. The three remaining reported accidents were all serious, yet in all cases the drivers received only minor injuries and it was clear that the barrier had prevented serious injuries or deaths.

The manufacturer reported that as of May 1, 1971, there were 135 barrier installations in 20 states and two foreign countries (12). There had been 81 impacts of the barrier at speeds of up to 65 mph with only one injury. In 80 percent of these impacts, the vehicle was driven away and the accident was not reported.

Design Considerations

Barrier size and configuration must be selected for each site. The barrier configuration will depend on (a) the width of the fixed object to be shielded, (b) the predicted speed and angle of the impacting vehicles, and (c) the available space in the gore, shoulders, and traffic lanes. The presence of curbs and guardrails may also affect the design. A curb immediately in front of the barrier nose could adversely affect barrier performance because the vehicle may vault over the curb, thus preventing the vehicle from impacting the modules at the optimum height for vehicle stability and uniform deceleration. Such a curb should be removed.

The width of the back row of modules should always be greater than the width of the fixed object. This will soften the impacts of those vehicles striking the rear portion of the barrier at an angle and provide some deceleration prior to striking the corners, if any, of the fixed object. The barrier modules should be set back from the traffic lanes to minimize the number of casual vehicular contacts with the barrier and the amount of debris thrown into the traveled way when an impact does occur. Also, space should be left behind the last row of modules so that sand and debris will not be confined and increase the ramping effect of the vehicle.

The lower foot of sand in the 2,100-lb modules provides additional mass as a backup for the front of the barrier. However, the velocity of the vehicle at the time it makes direct contact with the back row of the barrier is not sufficient to explosively displace this sand. Consequently, it is displaced very little and thus tends to form a ramp. The use of 1,400-lb modules in place of 2,100-lb modules in the last row would therefore appear desirable to eliminate this relatively ineffective lower foot of sand.

A recent report (3) stated that some nonimpact failures of these cores had occurred when they were placed on sloped gore areas. The failures occurred only when the strong axis of the core material was perpendicular to the cross slope and consisted of collapse of the core. To prevent this, one should place the strong axis of the form plastic core blocks parallel to the cross slope to prevent collapse of the core due to barrel movement down the cross slope that is induced by traffic vibrations. Also, the manufacturer is studying new core block configurations and new core materials. It might prove advisable to enclose cores made of light, crushable foam plastic with a flexible fine-mesh bag to limit their scatter after a barrier impact.

If placed in climates subject to temperatures below 32 F, the addition of at least 5 percent road salt to the sand should be specified to preclude solidification of the moist sand.

A thin wire or rope may be threaded continuously through all module lids and anchored to the ground at the rear of the barrier to minimize dispersal of lids during impact (Test 242).

A recommended minimum optimum barrier length is 21 to 24 ft. This length provides survivable deceleration levels for 60-mph impacts without taking away excessive recovery area for errant vehicles.

CONCLUSIONS

The results of the three full-scale tests reported here indicate that the hazards presented by many existing gore separation structures and other fixed objects can be significantly reduced by providing protection with energy-absorbing barriers that incorporate sand-filled plastic barrels.

Electronically measured vehicular and dummy decelerations, confirmed by analysis of the photographic data, indicate that occupants of full-sized vehicles (4,700 lb including occupants) that impact these barriers at a speed of 60 mph will, in most cases, sustain little or no injury if they wear a lap belt and shoulder harness, minor injuries if they wear only a lap belt, and moderate injuries if they are unrestrained. However, occupants of smaller vehicles, such as a 2,000-lb VW, may sustain serious injuries even if they are restrained by a lap belt. Because this barrier will provide no significant vehicular redirection, the lateral decelerations sustained during collisions with the barrier will be minimal.

Confinement of the sand will result in a tendency for an impacting vehicle to rise. Thus, the modules placed near the rear of the barrier should not be full (eliminate the relatively ineffective lower foot of sand), and a 2-ft-wide void should be provided between the rear of the barrier and the face of the fixed object to minimize the accumulation of barrier debris and the associated formation of a ramp adjacent to the fixed object.

A considerable amount of debris will be generated during a 60-mph collision with this barrier. However, most of this debris will be propelled straight ahead of the impacting vehicle. Thus, this debris will present a hazard for adjacent motorists only when high-speed, oblique-angle impacts occur unless the debris is scattered by wind. Tying the lids together and encasing the core material will improve this debris problem somewhat.

The reported first cost of approximately 20 installations of this barrier in Connecticut ranged from $1,500 to $3,300 each (3). Each barrel used for the test barriers costs $130. Thus, the material cost for the test barriers was approximately $2,000 because the test barriers contained 15 and 17 modules each. Although little or no routine maintenance should be required, even relatively mild impacts will almost always require replacement of at least several barrels. However, the simplicity of the barrier's construction will permit minimal on-site repair time once debris-removal operations are complete.

ACKNOWLEDGMENT

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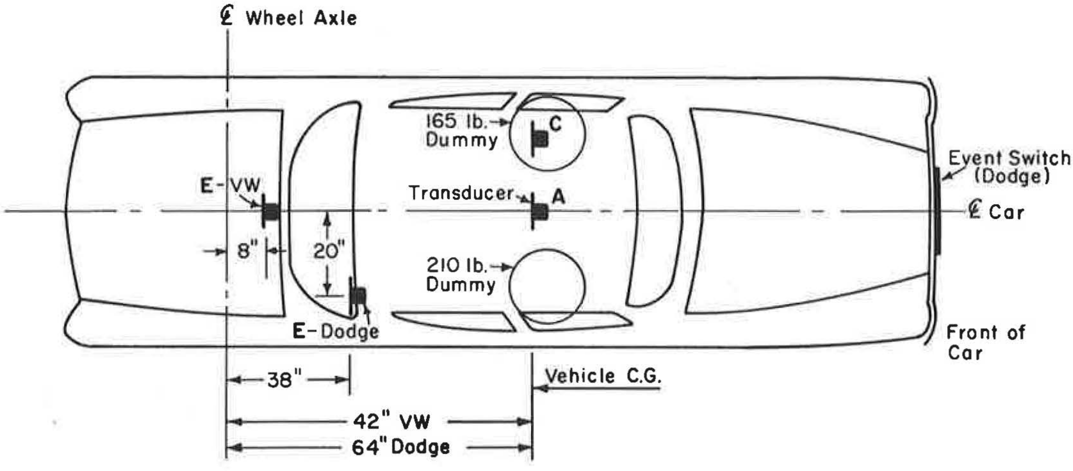
APPENDIX

DETAILS OF BARRIER DESIGN AND PERFORMANCE

Figure 20.

VEHICLE INSTRUMENTATION



Tests 241 & 243
(Dodge)

CHANNEL NO.	LOCATION[1]	DESCRIPTION
1	C	Longitudinal accelerometer - head.
2	C	Lateral accelerometer - head.
3	C	Vertical accelerometer - head.
4	C	Longitudinal accelerometer - chest.
5	A	Longitudinal accelerometer.
6	A	Lateral accelerometer.
7	E	Longitudinal accelerometer.
8	E	Lateral accelerometer.
9	C	Seat belt transducer - lap belt.
13	L	Event switch mounted across front bumper.
	E	Impact-O-Graph with mechanical stylus.

Test 242
(Volkswagen)

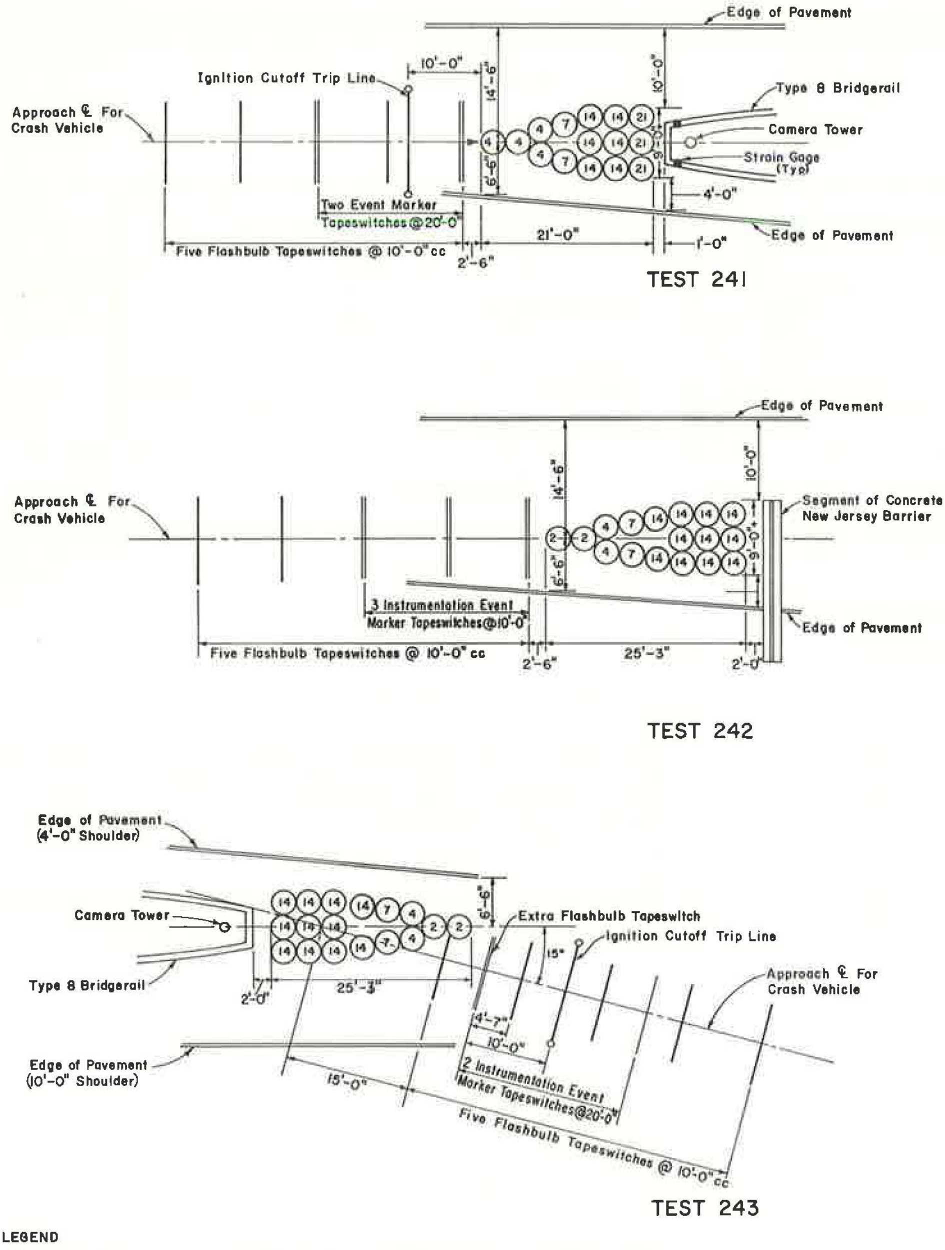
CHANNEL NO.	LOCATION	DESCRIPTION
1	C	Longitudinal accelerometer - head.
2	C	Vertical accelerometer - head.
3	C	Lateral accelerometer - head.
4	C	Longitudinal accelerometer - chest.
5	A	Longitudinal accelerometer.
6	E	Longitudinal accelerometer.
7	A	Lateral accelerometer.
8	E	Lateral accelerometer.
9	C	Seat belt transducer - lap belt.

Note:

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

Figure 21.

BARRIER INSTRUMENTATION

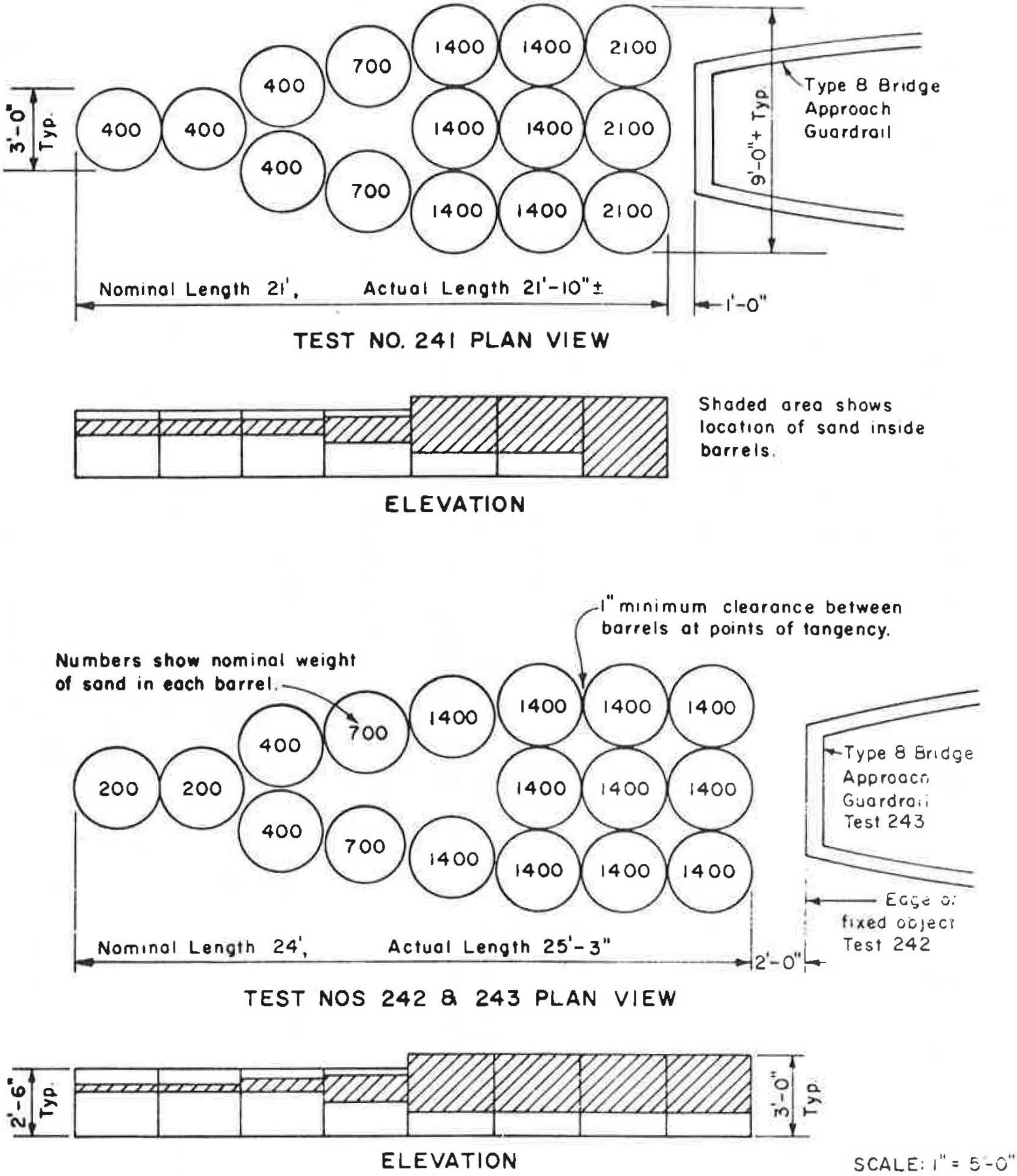


LEGEND

■ - Strain gage on top surface of upper and lower rails, 8 in. behind nose of bridgerail - total 3

(14) - Barrels with nominal wt. of sand in hundreds of pounds.

Figure 22.



TEST BARRIER PLANS

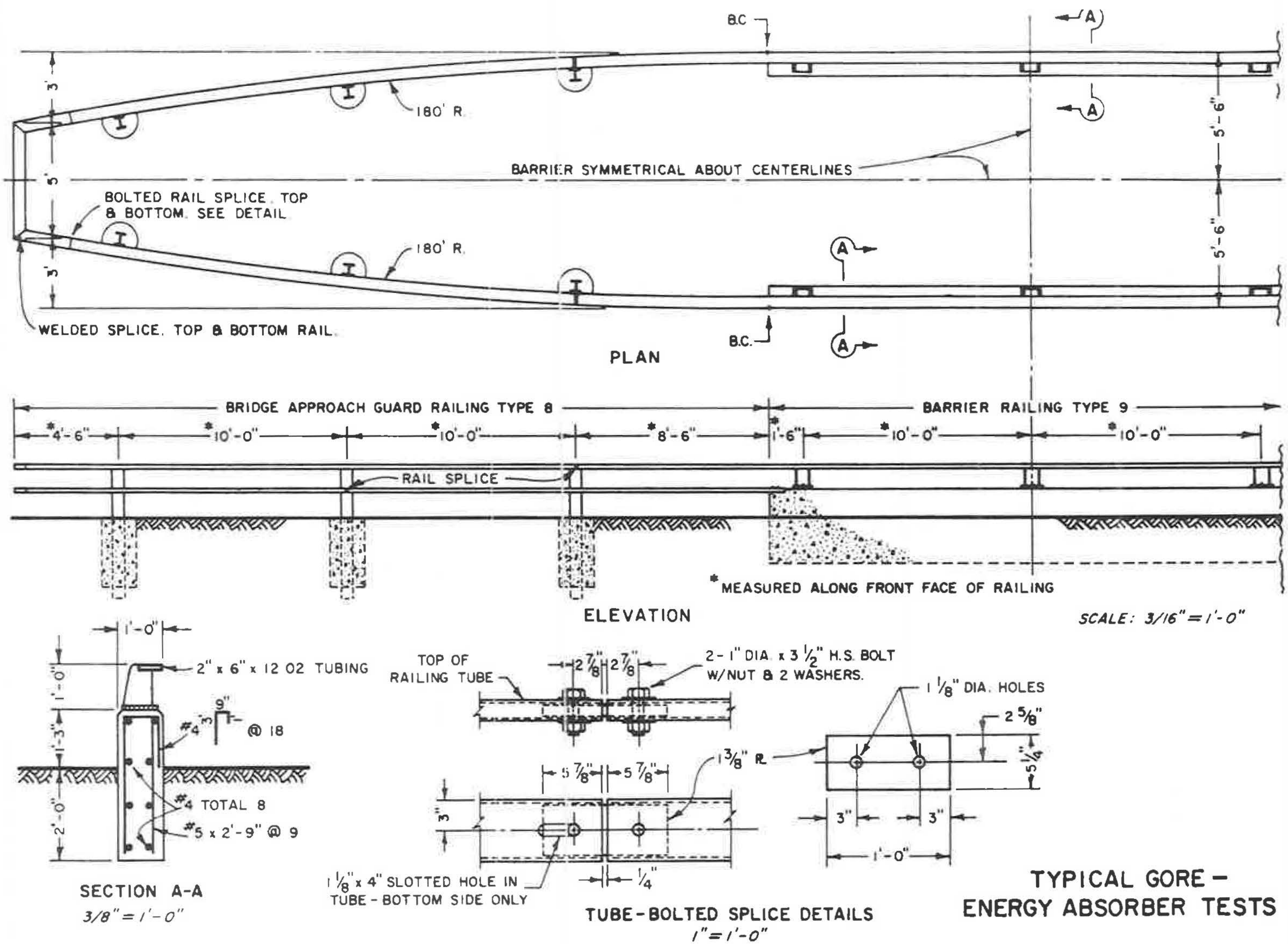
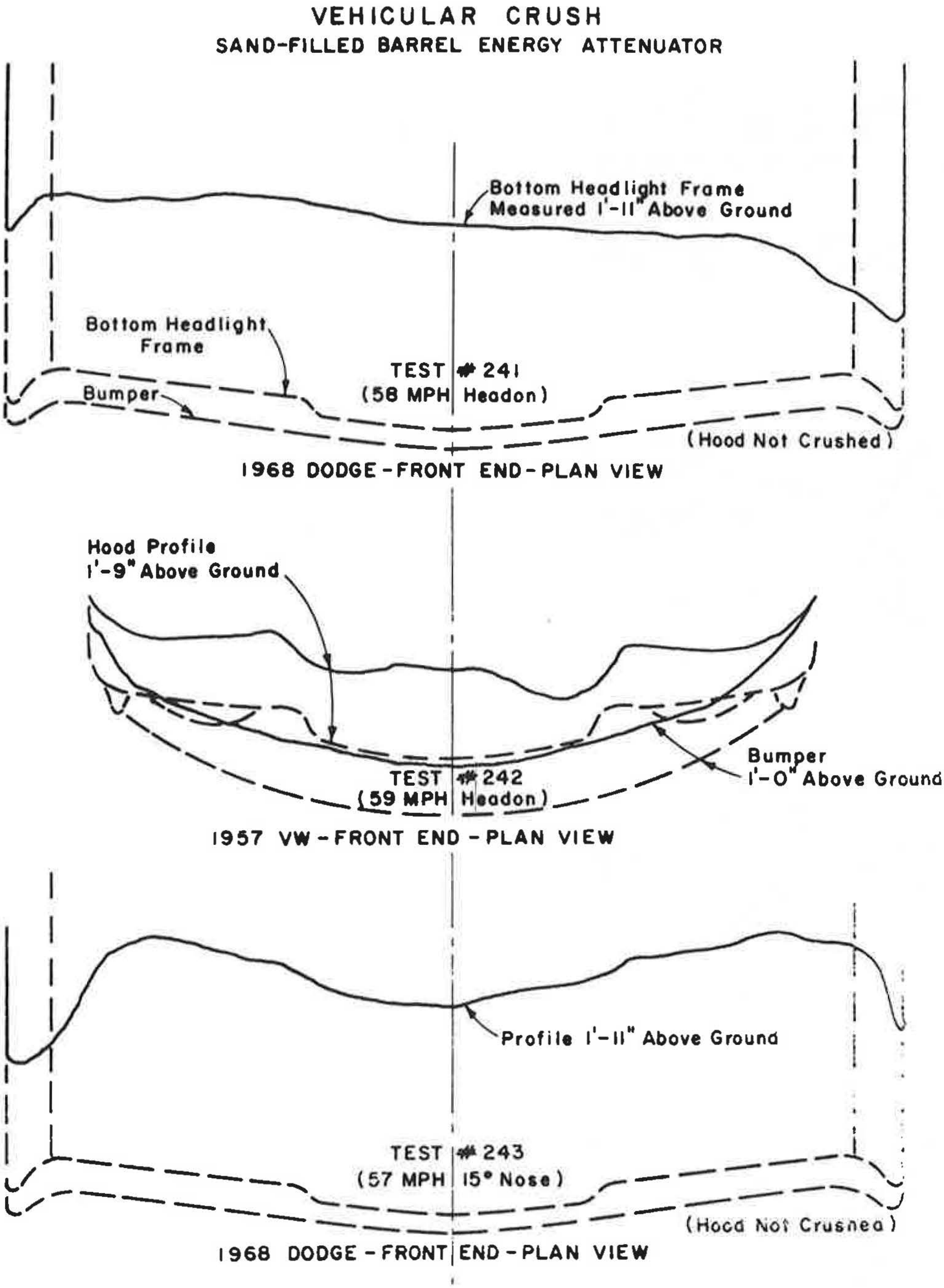

B.C
B.C.
180' R.
BARRIER SYMMETRICAL ABOUT CENTERLINES
BOLTED RAIL SPLICE, TOP & BOTTOM, SEE DETAIL
WELDED SPLICE, TOP & BOTTOM RAIL.
PLAN
BRIDGE APPROACH GUARD RAILING TYPE 8
BARRIER RAILING TYPE 9
RAIL SPLICE
*MEASURED ALONG FRONT FACE OF RAILING
ELEVATION
SCALE: 3/16" = 1'-0"
2" x 6" x 12 OZ TUBING
#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 3/8" R.
1 1/8" x 4" SLOTTED HOLE IN TUBE - BOTTOM SIDE ONLY
1 1/8" DIA. HOLES
TUBE-BOLTED SPLICE DETAILS
1" = 1'-0"
TYPICAL GORE - ENERGY ABSORBER TESTS

Figure 23.

Figure 24.



Dashed lines show precrash profiles. Scale 1" = 1'-0"

Figure 25.

Impact + 0.027 Sec.

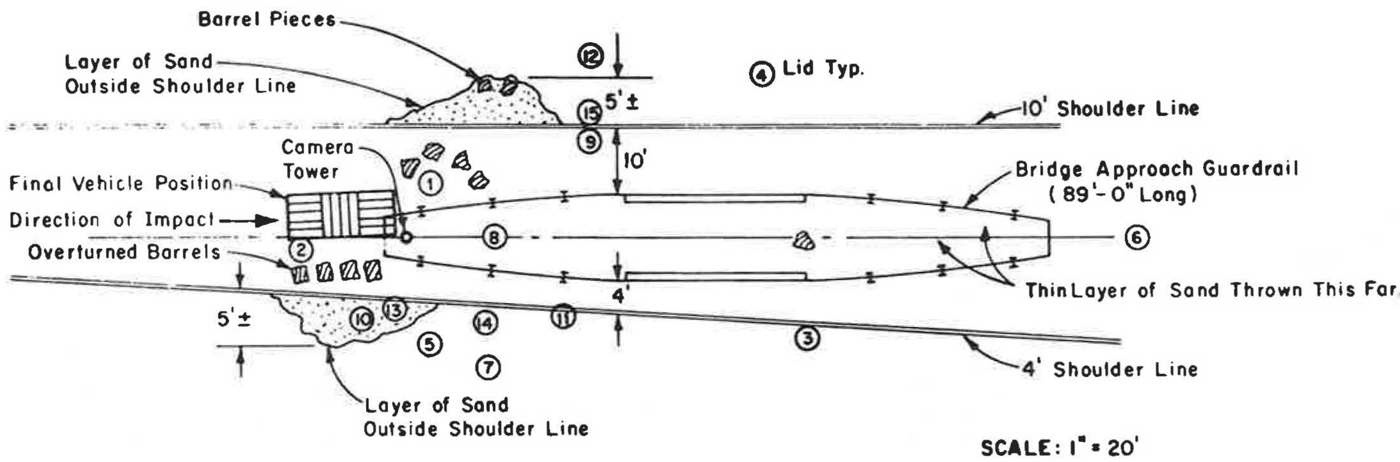
Impact + 0.231 Sec.

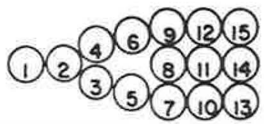
Impact + 0.435 Sec.

Impact + 2.373 Sec.

Test No.	241
Date of Test	May 21, 1970
Vehicle	1968 Dodge
Vehicle Weight (w/dummies and Instrumentation)	4690 lb.
Impact Velocity (V_o)	58.0 mph
Impact Angle	Head-on
Dummy Restraint	Lap Belt
Barrier Depth	21'-10"
No. of Plastic Barrels	15

Deceleration Distance of Passenger Compartment	24'-0"
Maximum Vehicular Deformation at Forestructure	1'-8"
Passenger Compartment Deceleration - Highest 50 ms. avg. - accelerometer record, 100 Hertz	10.7 G's
Vehicular Deceleration - Avg. value based on $V_o^2 = 2as$ where s = 24.0' (stopping distance)	4.7 G's
Gadd Severity Index (Dummy's head)	185





ORIGINAL BARREL CONFIGURATION & NUMBERS

DEBRIS LOCATION DIAGRAM
TEST 241

Figure 26.

Figure 27.

Impact + 0.022 Sec.

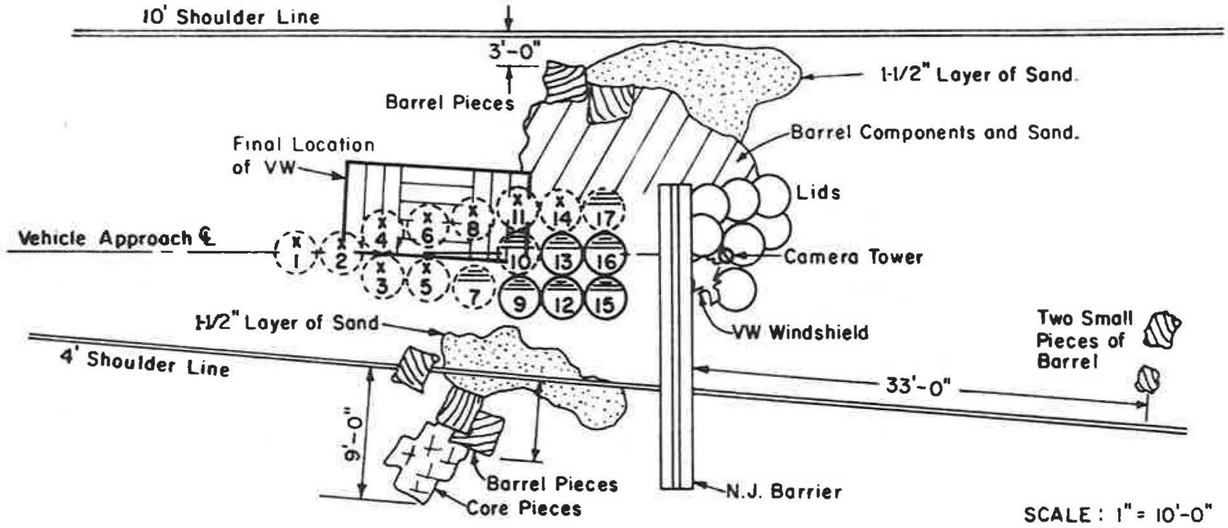
Impact + 0.163 Sec.

Impact + 0.586 Sec.

Impact + 4.536 Sec.

Test No.	242
Date of Test	September 4, 1970
Vehicle	1957 Volkswagen Sedan
Vehicle Weight (w/dummy & Instrumentation)	1940 lbs.
Impact Velocity (V_o)	59.0 mph
Impact Angle	Head-on
Dummy Restraint	Lap belt
Barrier Depth	25'-3"
No. of Plastic Barrels	17

Deceleration Distance - Passenger Compartment	19'-0"
Maximum Vehicular Deformation at Forestructure	8"
Passenger Compartment Deceleration - Highest 50 ms. avg. - Accelerometer Record, 176 Hertz	8.7 G's
Vehicular Deceleration = Avg. value based on $V_o^2 = 2as$ where s = 19.0' (stopping distance)	6.1 G's
Gadd Severity Index (Dummy's head)	1280



NOTES:

1. Barrels 9, 12, 13, 15, & 16 were all intact with lids on; two were slightly compressed. No. 16 was 9" from N.J. Barrier.
2. Barrels with an (x) were broken and thrown out of position.
3. All lids remained tied together.
4. Small number of core pieces under car.
5. All 4 wheels of VW on ground.
6. Barrels 7 & 10 were compressed but unbroken, lids were off.
7. Barrel 17 was compressed, unbroken, lid off, leaning against N.J. Barrier.

DEBRIS LOCATION DIAGRAM
TEST 242

Figure 28.

Figure 29.

Impact + 0.012 Sec.

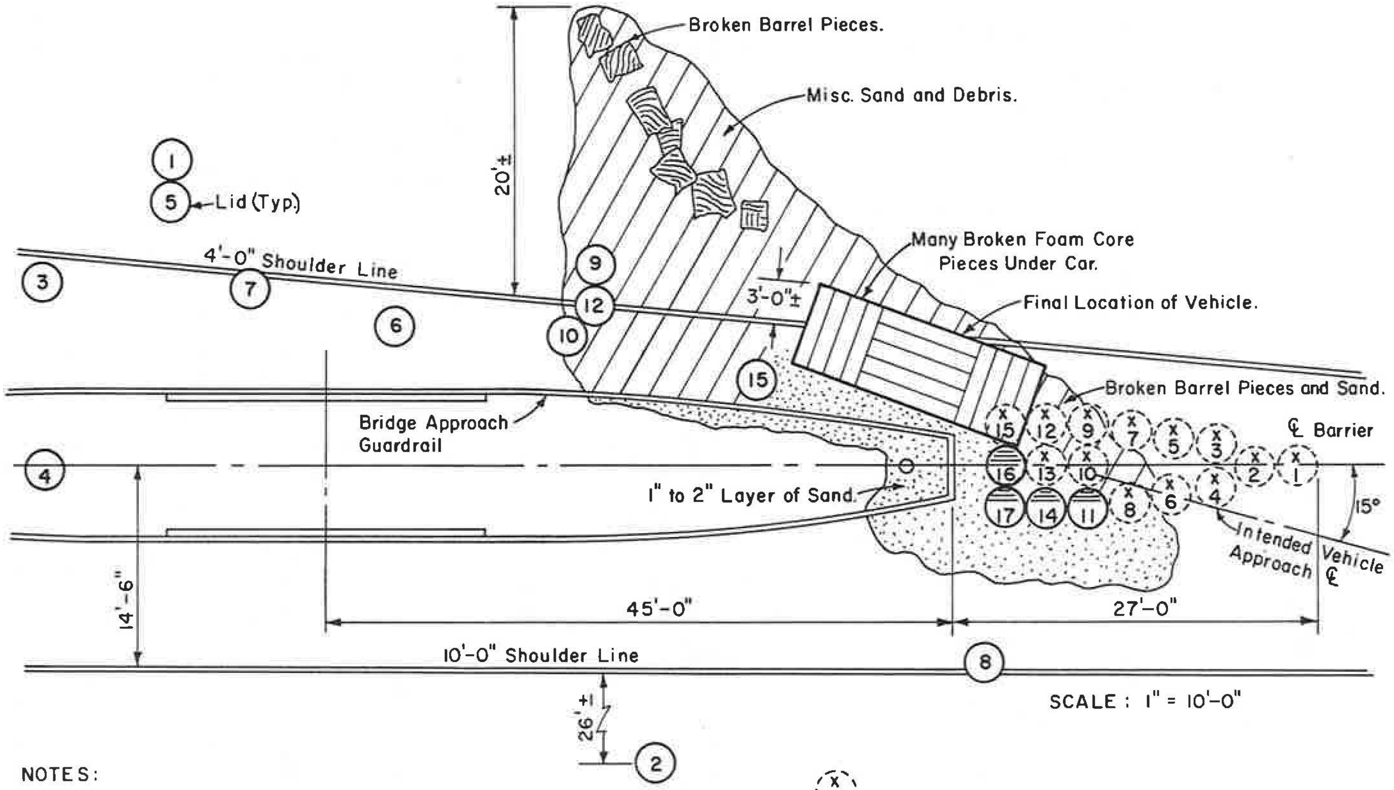
Impact + 0.180 Sec.

Impact + 0.348 Sec.

Impact + 8.880 Sec.

Deceleration Distance - Passenger Compartment	39'-0"
Maximum Vehicular Deformation at Forestructure	1'-9"
Passenger Compartment Deceleration - Highest 50 ms. avg. - accelerometer record, 176 Hertz	7.9 G's
Vehicular Deceleration - Avg. value based on $V_o^2 = 2as$ where s = 39'-0" (stopping distance)	2.8 G's
Gadd Severity Index (Dummy's head)	580

Test No.	243
Date of Test	September 24, 1970
Vehicle	1968 Dodge
Vehicle Weight (w/dummy & instrumentation)	4770 lbs.
Impact Velocity (V_o)	57 mph
Impact Angle	15° nose
Dummy Restraint	Lap belt
Barrier Depth	25'-3"
No. of Plastic Barrels	17



NOTES:

1. Many small, broken foam core pieces blown in all directions by wind.
2. Barrels 11, 14, 16 & 17 still upright, but squashed out of shape with lids still on.
3. Vehicle struck barrier 1 foot to right of intended vehicle approach centerline.
4. (x) x indicates barrel was demolished.
5. Shoulder width measured at last row of barrels.

DEBRIS LOCATION DIAGRAM
TEST 243

Figure 30.