DYNAMIC TESTS OF AN ENERGY-ABSORBING BARRIER EMPLOYING STEEL DRUMS

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The results of three full-scale vehicle impact tests of an energy-absorbing barrier employing 55-gal tight-head steel drums are reported. The 19.6-ft long test barriers were designed as gore installations. The tests were conducted with 1968 sedans weighing approximately 4,700 lb and traveling at speeds of from 54 to 64 mph. The tests were run head-on and at 9 deg with the barrier axis into the barrier nose, and at 11 deg with the barrier axis midway along the side of the barrier.

The head-on and angle impacts into the nose of the barrier resulted in vehicle passenger-compartment decelerations less than the 12-g limit suggested by the Federal Highway Administration. Vehicle damage was moderate. The vehicle remained stable and upright during impact. The impact into the side of the barrier did not produce completely satisfactory results. The vehicle was redirected but by the bridge approach guardrail behind the barrier.

The results of the three tests indicate that the barrier effectiveness in reducing the severity of most impacts is such that it should be used operationally on an experimental basis. However, future refinements in the design need to be made, particularly with regard to redirection of vehicles that collide with the side of the barrier. A study of accident statistics and human tolerance to deceleration is also summarized. This study indicated that the deceleration imparted to the impacting vehicle should be as low as possible, perhaps lower than in some current criteria.

•ABOUT HALF of all the fatalities on the California freeway system in 1967 and 1968, an average of 430 a year, were caused by vehicles that ran off the road. Of this number, 225 fatalities (over 25 percent of all freeway fatalities) were the result of hitting a fixed object. The types struck most frequently were abutments and piers, bridge rails, guardrails at fixed objects, steel sign poles, light poles, and cable types of median barriers.

In an attempt to decrease the frequency of these relatively severe accidents, the California Division of Highways is now striving to provide a minimum of 30 ft of recovery area alongside the traveled way into which an out-of-control vehicle can intrude without striking an immovable or unprotected fixed object. Every effort is first being made to eliminate the fixed object. If it cannot be eliminated, an attempt is then made to incorporate breakaway features. In cases where the fixed object can neither be eliminated nor made to yield, protection in the form of guardrails is now being provided.

Recent improvements in bridge approach guardrailing, confirmed by full-scale tests (1, 2), should minimize the probability of impact into the ends of bridge barrier rails. However, one of the remaining problems, for which no satisfactory solution has been developed, is protection from hazardous fixed objects located in the gore area

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at freeway off-ramps. Collisions with the concrete wedge-shaped deflectors or large overhead sign supports or both, often found in these gores, are usually very severe. In an effort to alleviate this problem, the California Division of Highways has been involved for the last 2 years in a research program to investigate and develop energy-absorption barriers for use in gore areas. Three types of energy-absorption barriers have been tested to date. These barriers used (a) water-filled plastic cells, (b) 55-gal tight-head steel drums, and (c) plastic drums containing sand. The results of tests of barriers employing water-filled plastic cells are documented in a report included in this Record (4). The testing of a barrier employing sand-filled plastic containers has just been completed and will be reported. The three tests reported here were of barriers containing 55-gal tight-head steel drums as the primary energy-absorbing mode.

The results of research at the Texas Transportation Institute (TTI) indicated that the resistance to deformation of modified 55-gal tight-head steel drums could be effectively utilized to decelerate a standard-size vehicle traveling 60 mph (3). A series of tests at TTI consisted of three 50 to 60 mph head-on tests and three 40 to 50 mph tests at angles of 20 deg (one test) and 30 deg (two tests) with the barrier axis. The weights of the test vehicles varied from 3,200 to 4,400 lb. Although the results of these six TTI tests were generally favorable, additional testing using heavier vehicles (4,700 lb) impacting head-on and at 10 to 15 deg angles into the front and side of the barrier were felt to be more representative of the conditions encountered on California highways. The utilization of a fendering system similar to that employed for the water-filled cell barrier (4) was also considered advisable. Consequently, the series of three tests reported herein was conducted.

OBJECTIVE

The objective of this research was to conduct instrumented vehicular impact tests of energy-absorbing barriers incorporating 55-gal tight-head steel drums and, based on the results of these tests, determine the degree to which these barriers would minimize the hazards created by many existing 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 energy-absorbing barrier should be at least as effective as the anchored W-beam guardrail currently used in California to redirect vehicles impacting at oblique angles into the side of the barrier.
3. The barrier components should not be susceptible to dislodgment or ejection onto the traveled way such that they become a hazard to adjacent traffic when an impact occurs.
4. First cost and maintenance costs should be economically feasible.
5. On-site repair time should be minimal because of the safety hazards to maintenance personnel and adjacent traffic when field repairs are in progress.

DESCRIPTION OF TEST BARRIER

As stated previously, the records of the California Highway Patrol for the years 1967 and 1968 show that about 25 percent of all California freeway fatalities occurred when vehicles ran off the road and collided with fixed objects. Another tabulation of California freeway fixed-object fatal accidents for the years 1965 through 1967 contains a total of 640 for this 3-year period. Of this number, 548 involved a vehicle traveling at an estimated speed of over 50 mph at impact, with 171 of these 548 traveling over 70 mph. A further breakdown of this total of 640 accidents indicates that 376 standard-size cars, 159 compact cars, and 105 other miscellaneous vehicles were involved. These results indicate that energy-absorbing barriers must be designed to cushion impacts of standard-size cars traveling at high speeds.

In an effort to determine the most prevalent impact angle, 47 California Highway Patrol (CHP) accident reports involving fatalities at gore installations during 1965-

Figure 2.

Figure 3.

component of the impact forces. The trailing edge of each fender panel overlapped the leading edge of the next rearward panel in a fish-scale manner such that barrier crush would not be restricted during a head-on impact. Light springs were used to maintain the fender panels in the closed position (Fig. 2).

Lateral and vertical restraint was provided by four $^3/_4$-in. wire ropes attached to fabricated steel T-sections embedded in cast-in-place concrete anchors. The wire rope was threaded between the drums so that the drums would be free to slide backward during impact and then attached to the bridge approach guardrail using swaged fittings. A slight pre-impact tensile force was applied to the cables, which were aligned in a straight line to minimize the slack, and subsequent lateral movement that develops during an oblique-angle impact. The concrete anchors were located so that the front drums would receive as much lateral support as possible from cables placed low enough to minimize the possibility of snagging the impacting vehicle (Fig. 3).

The barrier was elevated 4 in. above the ground with U-bolts bolted to the bottom of each drum. The drums were bolted together at all points of contact. For test 221, bolts were placed 2 in. below the drum tops and 2 in. above the drum bottoms; wood spacer blocks were used between drums. For tests 222 and 223, the bolts were located at the two rolling hoops, and a steel washer was placed between the drums so that the cable could be threaded between the drums easily. Because the drums were bolted together in a relatively rigid assembly, some of the U-bolt chairs were not in contact with the slightly irregular ground surface at all times. (Bolts were used in lieu of the welded connections used in the TTI test barriers because, although slightly more expensive initially, it was felt that the bolted connections would simplify and accelerate barrier repairs.)

DESCRIPTION OF TESTING

All of the tests reported were conducted on an unused portion of a runway at the Lincoln Municipal Airport, Lincoln, Calif. The test vehicles used for this series were 1968 Dodge sedans. The test vehicles were operated remotely from a control car that followed them along the approach line. A trip switch cut off the ignition in the test vehicle 10 ft prior to impact. A more complete description of the control system is given elsewhere (6).

1967 were examined and classified (Table 1). These data were based on the sketches of the accident site included in the CHP officers' reports. In many cases, no barriers were present so the impact angle was estimated assuming an energy-absorbing barrier was in place. Also, funds were not available to locate and examine all the police reports involving gores. Thus, the sample was small and the accuracy of the data definitely subject to question. In any event, the study indicated that a number of collisions were side-angle impacts (most less than 10 deg); hence, energy-absorbing barriers should be capable of redirecting vehicles impacting at oblique angles in addition to effectively decelerating vehicles impacting head-on.

TABLE 1

ANALYSIS OF 47 FREEWAY FATAL ACCIDENTS INVOLVING GORES

Category	Fatalities			
	1965	1966	1967	Total
Angle of Impact[a, b]				
Head-on[c]	6	5	8	19
Flat angle (≤ 10 deg)	4	8	6	18
Large angle (> 10 deg)	3	4	1	8
Location[a]				
Nose	11	12	12	35
Side	2	6	4	12
Barrier or object				
Concrete	2	11	5	18
Guardrail	8	6	8	22
Pole[d]	2	1	2	5
Concrete curb	1	0	1	2

Note: The 1966 and 1967 accidents all involved one fatality per accident.

[a]When a pole was impacted, an imaginary barrier was assumed in front of it, and the vehicle path was studied to determine the location and angle of a hypothetical barrier impact.

[b]No estimate was made on two accidents.

[c]Includes broadside impacts.

[d]Includes both sign posts and lighting standards.

Thus, the test barrier was designed to decelerate a 4,700-lb vehicle impacting head-on or at an angle of 10 deg with the barrier axis at an impact velocity of 60 mph without subjecting the passenger compartment to an average deceleration greater than 10 g. (This choice of a relatively shallow 10-deg angle has since been justified, at least to some extent, by reports from several other states indicating that in-service energy-absorbing barriers are being impacted head-on in almost all cases.) The construction details for the barrier are shown in Figure 17 of the Appendix.

The primary energy-absorbing media used for the test barrier were 55-gal tight-head steel drums. Forty-one of these drums, which were approximately 24 in. in diameter and weighed 38 lb each, were used for each barrier. The drums contained 18-gage tops and bottoms and 20-gage sides. The tops and bottoms each contained one 7-in. diameter hole to decrease the magnitude of the force required to crush the drum (Fig. 1). The barrier design procedure used was developed and reported by the Texas Transportation Institute (3). The design calculations are given elsewhere (5).

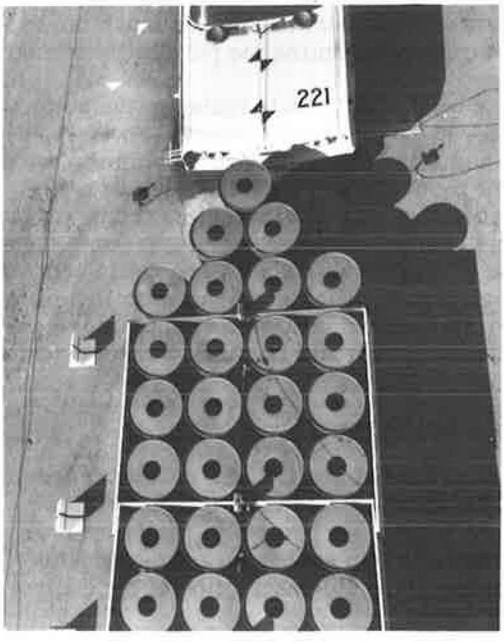

Figure 1.

In an effort to provide an effective redirective capability, a system consisting of three 1-in. thick plywood diaphragms and eight 1-in. thick plywood fender panels was used for the first test barrier. The diaphragms were intended to provide support for the fender panels and to transmit the lateral component of the impact force to the cable system when oblique-angle impacts occurred. Although not of primary importance, it was felt that the lateral distribution of the impact forces provided by the diaphragms during an offset head-on impact would also be of some benefit.

The fender panels, attached to the diaphragms using steel hinges, were intended to act as beams when resisting the lateral and 6). Maximum vehicular crush was 16.5 in.

All the drums in the barrier were deformed (Figs. 7 and 8). The cables were slack but undamaged. The plywood fender panels were badly cracked and splintered but remained attached to the barrier as it was deformed around the nose of the bridge approach guardrail. The drums crushed one row at a time, in successive order, as had been assumed in the design procedure. Figure 20 in the Appendix shows additional test data.

Figure 5.

Test 222

The barrier used for test 222 was identical to that used for the first test with the following exceptions: (a) the length of the fender panels was decreased to minimize contact of the bottom corner of the trailing edge of these panels with the ground (this required an increase in the number of diaphragms used); and (b) the drum-to-drum bolted connections were made at the rolling hoops to eliminate the need for wood spacers and make it easier to tighten the lower bolts from the top of the barrier.

The 4,760-lb 1968 Dodge sedan impacted the left side of the barrier 10.2 ft in front of the bridge approach guardrail at a speed of 59.8 mph and an angle of 11 deg with the barrier. The vehicle was redirected, but minimal redirectional forces were provided by the drums as the vehicle axis was displaced 12 in. laterally from its location at impact before any redirection began (i.e., crabbing occurred). At this time, solid contact with the bridge approach guardrail had been established.

Figure 6.

Figure 7.

Instrumentation

For tests 221 and 222, a telemetry instrumentation system on loan from the Federal Highway Administration was used (7). It consisted of seven channels of FM telemetry for use in the crash vehicle or dummies and seven hardwire channels for use on the test barrier and backup bridge approach guardrail. The system included seven accelerometers and two seat-belt force transducers and all the necessary signal-conditioning equipment. The dynamic data from these transducers were recorded on a 14-channel analog magnetic tape recorder. For tests 222 (partial) and 223, data from instrumentation on the test vehicle were transmitted through an umbilical cord (hardwire) system. All the accelerometers in the test vehicle and the dummies were of the unbonded strain-gage type. Additional data regarding the vehicular and barrier instrumentation are shown in Figures 18 and 19 of the Appendix.

Impactographs (mechanical stylus devices designed to measure acceleration) were placed in the chest cavity of the dummy in the passenger position and also on the floor of the test vehicle.

Photography

High-speed photography was used to study the vehicular, dummy, and barrier kinematics for all three tests. Eight Photosonic cameras operating at frame rates of 200 to 400 frames per second were placed as shown in Figure 19 of the Appendix. Cameras 1 and 2 were mounted overhead. Camera 8 was placed in the crash car to record the movement of the dummies. Red-orange pips were placed on the edge of the film at a rate of 1,000 ± 5 pips per second, using Adtrol timing light generators, to provide a means of determining the frame rate of each camera.

The authors' original study (5) contains a discussion of the data obtained with the photographic, mechanical, and electrical data-acquisition systems described here.

TEST RESULTS

Test 221

A 4,690-lb 1968 Dodge sedan impacted the barrier head-on at a speed of 64.2 mph. Deceleration was relatively constant. However, the record of the accelerometers on the floor of the vehicle indicated that the barrier bottomed out. The maximum average 50-millisecond (msec) passenger-compartment deceleration, based on accelerometer data, was 10.3 g and occurred at the end of the collision. The average deceleration (based on impact velocity and the total passenger-compartment stopping distance) was 8.4 g.

This magnitude of deceleration exceeds the tolerable limits for unrestrained occupants, as discussed later. Thus, unrestrained occupants probably would have sustained moderate to severe injuries. Occupants restrained by seat belts or seat belts and shoulder harnesses would have sustained no more than moderate injuries in most cases.

Figure 4.

There was a noticeable vertical force imparted to the vehicle as shown by the vehicular rise in Figure 4. The rise was caused at least in part by the right-front wheel riding up on the cable. There was virtually no vehicular rebound.

Vehicular damage consisted of some bumper deformation, a cracked windshield, a jammed door on the right-front side, damage to both front quarter panels, 3.4 in. of steering column collapse (energy-absorbing steering column), and some dashboard deformation (Figs. 5

Figure 8.

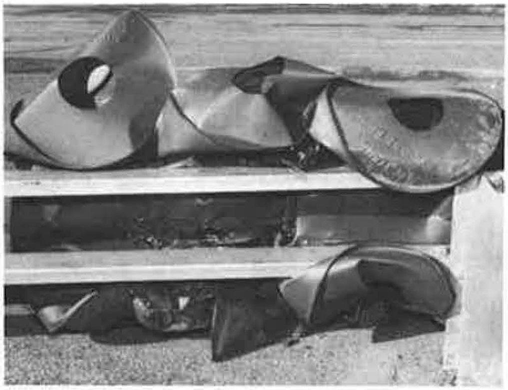

Figure 9.

The force of the impact caused a clamping action to take place between the rear drums and the bridge approach guardrail, thus preventing drum ejection (Fig. 9). Additional barrier damage consisted of crushing of the outside drums in the back half of the barrier on the impacted side. All the fender panels beyond the point of impact were torn off the barrier. There were some failures of hinge pins; the ends of the last few diaphragms were broken off on the impact side. There was an unacceptable amount of debris deposited in what would be the adjacent traveled way. Some of the fender-panel fragments were thrown approximately 155 ft from the point of impact (Figs. 10 and 11).

The maximum 50-msec average passenger-compartment decelerations recorded were 5.3 g laterally and 6.6 g longitudinally. Thus, unrestrained occupants would probably have sustained moderate injuries. Although the lateral deceleration was slightly in excess of the tolerance limits for seat-belt restrained occupants, little or no injury would probably be sustained in most collisions of this severity if any occupant restraints were in use at the time of the collision.

Vehicle damage included severe crushing of the right-front quarter panel, jamming of the right-front door, scars on the right doors and right-rear panel, and displacement of the radiator to the point of touching one fan blade (Fig. 12). Figure 21 in the Appendix shows additional test data.

Figure 10.

Figure 11.

Figure 12.

Figure 13.

Test 223

Test 223 consisted of a 4,740-lb 1968 Dodge sedan impacting the same barrier design used for the previous test. The vehicle impacted the left corner of the barrier nose at a speed of 53.6 mph and an angle of 9 deg. At impact, the center of the front of the vehicle was offset 3.5 ft from the barrier axis. Significant elastic lateral deflection of the barrier took place as the vehicle penetrated 13.2 ft, rotated clockwise, and then rebounded 2.5 ft. The maximum 50-msec average passenger-compartment deceleration, based on accelerometer data, was 10.9 g longitudinally. The average passenger-compartment longitudinal deceleration was 7.2 g. Deceleration of this magnitude would, in most cases, result in moderate to severe injury for an unrestrained occupant, minor to moderate injury for an occupant restrained by a seat belt, and little or no injury for an occupant using both a seat belt and a diagonal shoulder harness. The position of the vehicle after the collision was such that it would have been a hazard to adjacent traffic (Fig. 13).

Vehicle damage consisted of a crimp in the roof on the passenger side, extensive hood deformation, slight displacement of the left-front quarter panel, and 3.6 in. of energy-absorbing steering column collapse (Figs. 14 and 15). There was a slash high on the cheek of the dummy driver, and the windshield was broken in front of the dummy passenger. The dummy passenger was badly cut on the tip of the bridge of his nose, over his right eye and on his forehead, and on the right side of his face and cheek. (The removal of this dummy's lower legs before the crash may have contributed to some excessive movement of his upper body during the collision.)

Figure 14.

Figure 15.

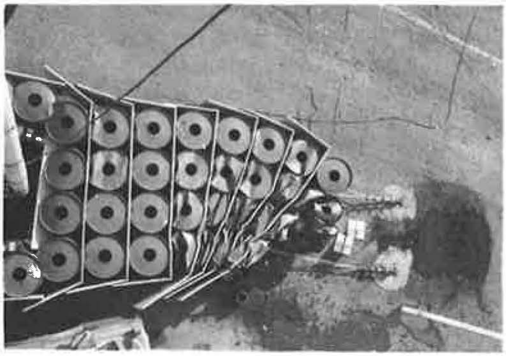

Figure 16.

All but two drums were damaged. The left-front and the right-rear plywood fender panels were the only ones damaged. It appeared that the impact force was transmitted somewhat diagonally from the left-front to the right-rear portion of the barrier (Fig. 16). The left-front portion of the barrier was crushed much more than the right-front side. The film record shows the drums crushing one row at a time in successive order with the exception of the back row, which was deformed soon after impact. This was very similar to the dynamic barrier compression sequence observed during test 221.

The movies showed the car being ejected outward from the barrier due to the elastic energy stored within the barrier. The clockwise rotation of the car was probably caused by a moment couple consisting of the vehicular momentum, acting through the vehicle center of gravity, and this elastic energy, acting through the centroid of the vehicle-barrier contact interface. Figure 22 of the Appendix shows additional test data.

DISCUSSION OF RESULTS

In addition to studying accident records, it is necessary to investigate the various aspects of human and vehicle tolerance to deceleration before an energy-absorbing barrier can be designed effectively.

Longitudinal decelerations (Appendix Fig. 23) as high as 40 g have been tolerated by fully restrained, healthy young male volunteers for up to 100 msec with no ill effects (8). Acceleration above this level caused extreme chest pain, difficulty in breathing, and visual malfunctions such as blurred vision, pain, headache, and retinal hemorrhage. The deceleration of a 160-lb driver in a head-on rigid barrier crash at 22 mph is about 25 g (9). The same reference reported that few serious injuries occurred in vehicle collisions at 20 mph. This would indicate that a tolerable occupant longitudinal deceleration of 25 g would be appropriate.

A 12-g maximum deceleration is permitted for devices classified as satisfactory when evaluated under the 4S program of the Federal Highway Administration (10). This 4S criterion is intended to provide a survivable environment and, as such, applies to the decelerations sustained by the passenger compartments of 2,000- to 4,500-lb vehicles. This criterion was based on the tentative tolerable limits of deceleration proposed by Cornell Aeronautical Laboratory in 1961 (11) given in Table 2. The duration of impact must be less than 200 msec and the rate of onset less than 500 g per second.

Table 2, although helpful as a rough guide for vehicle decelerations, does not give completely the shape of the deceleration pulse, which can vary considerably and still satisfy the 12-g average limitation.

A small but detailed accident study has been conducted at Cornell University to determine the benefits of seat belts in other than the prevention of ejection (12). The study showed no significant reduction in the severity of injuries due to the wearing of seat belts. It did determine that the type of injury varied; namely, whereas unbelted occupants impacted the windshield, belted occupants jackknifed toward and hit the steering wheel or instru-

TABLE 2

DECELERATION LIMITS

Occupant Restraint	Maximum Deceleration (g)		
	Lateral	Longitudinal	Total
Unrestrained	3	5	6
Seat belt	5	10	12
Seat belt and shoulder harness	15	25	25

ment panel and received head injuries in a slightly different manner. This suggests that the deceleration of the vehicle by the protective barrier may need to be almost as low for seat-belted passengers as for unrestrained passengers in order to minimize head injuries during a collision in which ejection would be quite unlikely even if no restraint were used.

Another study has been completed in which average longitudinal vehicular deceleration was related to the proportion of those vehicles in which unrestrained occupants sustained injuries (13). This study indicated that a 12-g vehicular deceleration will result in occupant injuries in the majority of cases. When this study is tied to one regarding general use of seat belts (12), one can conclude that, even with energy-absorbing barriers designed for maximum vehicle decelerations of 12 g (60-mph impact velocity), the 65 to 70 percent of the public who disdain the use of seat belts will probably be injured in a major collision with these barriers (10). Consequently, for the purposes of this study, the deceleration limits established by Cornell Laboratory (Table 2) were applied to the maximum average vehicle passenger-compartment deceleration measured over a 50-msec period. It is acknowledged that higher decelerations could be safely tolerated for shorter time intervals.

An injury study by UCLA indicated that impact into the steering wheel and column is the most common and also most dangerous cause of injuries during nonfatal accidents. Therefore, it would be well to adjust the design of the energy-absorbing barrier, with due consideration given to the energy-absorbing properties of steering columns in current vehicle models.

A paper from a General Motors seminar (14) includes information on energy absorption in steering columns. This type of column was first installed in 1967 in cars made by General Motors, American Motors, and Chrysler. This column was designed to collapse a maximum of 8¼ in. under loads no greater than 1,000 to 1,500 lb. The Federal Motor Vehicle Safety Standards limit the impact force of a simulated body traveling at a relative velocity of 15 mph to 2,500 lb when impacting the steering control system (15). Accident statistics from 257 cases involving the steering column in 1967 model cars traveling at speeds of 10 to 125 mph show that the column collapsed more than 5 in. in only six cases. A more detailed study of 88 head-on accidents out of the total 257 cases revealed two fatalities. This study also indicated that, at 60 mph, the maximum column compression for all 88 cases was slightly less than 8 in. and the average compression was about 3½ in. There were numerous cases of steering column compression with closure speeds of 50 to 60 mph that resulted in no injury to the chest.

The main conclusions that can be drawn from this limited review of the effect of energy-absorbing steering columns is that recent improvements to the steering column are probably reducing fatalities and serious injuries. The severity of those chest injuries being sustained will decrease even more if the passenger-compartment longitudinal deceleration is decreased. (This conclusion is based on the assumption that no occupant ejection occurs.) The steering column collapse of 3.4 in. for test 221 and 3.6 in. for test 223 indicates that there would be a good possibility of little or no chest injuries being sustained during 60-mph head-on or nearly head-on collisions with the drum type of energy attenuator. This correlates well with the predicted severity based on passenger-compartment decelerations.

CONCLUSIONS

The results of the three full-scale tests reported herein 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 incorporating 55-gal tight-head steel drums. Occupants of full-size vehicles (4,700 lb. including occupants) impacting these barriers at 60 mph will, in most cases, sustain little or no injury if wearing a seat belt and shoulder harness, minor injuries if wearing only a seat belt, and moderate injuries if unrestrained.

The fendering system tested did not satisfactorily redirect a vehicle impacting midway along the side of the barrier at an 11-deg angle with the barrier axis. Also, the debris that resulted from this collision would definitely have been hazardous to adjacent traffic. Consequently, the fendering system included on the test barriers should not be used for an operational installation.

The reported average first cost of each of three freeway installations of energy-absorbing barriers incorporating 55-gal drums near Houston, Texas, was $3,600. As would be the case with most barriers, some on-site preparation was included in this cost. These barriers contained no fendering systems.

The maintenance costs for this barrier would probably be relatively high. Although no routine maintenance should be required, with the possible exception of checking the cable tension, relatively mild impacts will probably necessitate considerable repair work to restore the barrier's effectiveness. However, on-site repair time could be relatively short if prefabricated modules were used.

ACKNOWLEDGMENT

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Appendix

DETAILS OF HIGHWAY GORE DESIGN AND PERFORMANCE

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

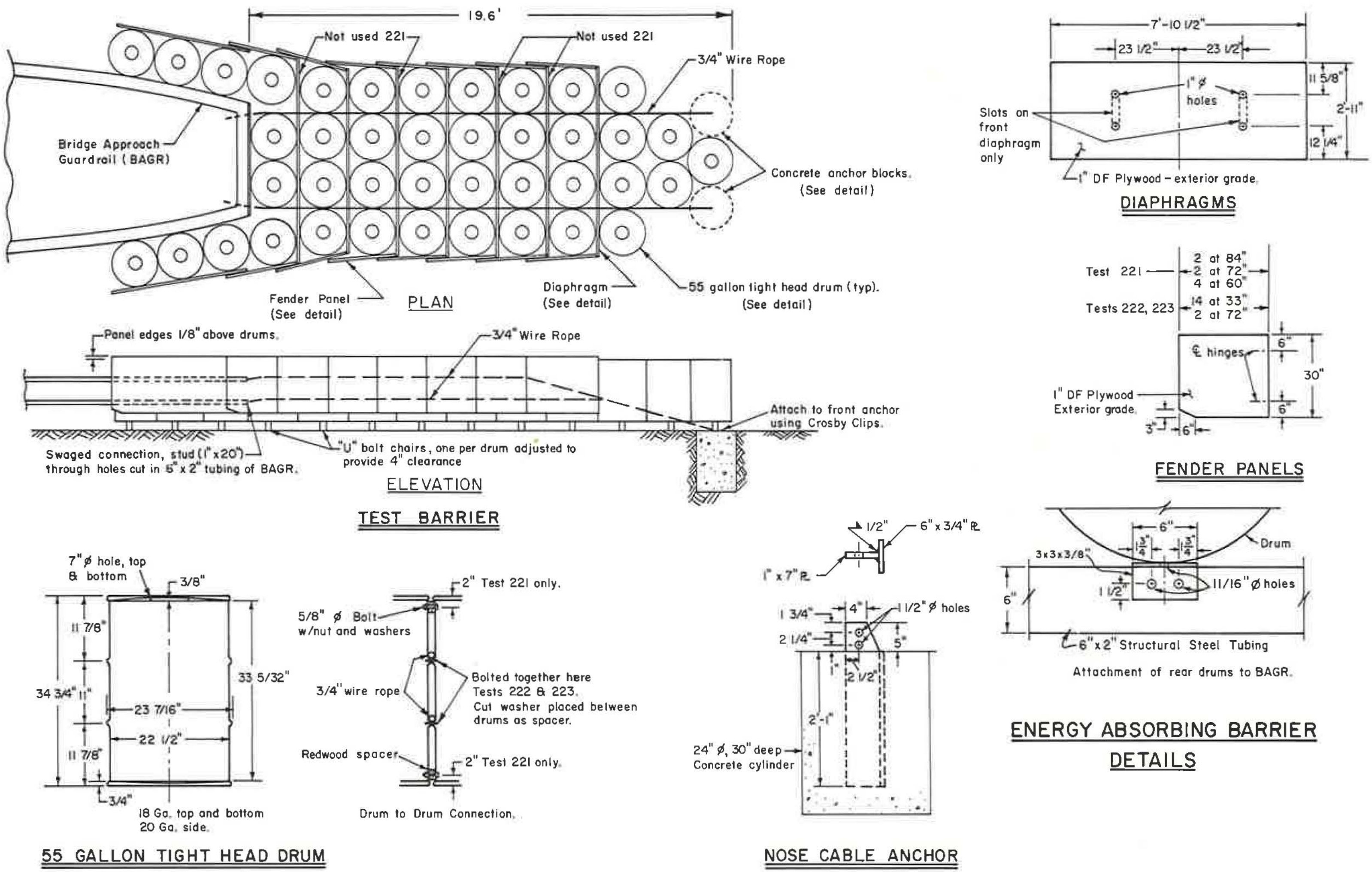
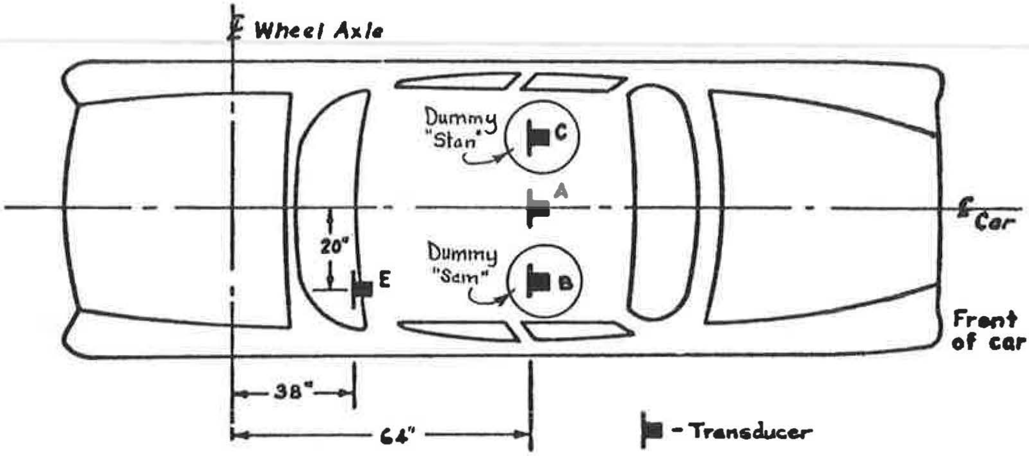

19.6'
Not used 221
Not used 221
3/4" Wire Rope
Bridge Approach Guardrail (BAGR)
Concrete anchor blocks. (See detail)
Fender Panel (See detail)
PLAN
Diaphragm (See detail)
55 gallon tight head drum (typ). (See detail)
Panel edges 1/8" above drums.
3/4" Wire Rope
Attach to front anchor using Crosby Clips.
Swaged connection, stud (1"x20") through holes cut in 6"x2" tubing of BAGR.
"U" bolt chairs, one per drum adjusted to provide 4" clearance
ELEVATION
TEST BARRIER
7'-10 1/2"
23 1/2"
23 1/2"
1" ø holes
Slots on front diaphragm only
11 5/8"
2'-11"
12 1/4"
1" DF Plywood - exterior grade.
DIAPHRAGMS
Test 221
2 at 84"
2 at 72"
4 at 60"
Tests 222, 223
14 at 33"
2 at 72"
℄ hinges
6"
30"
1" DF Plywood Exterior grade.
6"
3"
6"
FENDER PANELS
7" ø hole, top & bottom
3/8"
11 7/8"
34 3/4"
11"
33 5/32"
23 7/16"
22 1/2"
11 7/8"
3/4"
18 Ga. top and bottom
20 Ga. side.
55 GALLON TIGHT HEAD DRUM
2" Test 221 only.
5/8" ø Bolt w/nut and washers
3/4" wire rope
Bolted together here Tests 222 & 223. Cut washer placed between drums as spacer.
Redwood spacer
2" Test 221 only.
Drum to Drum Connection.
1/2"
6" x 3/4" ℞
1" x 7" ℞
1 3/4"
4"
1 1/2" ø holes
2 1/4"
5"
1"
2 1/2"
2'-1"
24" ø, 30" deep Concrete cylinder
NOSE CABLE ANCHOR
6"
Drum
3x3x3/8"
1 3/4"
1 3/4"
1 1/2"
11/16" ø holes
6"
6"x2" Structural Steel Tubing
Attachment of rear drums to BAGR.
ENERGY ABSORBING BARRIER DETAILS

Figure 17.

CALIFORNIA DIVISION OF HIGHWAYS

VEHICLE INSTRUMENTATION



Test #221

CHANNEL NO.	LOCATION[1]	DESCRIPTION[2]
1	A	100 "G" longitudinal accelerometer (T)
2	E	100 "G" longitudinal accelerometer (T)
3	C	50 "G" longitudinal accelerometer (T)
4	C	50 "G" lateral accelerometer (T)
5	C	50 "G" vertical accelerometer (T)
6	C	Force meter in "Stan's" chest (T)
7	C	Lap belt tension transducer, "Stan" (T)

Test #222

1	A	100 "G" longitudinal accelerometer (T)
2	A	50 "G" lateral accelerometer (T)
3	E	100 "G" longitudinal accelerometer (T)
4	E	100 "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)
A	A	50 "G" lateral accelerometer (U)
B	E	100 "G" longitudinal accelerometer (U)
C	E	50 "G" lateral accelerometer (U)
D	B	50 "G" longitudinal accelerometer (U)

Test #223

1	A	100 "G" longitudinal accelerometer (U)
2	A	50 "G" lateral accelerometer (U)
3	C	50 "G" longitudinal accelerometer (U)
4	C	50 "G" lateral accelerometer (U)
5	E	50 "G" longitudinal accelerometer (U)

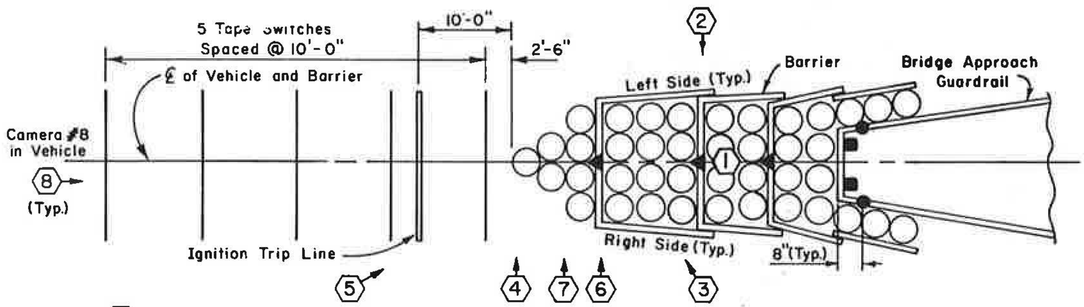
Notes:

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

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

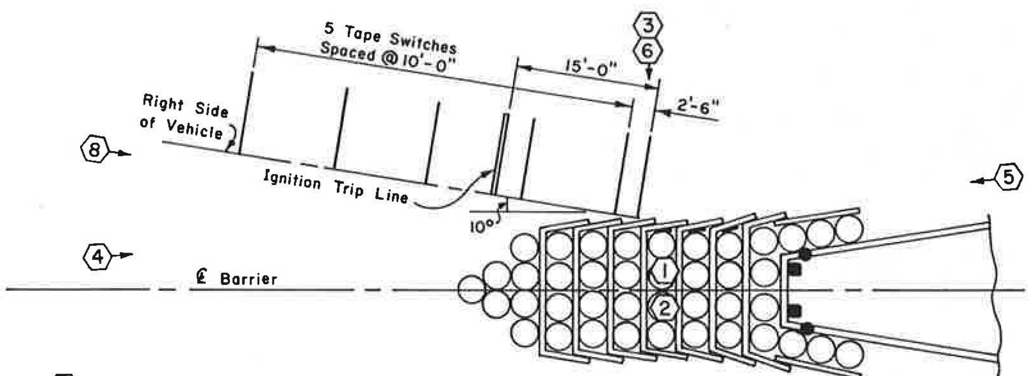
Figure 18.

CAMERA AND INSTRUMENTATION LOCATIONS AT BARRIER



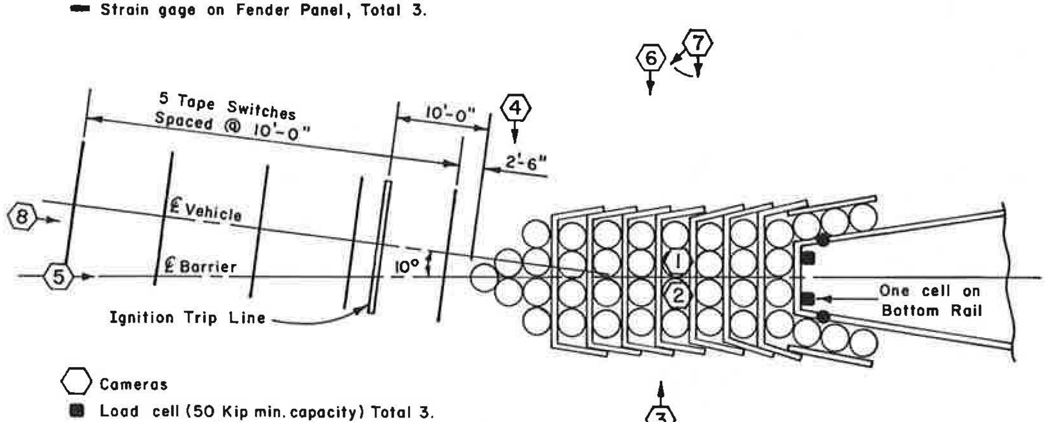
○ Cameras
▶ Accelerometer (200 G's) Total 3.
■ Load cell (50 Kip min. capacity) Total 4.
● Strain gage (℄ top surface, upper & lower rails, ℄ 8" behind nose of steel barrier) Total 4.

TEST 221



○ Cameras
■ Load cell (50 Kip min. capacity) Total 4.
● Strain gage (℄ top surface, upper & lower rails, ℄ 8" behind nose of steel barrier) Total 4.
▬ Strain gage on Fender Panel, Total 3.

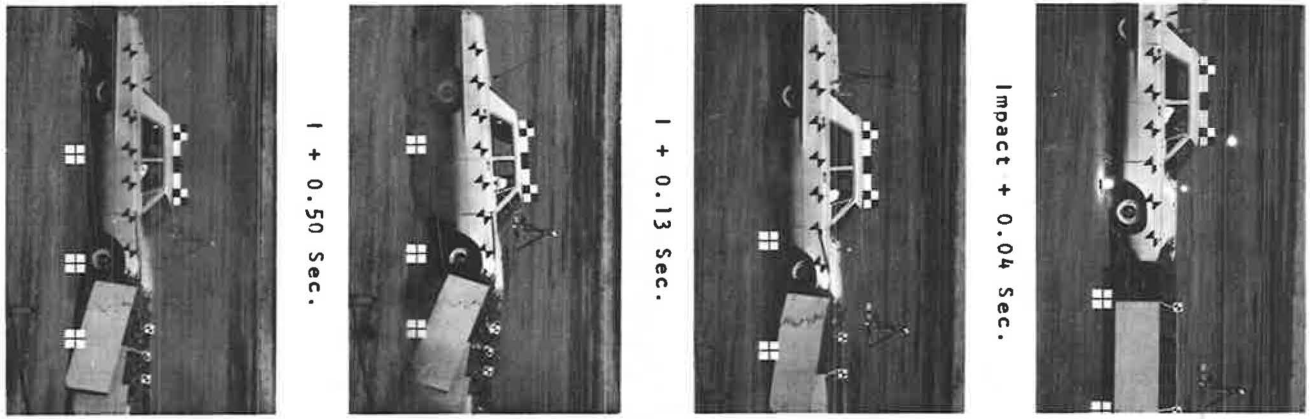
TEST 222



○ Cameras
■ Load cell (50 Kip min. capacity) Total 3.
● Strain gage (℄ top surface, upper & lower rails.
℄ 8" behind nose of steel barrier) Total 4.

TEST 223

Figure 19.



Impact + 0.04 Sec.

I + 0.13 Sec.

I + 0.50 Sec.

I + 3.10 Sec.

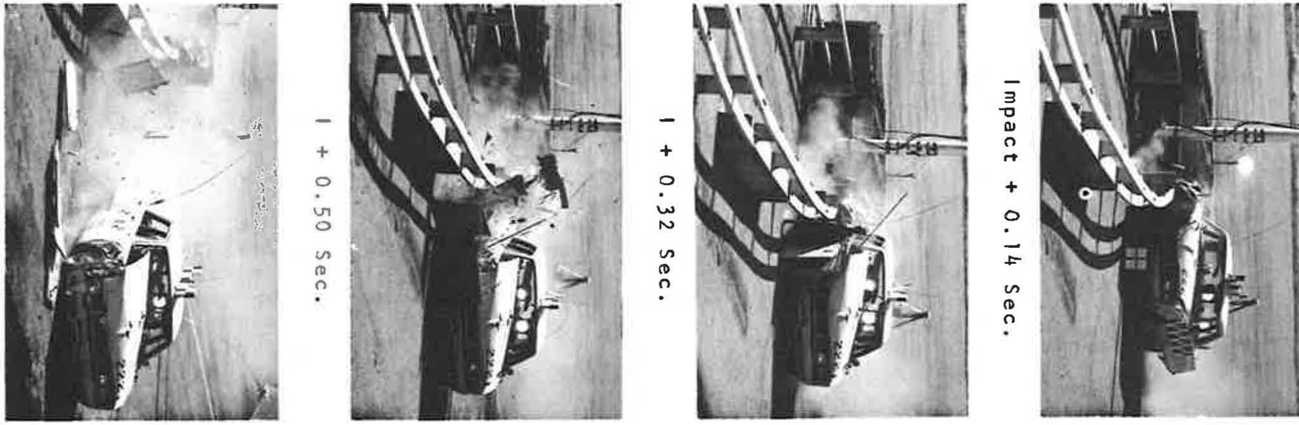
Figure 20.

Barrier Depth	19.6 Ft.
No. of Drums	41
Permanent Displacement of Barrier Nose	10.7 Ft.
Deceleration Distance-Passenger Compartment	16.5 Ft.
Maximum Vehicular Deformation	16.5 In.
Steering Column Collapse[1]	3.4 In.
Passenger Compartment Deceleration (Highest 50 ms avg.)	10.3 G's
Vehicle Average Deceleration-Calculated	8.4 G's

Test No.	221
Date	9-11-69
Vehicle	1968 Dodge
Vehicle Weight (W/Dummy and Instrumentation)	4690 Lbs.[2]
Impact Velocity	64.2 MPH
Impact Angle	Head-On
Dummy Restraint	Lap Belt

[1] Energy Absorbing Steering Column - 1500 lb. design axial force required to initiate collapse.

[2] Left front door removed.

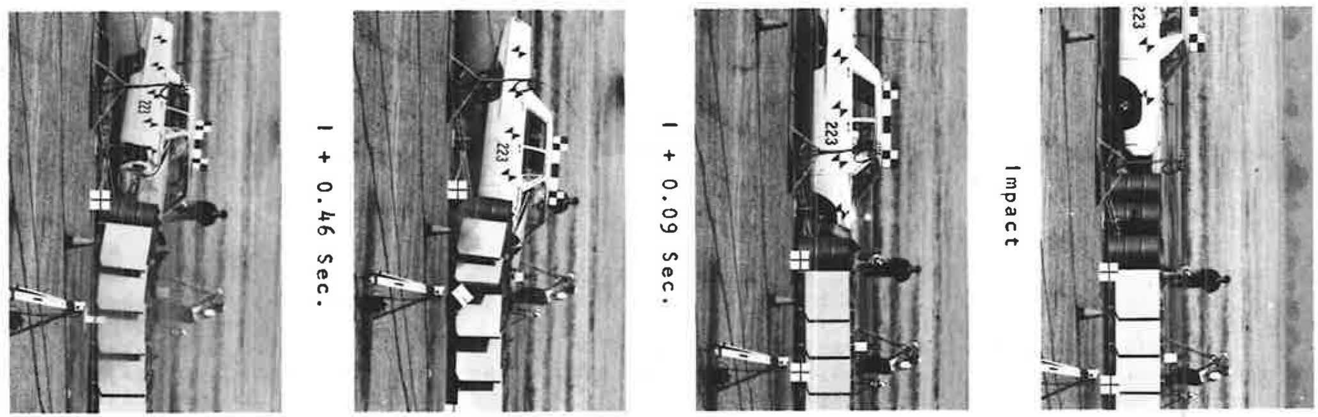


I + 1.05 Sec. | I + 0.50 Sec. | I + 0.32 Sec. | Impact + 0.14 Sec.

Figure 21.

Barrier Depth	19.6 Ft.	Test No.	222
No. of Drums	41	Date	11-21-69
Permanent Displacement of Barrier Nose	None	Vehicle	1968 Dodge
Deceleration Distance-Passenger Compartment	Redirected	Vehicle Weight	4760 Lbs.
Maximum Vehicular Deformation	27 In.	(W/Dummy and Instrumentation)	
Steering Column Collapse[1]	None	Impact Velocity	59.8 MPH
Passenger Compartment Deceleration	6.6 G's Long.	Impact Angle	11° (Side)
(Highest 50 ms avg.)	5.3 G's Lat.	Dummy Restraint	Lap Belt
Vehicle Average Deceleration-Calculated	-		

[1] Energy Absorbing Steering Column - 1500 lb. design axial force required to initiate collapse.



Impact   I + 0.09 Sec.   I + 0.46 Sec.   I + 1.69 Sec.

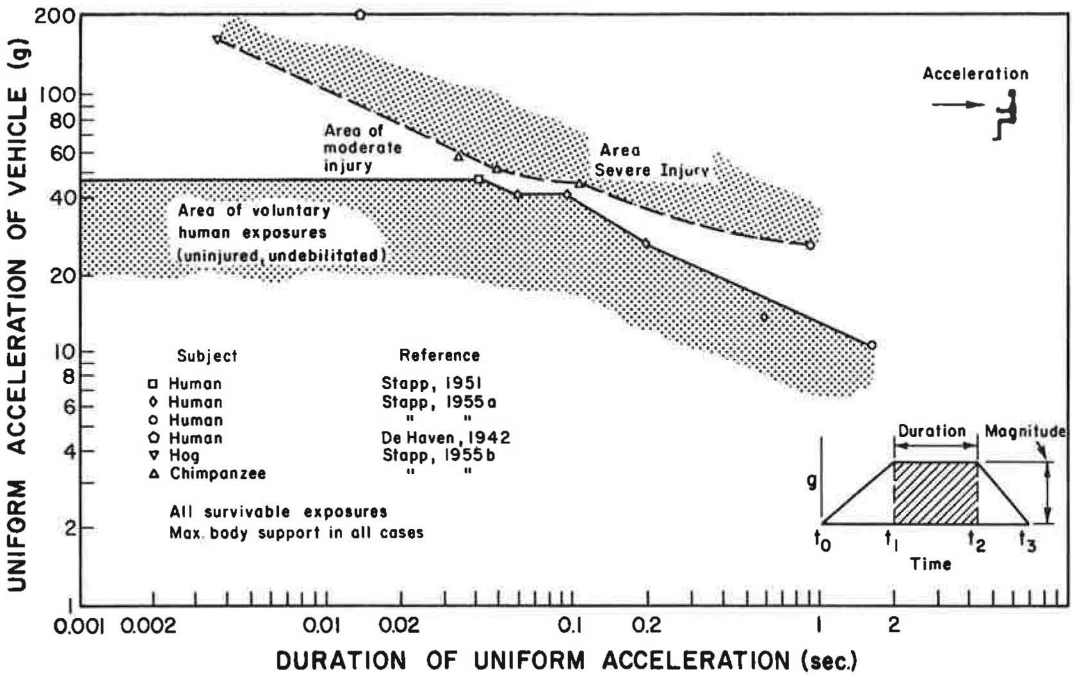
Figure 22.

Barrier Depth	19.6 Ft.	Test No.	223
No. of Drums	41	Date	12-5-69
Permanent Displacement of Barrier Nose	5.5 Ft.	Vehicle	1968 Dodge
Deceleration Distance-Passenger Compartment	13.2 Ft.	Vehicle Weight (W/Dummy and Instrumentation)	4740 Lbs.[3]
Maximum Vehicular Deformation	14.5 In.	Impact Velocity	53.6 MPH
Steering Column Collapse[1]	3.6 In.	Impact Angle	9^{o} (Nose)
Passenger Compartment Deceleration (Highest 50 ms avg.)	10.9 G's Long.	Dummy Restraint	Lap Belt
Vehicle Average Deceleration-Calculated	7.2 G's[2]		

[1] Energy Absorbing Steering Column - 1500 lb. design axial force required to initiate collapse.

[2] Lateral components of deceleration not included.

[3] Lower legs removed from dummy placed in passenger location to facilitate handling of dummy.



UNIFORM ACCELERATION OF VEHICLE (g)
200
100
80
60
40
20
10
8
6
4
2
1
Acceleration
Area of moderate injury
Area Severe Injury
Area of voluntary human exposures (uninjured, undebilitated)
Subject
Reference
Human
Stapp, 1951
Human
Stapp, 1955a
Human
" "
Human
De Haven, 1942
Hog
Stapp, 1955b
Chimpanzee
" "
All survivable exposures
Max. body support in all cases
Duration
Magnitude
g
t0
t1
t2
t3
Time
0.001
0.002
0.01
0.02
0.1
0.2
1
2
DURATION OF UNIFORM ACCELERATION (sec.)

Figure 23.