Impact severity as defined by the occupant flail space approach was also computed from the accelerometer data. The recommended threshold values for the flail space evaluation are 40 ft/sec and 30 ft/sec for the longitudinal and lateral occupant impact velocity, and 20 g for the highest 10 msec average after contact. The computed values for this test were well below the recommended values. The longitudinal impact velocity was 7.6 ft/sec, and the highest 10 msec average acceleration after impact was 1.2 g. The lateral impact velocity was 18.3 ft/sec, and the highest 10 msec average acceleration was 3.3 g.

The design intent of the upper C4 rail centered at 51.5 in. (131 cm) was to allow the relatively hard trailer floor to strike this rail and thus provide a resistance to overturning by the trailer. The trailer actually struck this rail about 6 in. (15 cm) above the centroid of the floor system and thus was in the relatively soft sheet metal portion of the trailer body. Some of the 16.5-degree roll angle of the trailer was thus due to this softer impact and some was due to the early fracture of the cast steel washers on the anchor bolts.

SUMMARY AND CONCLUSIONS

A standard Texas traffic rail type C202 was modified by increasing its height and strengthened so that it could restrain and redirect an 80,000-lb van-type truck or tractor-trailer. The modified C202 rail consisted of a concrete beam element 13 in. (33 cm) wide and 23 in. (58 cm) deep, mounted 36 in. (91 cm) high on concrete posts located at 10-ft (3.0-m) center-to-center spacing. The concrete posts were 7 in. (18 cm) thick by 5 ft (1.5 m) long concrete walls with 5-ft (1.5-m) openings between each post. To increase the effective height of the bridge rail, a standard type C4 steel rail was mounted on top of the concrete rail.

The crash test was conducted on this bridge rail with a 79,770-lb (36 184-kg) van-type tractor-trailer impacting the rail at 49.1 mph (79.0 km/h) and 15 degrees. The vehicle was smoothly redirected. Damage to the truck and rail was moderate.

One significant conclusion that can be deduced from this test is that the upper rail centered at 51.5 in. (131 cm) probably would have performed better had it been lower and if the post anchorage cast steel washers had not shattered prematurely. The trailer roll angle (16.5 degrees) probably would have been smaller. Part of the trailer roll angle was due to the rail contacting the soft body sheet metal. Had the upper rail posts been stiffer and if the rail had contacted the trailer floor as was the design intent, the trailer roll angle would have been reduced. Thus, some believe that a better location for the upper rail would have been at a height of about 51 in. (130 cm) rather than the 54-in. (137-cm) height used.

This test has shown that a bridge rail can be built on standard concrete decks to contain large van-type trucks and redirect them without rollover.

The cost of this heavy truck bridge rail is estimated at about $80 to $90/linear ft. The cost of typical metal or concrete bridge rails now in use in Texas is about $25 to $35/linear ft.

ACKNOWLEDGMENT

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Crash Cushion for Narrow Objects

DEAN L. SICKING AND HAYES E. ROSS, JR.

A crash cushion designed for narrow objects such as the end of the concrete safety shaped barrier is described. Features of the cushion are as follows: (a) it meets current safety performance standards, (b) it is constructed of readily available materials (steel barrels, thrie beams, steel channels, and steel cables), and (c) it is relatively inexpensive to install and maintain. Also presented in the paper are results of four full-scale vehicle crash tests conducted in accordance with recommended procedures in Transportation Research Circular 191. The crash cushion met the performance standards of the circular and NCHRP Report 230.

The concrete safety shape barrier (CSSB) has gained widespread use in recent years and has been both a cost-effective and crashworthy system. When the barrier must be terminated within the clear zone, however, the exposed end poses a serious hazard to the motorist. Four acceptable end treatments are now available:

1. Flare the barrier end out of the clear zone (at an acceptable flare angle) or bury the end in a cut slope (this option is available for roadside barrier application only);
2. Use the guardrail energy absorbing terminal (GREAT), which is a proprietary system;
3. Use the median barrier breakaway cable terminal; and
4. Use an approved crash cushion.

In many cases the barrier end cannot be flared out of the clear zone or buried because of roadway geometrics or other constraints. Although the GREAT system is a crashworthy crash cushion, its use has been limited by its relatively high cost. Similarly, alternative 3 has not been widely used because of its relatively high cost and marginal impact performance for the small car. Approved crash cushions are also costly and require more space than is often available.

A portable crash cushion for the CSSB that is both inexpensive and suitable for narrow medians was developed recently at the Texas Transportation Institute (TTI) (1). This crash cushion was developed for use in construction zones and is made of empty and sand-filled steel drums that have W-beam guardrails attached to the drums. Although this cushion is not suitable for permanent installations, it has proven the merit of a crash cushion constructed from empty and sand-filled steel drums.

The objective of this research was to use the TTI crash cushion in the development of a crash cushion for the CSSB that would (a) meet nationally recognized impact performance standards for a permanent crash cushion, (b) be suitable for use in narrow medians and on the roadside, (c) be reasonably inexpensive to install and maintain, and (d) be constructed of materials readily available to highway maintenance personnel.

The findings of a research study conducted in 1981 (2) are described briefly in this paper; refer to the report for more information.

CRASH CUSHION DESIGN

An impact attenuator for narrow objects must perform as a crash cushion if hit head-on and as a longitudinal barrier if hit downstream from the nose. The design of a system to satisfy both requirements presents special problems. The first function was achieved by the combined effect of a steel drum, energy-absorbing crash cushion, and a sand barrel, inertial cushion. This was accomplished with a single row of 55-gal loose-head steel drums, some of which were empty, some partly filled, and others completely filled with sand. Two 5/8-in. steel cables placed on each side of the row of barrels assist in redirecting a vehicle that impacts from the side. Thrie-beam fish scales distribute side impact forces between the drums and prevent vehicles that impact the side of the cushion from snagging on the steel drums (3).

Details of the crash cushion are shown in Figures 1 and 2. Each drum is mounted on two C4 x 5.4 steel channels. The channels prevent snagging of the drums on the ground during head-on and side impacts. If the drums do not slide freely excessive stopping forces could be transmitted to a vehicle that impacts head-on or the drums could overturn during side impacts and cause wheel snagging to become a problem. Further, the channels and false bottoms, placed in drums that contain less than 500 lb (227 kg) of sand, raise the center of gravity of the system, which reduces the possiblity that the vehicle will push the top part of the cushion down, ride over the top of the cushion, and become a projectile.

Other desirable features of the crash cushion are its size and construction. This crash cushion is only slightly wider than the CSSB and can therefore be placed in narrow medians as well as on the roadside. It is constructed of readily available materials, many of which are already used by highway maintenance personnel. All components of the attenuator can be shop-fabricated and assembled in the field. Repair of the device is facilitated by the ease with which a drum can be replaced. The sand is placed in bags and can be lifted easily out of a damaged drum. Individual drums can be replaced without taking the other drums out of the device. For most impacts all thrie-beam fish scales and steel channels can be salvaged from damaged drums and thereby reduce material costs. Therefore, the crash cushion should be inexpensive to install and maintain.

ANALYSIS

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

When a vehicle impacts and crushes an empty drum the kinetic energy of the vehicle is reduced by the energy required to crush the drum. The energy required to dynamically crush an 18-gauge steel drum a distance of 18 in. (45.7 cm) was found by Hirsch and Ivey (1) to be 27 kips-ft (36.6 kN•m). By applying the law of conservation of kinetic energy, the velocity change of the vehicle and the average acceleration during the event can be estimated:

$$KE_i - KE_d = KE_f \tag{1}$$

$$0.5m\,V_i^2 - KE_d = 0.5m\,V_f^2 \tag{2}$$

$$V_F = \sqrt{(mV_i^2 - 2KE_d)/m} \tag{3}$$

$$a_{avg} = (V_i^2 - V_F^2)/2d \tag{4}$$

where

- KE_i = kinetic energy of vehicle before crushing a drum,
- KE_f = kinetic energy of vehicle after crushing a drum,
- KE_d = energy required to crush a drum,
- V_i = vehicle velocity before impact,
- V_f = vehicle velocity after impact,
- m = mass of vehicle,
- a_{avg} = average acceleration of vehicle during event, and
- d = distance drum is crushed.

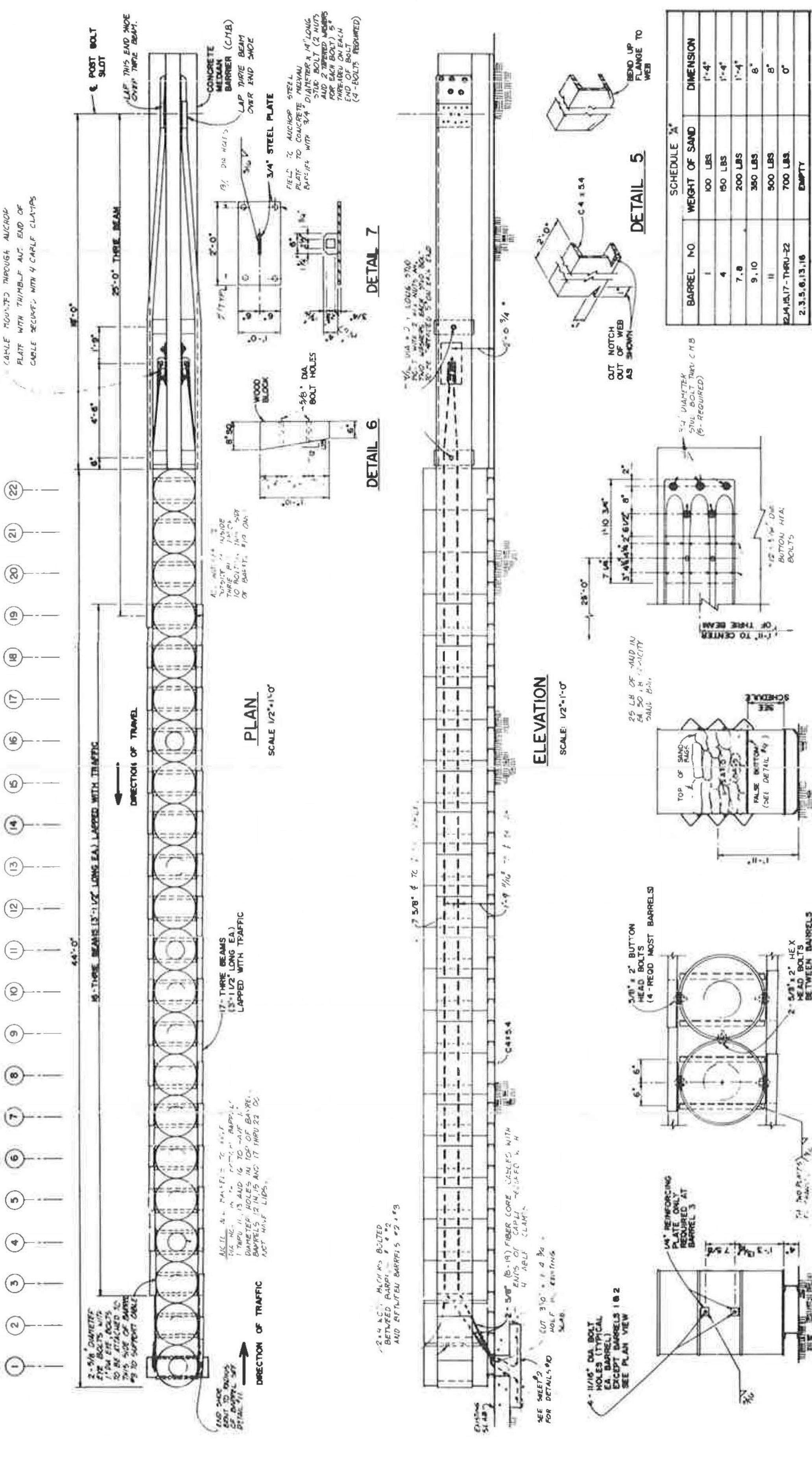
When a sand-filled drum is impacted by a vehicle the drum is crushed approximately 6 in. and accelerated to the velocity of the vehicle. The change in vehicle velocity can be estimated by applying the laws of conservation of energy and momentum. The law of conservation of energy can be applied as shown previously to determine the velocity change when the barrel is partly crushed. The law of conservation of momentum can be applied when a sand-filled drum is accelerated from rest, as shown in Equations 5 and 6.

$$m_iV_j = (m_i + m_d)\,V_F \tag{5}$$

$$V_F = m_iV_j/(m_i + m_d) \tag{6}$$

where

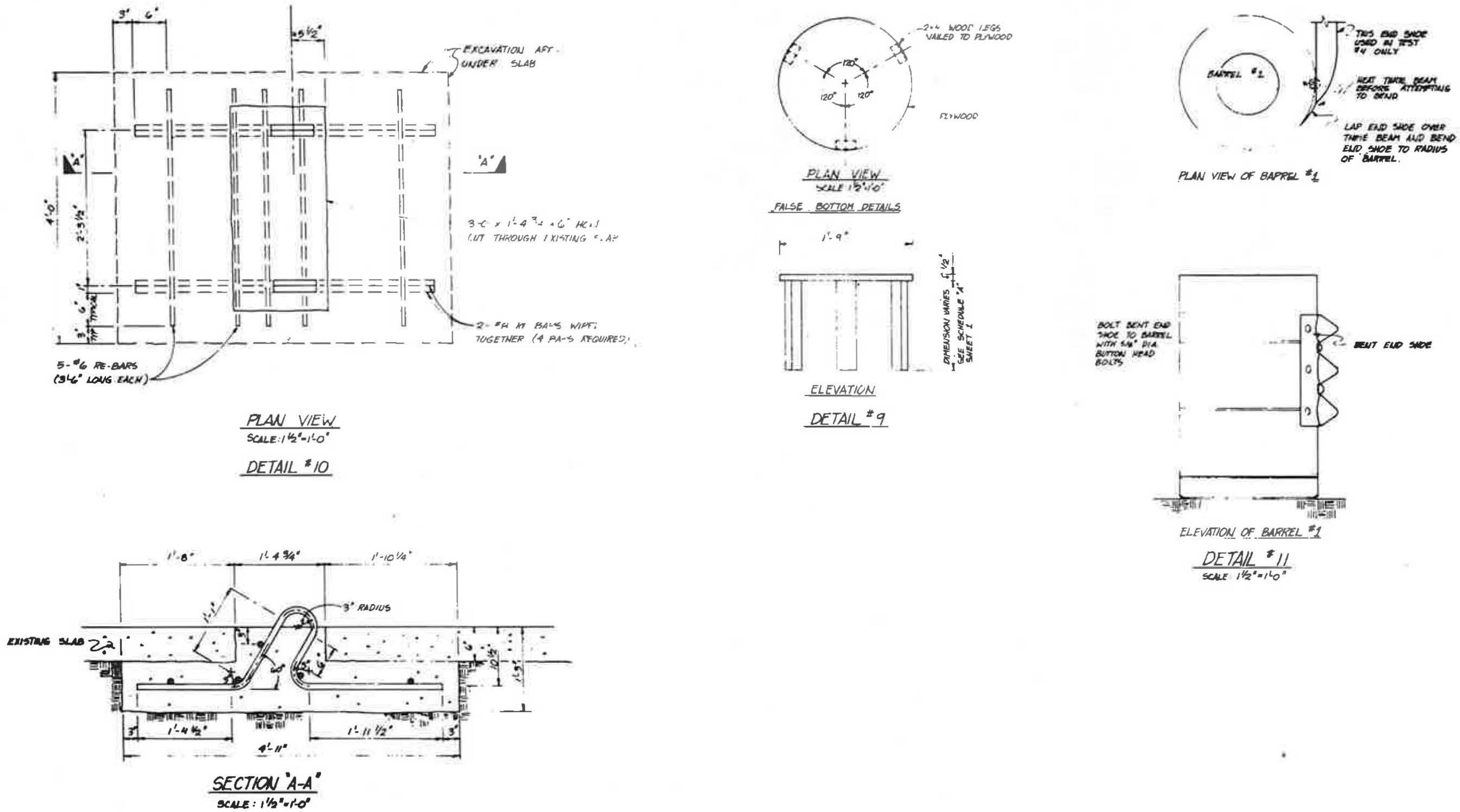
- V_j = velocity of vehicle after partly crushing a drum,
- V_F = velocity of vehicle after impact,
- m_i = mass of vehicle and previously impacted drums, and
- m_d = mass of sand-filled drum.



BARREL NO	WEIGHT OF SAND	DIMENSION
1	100 LBS	1'-4"
4	150 LBS	1'-4"
7, 8	200 LBS	1'-4"
9, 10	350 LBS	8"
11	500 LBS	8"
12,14,15,17-THRU-22	700 LBS	0"
2,3,5,6,13,16	EMPTY	

Figure 1. Construction drawings for narrow hazard crash cushion.

Figure 2. Construction details for narrow hazard crash cushion.



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

$$V_f = a_{avg}t + V_i \quad (7)$$

$$t = (V_F - V_i)/a_{avg} \quad (8)$$

$$S_v = V_i t - 0.5\, a_{avg}\, t^2 \quad (9)$$

$$S_o = V_o t \quad (10)$$

$$S_r = S_o - S_v \quad (11)$$

where

a_{avg} = average vehicle acceleration during event,
t = duration of event,
S_v = distance traveled by vehicle,
S_o = movement of occupant,
V_o = velocity of occupant (vehicle velocity on initial impact), and
S_r = movement of occupant relative to vehicle.

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

Predicted and test results for longitudinal occupant impact velocities and average accelerations over the stopping distance are given in Table 1. As given in the table the predicted results correlate extremely well with the test results for the 2,250-lb (1022-kg) vehicle. The results for the 4,500-lb (2043-kg) vehicle are somewhat lower than predicted values because an unexpectedly large number of the sand-filled drums were crushed. Although not proven by a test, the analysis shows that the crash cushion could decelerate safely an 1,800-lb (817.2-kg) vehicle impacting head-on at 60 mph (96.6 km/h).

CRASH TESTS

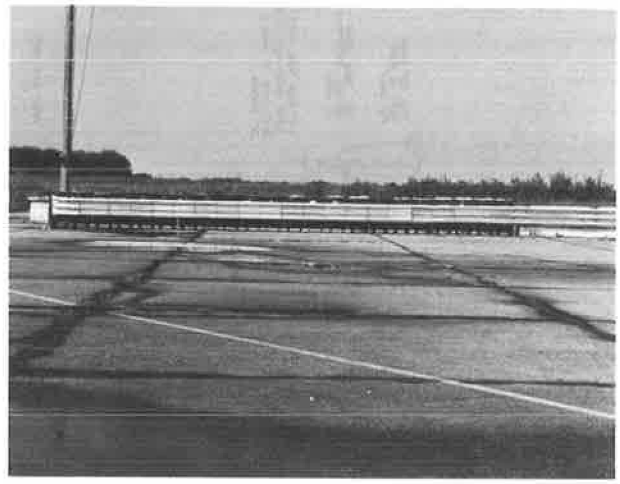
Four full-scale crash tests were conducted on the crash cushion shown in Figure 3. The first test examined the redirectional performance of the crash cushion and the other tests investigated its capacity to decelerate vehicles safely to a stop. Crash tests were conducted according to nationally recognized standards (4) and are summarized in Table 2. The crash cushion was designed and testing was initiated under the standards set by Transportation Research Circular 191 (4); however, NCHRP Report 230 (5) was published before completion of the final crash tests. Although the original test matrix was completed, the crash tests were evaluated by standards set in both reports. NCHRP Report 230 requires an additional crash test with a mini-car, which could not be conducted. However, the analysis shown previously indicates that the test would have been successful.

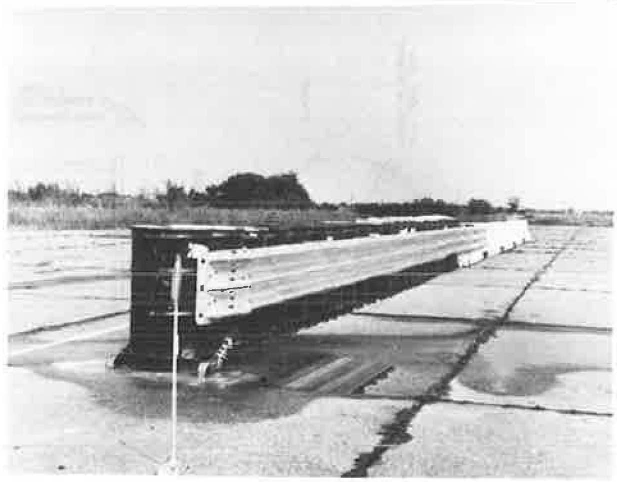
Table 1. Comparison of measured and predicted occupant risk values.

Vehicle Weight (lb)	Longitudinal Occupant Impact Velocity (ft/sec)		Avg Acceleration over Stopping Distance (g)	
	Predicted	Test Result	Predicted	Test Result
1,800	36	–[a]	9.3	–[a]
2,250	33	32.4	7.8	7.5
4,500	38	28.0	7.2	5.8

[a]No test conducted.

Figure 3. Narrow hazard crash cushion as tested in test 4.





Test 1

The first test evaluated the redirectional performance of the crash cushion. In this test a 4,500-lb (2043-kg) vehicle impacted the midpoint of the cushion at 20 degrees and 55.3 mph (89.0 km/h). This test was selected to test the transition from continuous thrie-beam rail element to thrie-beam fish scales. The test vehicle was redirected smoothly and exhibited no tendency to snag on the crash cushion. As given in Table 2, all occupant risk values and the vehicle trajectory hazard were below recommended values (4,5). The large lateral deflections given in Table 2 were caused by longitudinal movement of the portable concrete barrier elements to which the crash cushion was attached. In a permanent installation the crash cushion would be attached to a continuous concrete barrier that cannot displace longitudinally.

Figure 4 shows the test vehicle and installation after test 1. As shown in this figure, the damage to the vehicle was not severe for a test of this nature. Restoration of the crash cushion required replacement of two 25-ft (7.6-m) sections of thrie

Table 2. Summary of crash tests.

Test No.	Vehicle Weight (lb)	Impact Speed (mph)	Angle of Impact (degrees)	Point of Impact	Vehicle Stopping Distance (ft)	Cushion Displacement: Longitude (ft)	Cushion Displacement: Latitude (ft)	Occupant Impact Velocity: Longitude (ft/sec)	Occupant Impact Velocity: Latitude (ft/sec)	Vehicle Acceleration Data (g), Occupant Ridedown, Peak 10 msec avg: Longitude	Occupant Ridedown, Peak 10 msec avg: Latitude	Peak 50 msec avg: Longitude	Peak 50 msec avg: Latitude	Avg Over Stopping Distance	Vehicle Damage Classification: Traffic Accident Damage Scale	Vehicle Damage Index
1	4,500	55.3	20	Barrel 11	NA	0	3.1	19.8	6.6	3.1	0.8	4.7	4.8	NA	10LFQ4	10LYEW4
2	2,410	58.7	0	Nose	15.3	15.3	-	32.3	-[a]	7.5	-[a]	11.6	0.9	7.5	12FD2	12FDEW3
3	4,500	60.5	0	Nose	20.9	20.9	-	28.0	-[a]	9.4	-[a]	8.4	0.7	5.8	12FD2	12FDMW2
4	2,335	59.7	10	1-ft offset from nose	11.4	11.4	1.2	38.9	-[a]	10.0	-[a]	12.9	2.0	10.5	1FL4	01FDEW5

[a]No occupant impact during test.

Figure 4. Test vehicle and installation after test 1.

beam, five drums, and two 37.5-in. (95.3-cm) thrie-beam fish scales. This test was considered successful based on the safety performance and the relatively light damage incurred by the crash cushion.

Test 2

Test 2 examined the head-on impact behavior of the crash cushion. In this test a 2,410-lb (1094-kg) Chevrolet Vega (1976) impacted the nose of the cushion at 0 degrees and 58.7 mph (94.4 km/h). The test vehicle was decelerated smoothly to a stop and did not pitch or yaw significantly during the test. Occupant impact velocities and vehicle accelerations (see Table 2) were within acceptable limits (4,5) for this type of test. One thrie-beam fish scale was detached from the third drum and skidded along the ground approximately 60 ft (18.2 m). In a highway situation this thrie-beam plate could have posed a hazard to other traffic.

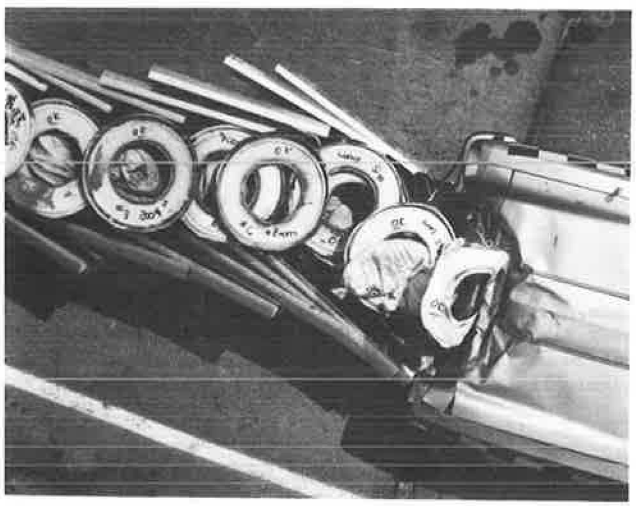
As shown in Figure 5 damage to the test vehicle was extremely light for a test of this nature. Figure 6 shows the crash cushion after test 2. The crash cushion was restored by replacement of 18 steel drums. All other materials were salvageable. The test was considered successful.

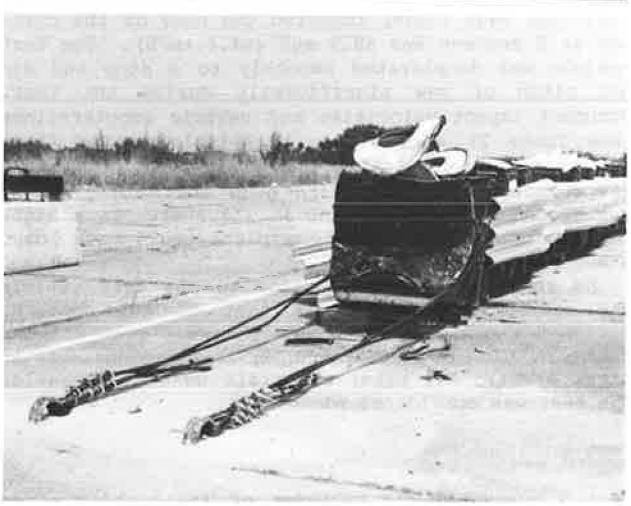
Test 3

Test 3 evaluated the behavior of the cushion after

Figure 5. Test vehicle after test 2.

Figure 6. Test installation after test 2.





head-on impact with a large vehicle. For this test a 4,500-lb (2043-kg) Plymouth Fury (1977) impacted the nose of the crash cushion head-on at 60.5 mph (97.4 km/h). The test vehicle was decelerated to a stop smoothly over a distance of 20.9 ft (6.4 m). The front of the test vehicle pitched up less than 5 degrees and did not yaw significantly during the test. All occupant risk values (given in Table 2) were well below acceptable limits (4,5). A thrie-beam fish scale became detached from the third drum and skidded along the ground approximately 135 ft (41 m).

The test vehicle, shown in Figure 7, experienced light damage for a test of this nature. Figure 8 shows the crash cushion after test 3. The cushion was heavily damaged, as would be expected from this test; however, the only unsalvageable materials were 19 steel drums. This test was successful, with the exception of the thrie-beam plate that became detached from drum no. 3.

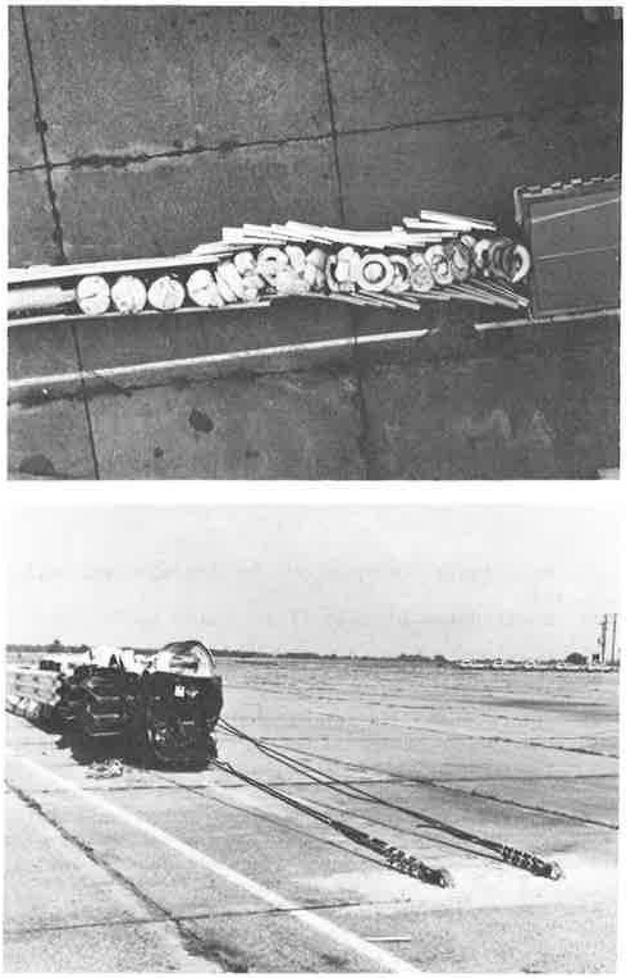
Test 4

Analysis of high-speed films from test 2 revealed that the test vehicle's bumper impacted the leading thrie-beam fish scale on the upstream side of the treatment before the drum to which the fish scale was attached was impacted. Researchers concluded that, if the leading fish scale could be bent around the drum and more bolts could be placed in it, this fish scale would not be dislodged during the head-on impacts. Therefore, two additional thrie-beam fish scales were added to the upstream side of the crash cushion before test 4. One of these thrie-beam plates, a standard thrie-beam end shoe, was attached to the leading drum and bent around it. Three bolts were also used to attach the end shoe to the drum.

Test 4 evaluated the crash cushion for unsymmetrical loading at the nose. For this test a 2,335-lb (1060-kg) Chevrolet Vega (1975) impacted the nose of the crash cushion at 10 degrees and 59.7 mph (96.1 km/h). On impact the left front side of the test vehicle snagged on the nose of the cushion. The vehicle then yawed approximately 45 degrees as it was decelerated smoothly to rest. The longitudinal occupant impact velocity was 38.9 ft/sec (11.9 m/sec), which is below the maximum recommended value of 40 ft/sec (12.2 m/sec). Other occupant risk values were also within acceptable limits (4,5). None of the thrie-beam fish scales became dislodged during this test.

Figure 7. Test vehicle after test 3.

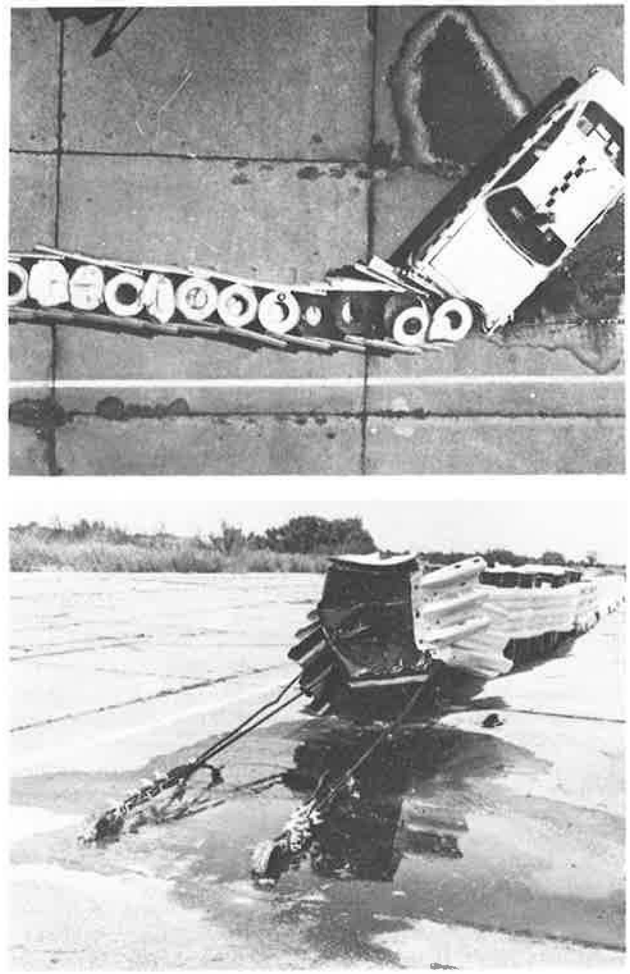
Figure 8. Test installation after test 3.



Damage to the test vehicle was moderate, as shown in Figure 9. Figure 10 shows the crash cushion after test 4. Restoration of the crash cushion involved replacement of 14 steel drums. The angle impact test on the nose of a crash cushion is a relatively new test and it is not known whether crash cushions tested previously could pass this test. Therefore, this test was considered successful even though the longitudinal occupant impact velocity was near the maximum acceptable limit.

Figure 9. Test vehicle after test 4.

Figure 10. Test installation after test 4.



CRASH CUSHION COSTS

Material costs and labor requirements for fabrication and installation of crash cushions are given in

Table 3. Installation costs of crash cushion.

Item	Cost ($)
Materials	
Steel drums	66
Thrie beam	694
Thrie-beam end shoes	135
C4 x 5.4 steel channels	179
5/8-in. steel cable	161
Sand bags and sand	360
Miscellaneous	247
Subtotal	1,842
Labor[a]	
Shop fabrication, 55 person-hr	825
Site installation, 39 person hr	585
Subtotal	1,410
Total	3,252

[a]Labor costs calculated at $15 per person-hr.

Table 4. Repair costs of crash cushion.

Repair	Item	Cost ($)
Replacement of damaged drums	Expendable material replacement, per drum	7.10
	Shop fabrication labor, including material salvage, 1.3 person-hr	19.50
		26.60
Repair of end treatment		
	Test 1	
	Material replacement	375.25
	Labor, 14.5 person-hr	217.50
	Total	592.75
	Test 2	
	Material replacement	127.80
	Labor, 38.9 person-hr	583.50
	Total	711.30
	Test 3	
	Material replacement	134.90
	Labor, 41.0 person-hr	615.00
	Total	749.90
	Test 4	
	Material replacement	99.40
	Labor, 30.2 person-hr	453.00
	Total	552.40

Note: Labor costs calculated at $15 per person-hr.

Table 3. Material costs were obtained through telephone bids and invoices for materials purchased during construction of the crash cushions. Labor requirements for fabrication were estimated from published productivity standards for industrial operations (6). Labor requirements for installation of crash cushions were estimated from observations of installation of the tested appurtenance. Material and labor requirements for the pavement cable anchor were not included in Table 3 because anchors used in the field would differ significantly from those used in the test installation.

As given in Table 3, total material costs for the narrow hazard crash cushion are approximately $1,841. Similar costs for commercial crash cushions are approximately $8,500. The total labor requirements for fabrication and installation of this safety treatment are fewer than 95 person-hours. If labor cost is $15 per person-hour, total costs for the crash cushion would be approximately $3,252. Thus, the initial cost of the narrow hazard crash cushion is approximately one-third of the cost of commercial crash cushions.

Estimates of repair costs for the tests conducted are given in Table 4. The average cost of repairing the barrier after the four tests was approximately $650. In view of the severity of the test conditions, this repair cost must be considered low. Therefore, repair costs for the crash cushion should be competitive with repair costs for other systems currently in use.

SUMMARY AND CONCLUSIONS

In recent years the CSSB has gained widespread acceptance. A nagging problem with this barrier has been the serious hazard to traffic posed by the end of the CSSB when it must be terminated within the clear zone. Inexpensive crash cushions are not currently available for the CSSB that are (a) crashworthy for permanent installations and (b) suitable for use in narrow medians. Therefore, a crash cushion has been developed to meet the following design criteria:

1. Constructed to impact performance standards as outlined in Transportation Research Circular 191 (4),
2. Suitable for use in narrow medians and for roadside applications,
3. Relatively inexpensive to install and maintain, and
4. Constructed of readily available materials.

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

All materials used in the construction of this crash cushion are available commercially, and the components of the cushion can be shop-fabricated and field-assembled. As given in Tables 3 and 4, the installation and maintenance costs of this crash cushion are relatively low compared with those for commercial crash cushions currently employed to protect the end of the CSSB.

Successful crash tests as required by Transportation Research Circular 191 (4) have been conducted to verify the crashworthiness of the crash cushion. In the first test a large vehicle was redirected smoothly. In tests 2 and 3 large and small test vehicles impacted the crash cushion head-on and were decelerated smoothly to a stop. For these tests all occupant risk values were at or below recommended levels (4,5). The final test involved a small car impacting the nose of the device at 10 degrees. For this test the vehicle yawed approximately 45 degrees as it was decelerated smoothly to a stop. The average acceleration over the stopping distance was 10.5 g and longitudinal occupant impact velocity for this test was 39 ft/sec, both of which are near maximum acceptable limits (4,5).

This crash cushion can be placed in narrow medians that could not be treated previously. The reduced cost associated with this cushion will allow placement of a safety treatment at sites where more expensive commercial cushions are either marginally or not now cost-effective. Therefore, this narrow hazard crash cushion should improve the level of highway safety.

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Portable Traffic Barrier for Work Zones

DEAN L. SICKING, HAYES E. ROSS, JR., D.L. IVEY, and T.J. HIRSCH

A portable, positive construction zone barrier is described. The barrier is suitable for use at sites where work will take as little as several hours. It is constructed from used cars and thrie-beam guardrail. Two full-scale vehicular crash tests of the portable barrier are described that demonstrate its adequacy in terms of impact performance. The barrier can be used in construction zones where conventional positive barriers have been impractical.

The number of injuries and fatalities among Texas highway construction and maintenance personnel has increased greatly during the past several years. In one Texas highway maintenance district traffic accidents have caused 39 injuries and 12 fatalities among highway construction and maintenance personnel during the past 2 years. Examination of these accidents has revealed that most of the injury- and fatality-producing accidents occurred at construction sites or routine maintenance sites where all blocked travel lanes were to be cleared at the end of each work period. Normal traffic control for this operation includes arrow boards and cones for traffic channelization. Often most of the cones are knocked down during the course of a single work period. After cones have been knocked down drivers may be confused and return to the blocked lane. Errant motorists also enter work zones as a result of collisions with other motorists or roadside objects.

Initial efforts to reduce the number of accidents in these work areas included increasing the number of law enforcement personnel, increasing efforts to replace cones that had been knocked down, reducing the length of the work zones, and conducting the work only during periods of light traffic. None of these alternatives proved effective, however, so an effort was made to develop a portable, positive barrier for use in certain critical work zones.

Conventional construction zone positive barriers include portable precast concrete barriers and W-beam on barrels. These barriers cannot be erected and removed quickly enough to allow their use in construction and maintenance zones where all blocked lanes are to be cleared at the end of each work period. Therefore, this research was undertaken to develop a truly portable positive work zone barrier that would be (a) portable enough for use in maintenance zones that are to be in place for only a few hours, (b) crashworthy for use in construction zones, and (c) relatively inexpensive to construct and maintain. The findings of a research study conducted in 1981 (1) are described in the following sections.

PORTABLE CONSTRUCTION ZONE BARRIER

A truly portable construction zone barrier can be brought to the work site and set up in a few minutes. Heavy machinery or specialized equipment should be unnecessary because these may not be available at the site. The barrier must be capable of redirecting an errant vehicle without deflecting it excessively and thereby endangering workers standing behind the barrier. Finally, the barrier should be relatively inexpensive to build and maintain.

Researchers examined many portable construction zone barrier concepts before concluding that the used car barrier was the most promising design considered. This barrier consists of a line of cars connected together with tow bars. The barrier is portable and can be driven to the work site. Special equipment is not required for its setup, and the barrier is relatively inexpensive when compared with other barriers considered.

The used car barrier is shown in Figure 1 and described in Figures 2 and 3. The vehicles used in

Figure 1. Used car barrier.