Barrel/W-Section Barriers for Construction Zones

DON L. IVEY AND RICHARD ROBERTSON

The history of barrel/W-section construction barriers is traced. Three crash tests conducted by Southwest Research Institute are analyzed to indicate a probable performance zone for the current barrel/W-section design. This design is the 12-gauge W-section mounted on barrels spaced at intervals of 6 ft 3 in (1.91 m) and filled with sand. Three new designs of barrel/W-section barriers are presented. By using a formal comparative structural analysis, the conventional design and the three new designs are analyzed and predictions are made of comparative performance. Stabilized barrel/W-section 3 is shown to perform at much more critical levels of impact than the current barrel/W-section barrier does. However, its use is applicable where large deflections can be accommodated.

Of the many barrier designs that have found use in construction and maintenance zones, the one that seems to have followed a reasonably well-defined evolutionary path is the barrel/W-section barrier. Over the past 10 years, steel barrels [55-gal (170-L) oil drums] have been put to a wide variety of uses by highway engineers. The range of uses that affect traffic is from simple delineation through barrel crash cushions. When barrels are effectively painted to achieve high visibility and arranged in lines to delineate the appropriate path of vehicles, they form a barricade, depending on their spacing and ballast, to discourage vehicle entry into an inappropriate zone. The physical effectiveness of this barricade is almost negligible except when barrels are spaced closely and filled with heavy ballast. In this case an intruding vehicle will not be redirected by the lines of weighted barrels unless the impact angle is extremely low, but significant deceleration of the vehicle will result.

The next evolutionary step was the addition of a W-section (flex-beam) guardrail. It is not known when this step was taken, but it was probably in the early 1970s. Since there were quantities of used guardrail available, this step probably seemed natural to an engineer, and suddenly the barrel-delineation system was converted from a barrier that had only inertia properties to a barrier that was capable of some significant positive structural redirection. It resulted in stabilization of barrier spacing in multiples of 25 ft (7.62 m), which is the standard guardrail length.

The barrier of this type that has the most positive automobile redirection potential is the standard barrel/W-section barrier shown in Figure 1. It consists of steel barrels spaced 6 ft 3 in (1.91 m) apart that have a section of standard steel flex beam (12 gauge) attached directly to their sides. The top edge of the flex beam is 27 in (68.6 cm) above the ground. The ballast normally used in the barrels is sand, which produces a total barrel weight of approximately 800 lb (363 kg). Although barriers that have larger spacing and lower amounts of ballast are commonly used, either of these changes results in severely decreased barrier performance.

TEST RESULTS

Three tests of the standard barrel/W-section barrier were conducted and reported by Southwest Research Institute (SwRI) early in 1977. These tests were described by Bronstad and Kimball (1) in December 1977. Principal results and descriptions of these three tests are given in Table 1, which shows that tests TB-3 and TB-4 were reasonably acceptable but that test TB-5 was unacceptable. Since experience with this barrier in the field had shown that vehicles occasionally penetrate it, the performance range prior to testing was speculative. SwRI began with the relatively modest impact conditions of a 4500-lb (2040-kg) vehicle that was moving 35.0 mph (57 km/h) at an impact angle of 15°. The actual test conditions in test TB-3 were 4303 lb (1952 kg), 35.5 mph (57.1 km/h), and 14.3°. In terms of the performance with respect to the impacting vehicle, the test was quite successful. The vehicle was smoothly redirected and there was minor damage; the deflection of the barrier was initially 1.9 ft (0.58 m) in the major impact zone. However, the entire 100-ft (30.48-m) test installation overturned subsequent to impact. Structural damage to the barrier was minor. Bronstad and Kimball reported that the barrier was easily restored to an upright position and reused for test TB-4.

In test TB-4 the speed was increased to a nominal value of 45 mph (73.0 km/h). Actual test conditions were 4303 lb, 45.4 mph (73.1 km/h), and 14.6°. Again, vehicle redirection performance was excellent. The maximum deflection in the main impact area was 3.4 ft (1.04 m) and smooth redirection was produced on the vehicle. As in the 35-mph test, the entire length of the barrier overturned. In this case, due to impact damage, a few barrels needed to be replaced after the barrier had been set upright.

In the final test (TB-5) the speed was raised to a level of 60 mph (95 km/h). Actual test conditions were 4424 lb (2007 kg), 57.6 mph (92.7 km/h), and 15.8°. This test proved unacceptable from the standpoint of vehicle reaction. The vehicle moved into the barrier approximately 5 ft (1.52 m) while overturning the first four barrels encountered. It deformed and snagged the W-section, which severed it at a connection point, and proceeded to ramp on the last 40 ft (12.19 m) of the barrier. The vehicle penetrated a maximum of 16 ft (4.88 m) into the protected zone and a section of the detached rail was thrown approximately 30 ft (9.14 m) inside the protected zone. All but 3 of the 17 barrels were overturned. The test must be considered inadequate in that several criteria of Transportation Research Circular (TRC) 191 (2) were not satisfied, specifically those in the Safety Evaluations Guidelines. Criterion I.A states, "The test article shall redirect the vehicle; hence the vehicle shall not penetrate or vault over the installation." Criterion I.B was violated because fragments of the barrier were displaced that could have penetrated the passenger compartment. Criterion III was also violated because the final testing position of the vehicle was inside the protected area.

In an effort to extrapolate the maximum information from these three tests, Figure 2 was developed in which the impact angle is the ordinate and the automobile speed is the abscissa. The results of each of the three tests are shown by solid circles. From this plot, the boundary zone between acceptable and unacceptable performance levels for the standard barrier was developed (3). It is based on a 4500-lb vehicle that strikes the barrier under various combinations of impact angle and speed. The performance boundary zone (the area between the two curves) must be viewed with some reservation since only the middle segment is reasonably justified by full-scale tests. The outer end of the boundary zone [50-70 mph (80.45-112.63 km/h)] is probably accurate, due to the fact that the basic interaction between vehicle and barrier is reasonably well de-

Figure 1. Standard barrel/W-section barrier.

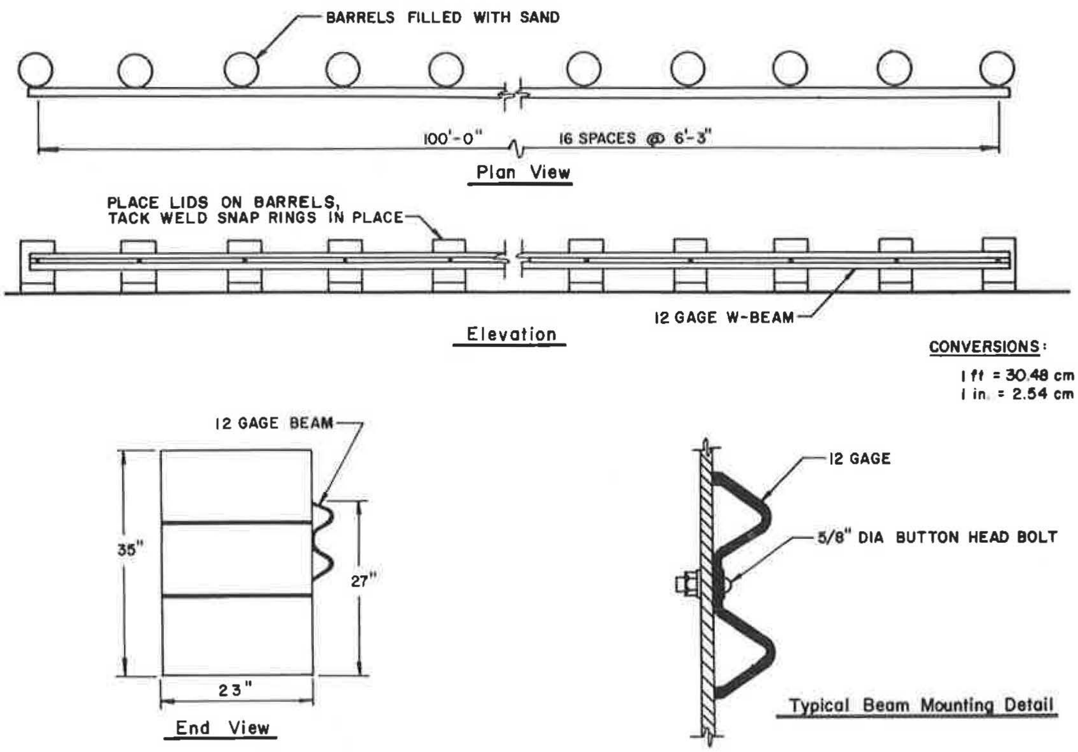


Table 1. Summary of SwRI test results.

	Test Number		
Test Parameter	TB-3	TB-4	TB-5
Vehicle	1969 Chevy Impala	1969 Chevy Impala	1975 Plymouth Grand Fury
Vehicle weight (lb)	4303	4303	4424
Test speed (mph)	35.5	45.4	57.6
Test angle (°)	14.3	14.6	15.8
Exit angle (°)	-8.0	-10.8	-60
Vehicle accelerations (maximum 50-ms avg) (g)			
Lateral	-1.9	-2.7	-2.2
Longitudinal	-0.6	-1.2	-3.5
Vehicle rebound distance (ft)	21	23	3
Maximum deflection (ft)			
Dynamic	1.9	3.4	5[a]
Permanent	1.9	3.4	30[b]

Note: 1 lb = 0.45 kg; 1 mph = 1.609 km/h; 1 ft = 30.48 cm.
[a]Approximate dynamic deflection of barrier while in contact with vehicle.
[b]Position of one rail section that was dislodged from the barrier and knocked 30 ft inside the original barrier line.

fined by the crash tests conducted at an angle of 15°. The inner end, between 25 and 35 mph (40.23 and 56.32 km/h), is somewhat more questionable, since the high impact angle between 20° and 30° could allow an interaction due to pocketing that has not been adequately defined by the previous tests. For this reason, the zones of questionable barrier performance are shown to be between 10 and 40 mph (16.09 and 64.36 km/h) and between 20° and 30°.

It is obvious that this barrier will not perform adequately at the level of the test parameters that is considered a strength test for permanent barriers. Those parameters, defined in TRC 191 (2) as 4500 lb (2041 kg), 60 mph (96.56 km/h), and 25°, are shown in Figure 2 to be well into the unacceptable performance zone.

The reasons for the performance limitations of the barrel/W-section barrier can be summarized as inadequacies in structure, stability, connection, and geometrics. If those reasons are considered in the order listed, test TB-5 illustrates the inadequacy of the W-section bending stiffness, represented primarily by the moment of inertia of the cross section in the plane of primary bending. The vehicle severely deforms the W-section, which results in direct contact of the vehicle with the barrels.

This contact with the barrels is further aggravated by the rotation of the barrels in front of the vehicle; this allows a ramping condition that brings elements of the vehicle's undercarriage in contact with the upper end of the barrels. This is a problem of stability and geometrics that results in forces so large on individual barrels that they are torn free of the W-section and scattered about the assumed construction zone. During this interaction, connections between W-section elements are also severed. If it is assumed that the W-section is strong enough to remain intact during a collision, the main problem is reducing the contact between the vehicle and the barrels. Obvious solutions seem to be (a) blocking out the W-section and (b) preventing the barrels from overturning.

DESIGN OF UPGRADED BARREL/W-SECTION BARRIERS

The major elements to be considered in the design of a barrel/W-section barrier for increased performance are the same as those items listed as reasons for the limited capacity of the standard barrier. Designs were developed that would increase the beam stiffness, increase the overall barrier stability, strengthen all connections, and correct geometric problems.

Although numerous new designs were proposed, all but two were discarded for reasons that ranged from low probability of performance to excess complexity. The two designs that were finally accepted for

Figure 2. Estimate of performance boundary for standard barrel/W-section barrier.

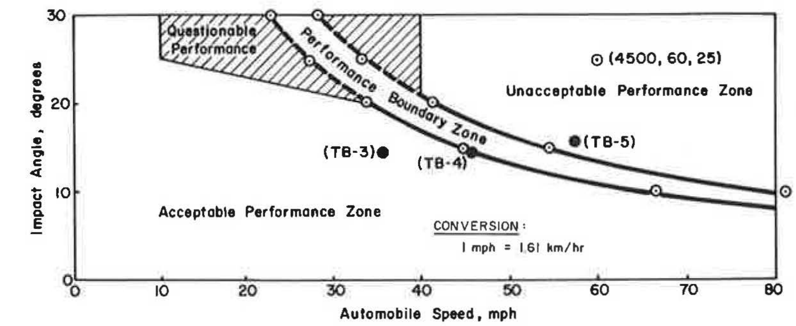
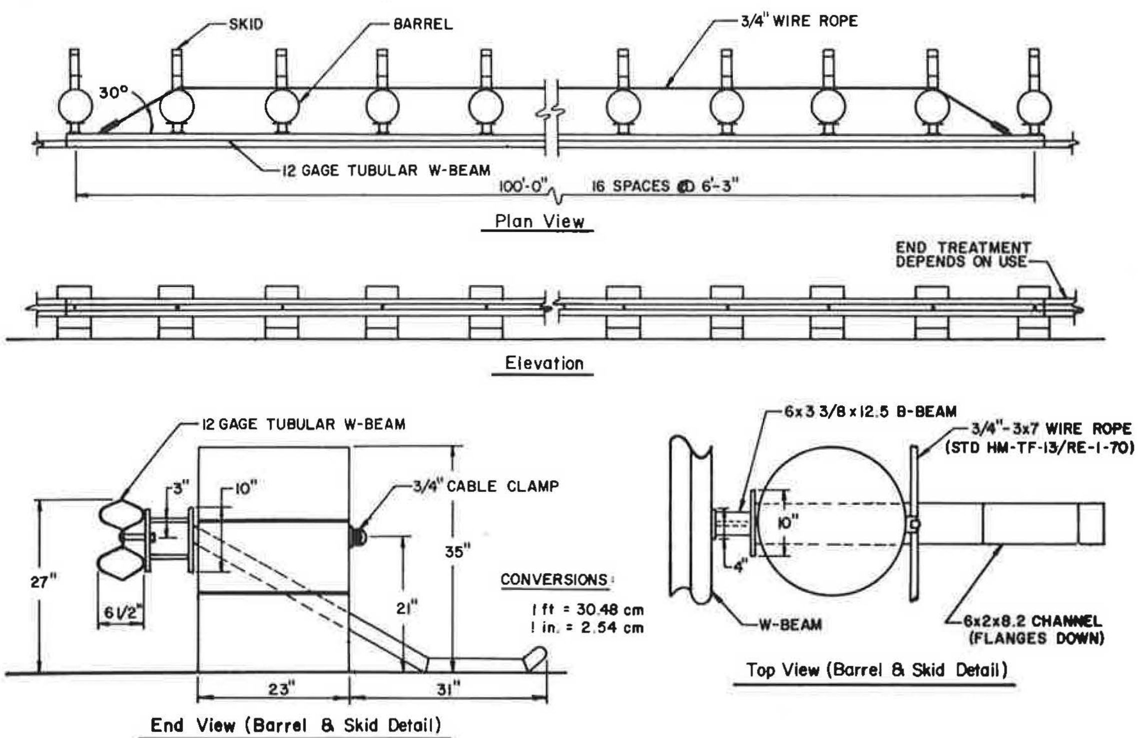


Figure 3. Stabilized barrel/W-section 1 (SBW1).



further analysis and possible testing are shown in Figures 3 and 4. They are designated stabilized barrel/W-sections 1 and 2 (SBW1 and SBW2).

SBW1 is the barrier that demonstrated the highest performance potential. It is shown by Figure 3 to have four major changes from the standard system:

1. Use of the double, or closed, W-section beam;
2. Addition of a 0.75-in (2-cm) wire rope on the side of the barrel away from the impact plane,
3. Use of a B-beam to form a 6-in (15-cm) block out from the supporting barrels, and
4. Use of a skid channel that extends from the tubular W-beam through the barrel to a point of support 40 in (101 cm) behind the impact plane.

SBW2 is shown in Figure 4. There are three major design changes from the standard barrier:

1. Use of the double, or closed, W-section beam [this also affects a 3.25-in (8-cm) block out compared with the standard barrier];
2. Grouping the barrels in sets of three; and
3. Changing the distance between the centroids of the groups of barrels to 12 ft 6 in (3.8 m).

Each of the design changes for SBW1 and SBW2 is responsive to a specific limitation of the standard system, except the final item under SBW2, which was required for practical reasons.

The two designs were submitted to Federal Highway Administration contract managers and to certain other interested engineers, including Dexter Jones of the Texas State Department of Highways and Urban Transportation. Jones reviewed these designs critically and stated that SBW1 was too complicated to construct; he suggested several changes. These suggestions were used to develop design SBW3 (Figure 5).

Design SBW3 is very similar to SBW1 and incorporates three major changes from the standard system:

1. Use of the double, or closed, W-section;
2. Use of a 6-in block out from the supporting barrels, and
3. Use of a skid plate welded to the base of the barrel.

This design was developed to keep the structural characteristics of the SBW1 barrier but to eliminate its complexity. The following analysis of the

Figure 4. Stabilized barrel/W-section 2 (SBW2).

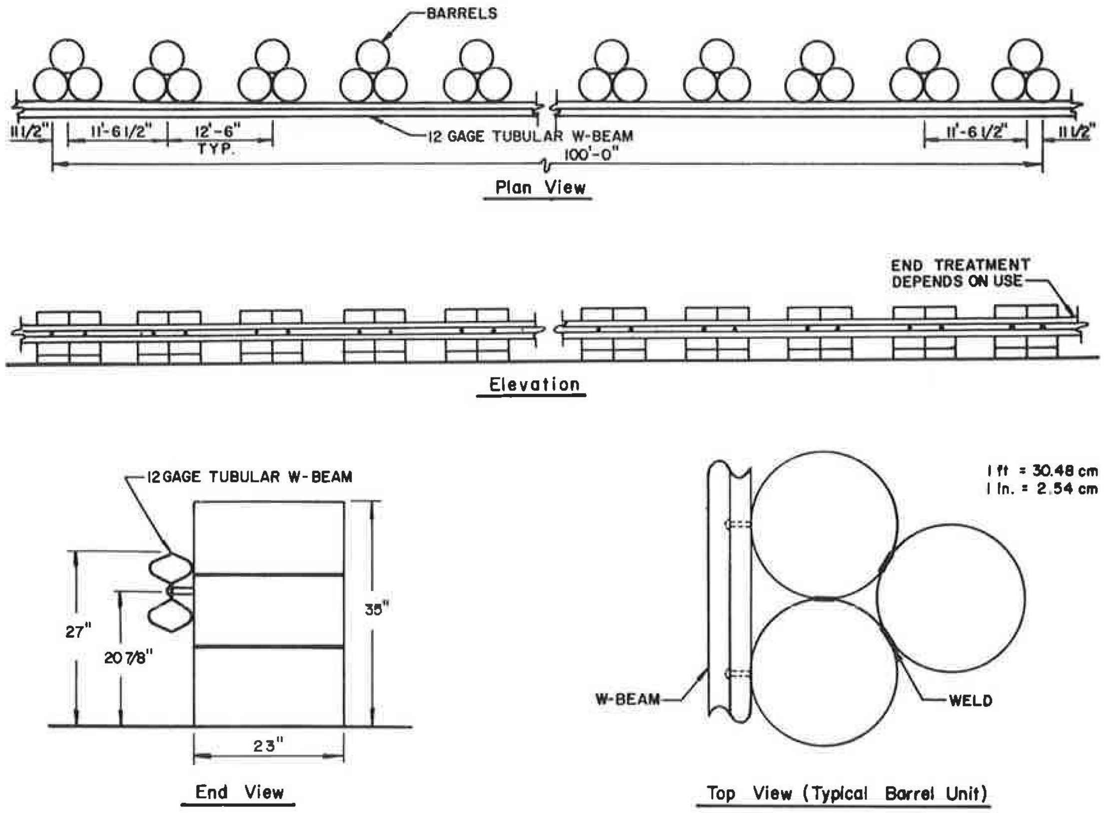
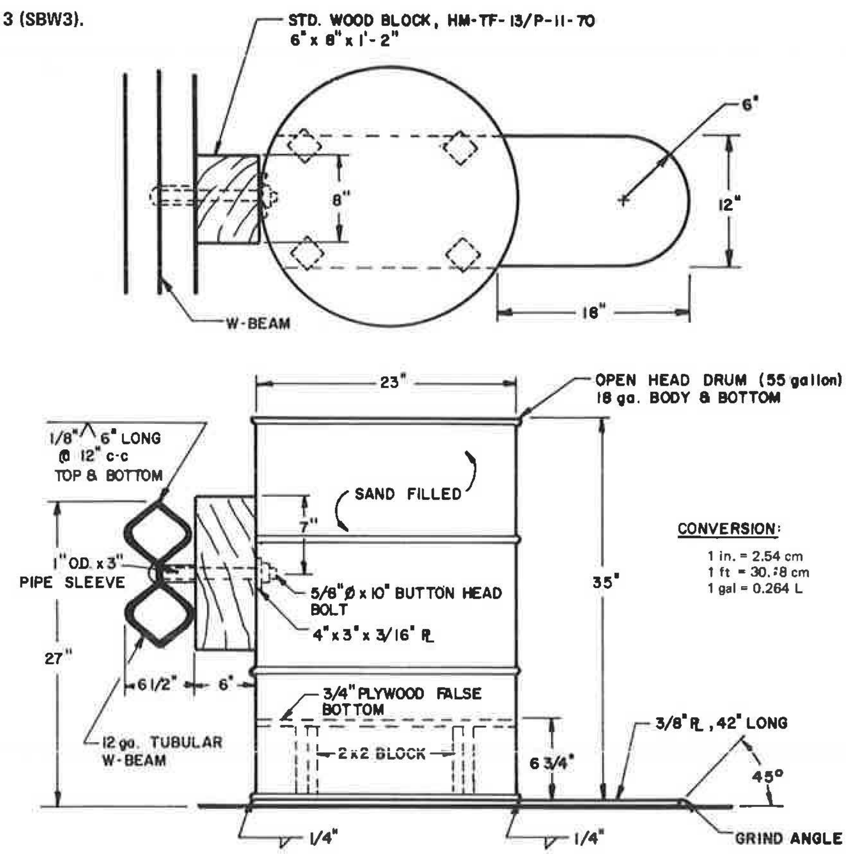


Figure 5. Stabilized barrel/W-section 3 (SBW3).



structural characteristics of all the designs will show their similarities.

ANALYSIS OF PROPOSED SYSTEMS

An approach that may be termed "comparative structural analysis" was used to analyze the barrier systems. Comparative structural analysis requires the listing and/or development of a number of performance factors by which the relative performances of new designs and known designs can be compared. For example, if it is known that the standard barrier performs reasonably up to a certain level by using a beam stiffness of BS_1 and if beam stiffness is one of the factors that limits the performance level of the standard barrier, it may be assumed that raising beam stiffness to level BS_2 will have a positive effect on the performance of a new barrier. Comparative structural analysis is not new. It is continually practiced in the field of collision dynamics engineering in a less formal format and has resulted in some major design improvements.

The comparative factors developed here can be shown by theory and by analysis of test results to affect barrier performance significantly (3). The factors developed are defined as follows.

Mass Mobilization Factor

Mass mobilization (MM) is the average weight of the barrier in pounds per 10 ft (3 m) of length.

Beam Stiffness Factor

Beam stiffness (BS) is defined as the moment of inertia of the beam cross section about the axis of major bending (in inches) divided by the cube of the unsupported beam length between major attachment points: $BS = I_y/L^3$.

Table 2. Structural properties of individual barrier designs.

Design Property	Barrier Design			
	Standard Barrel/W-Section	SBW1	SBW2	SBW3
Beam				
Area[a] (in^2)	1.99	3.98 (4.18)	3.98	3.98
I_y[a] (in^4)	2.31	16.42 (245)	16.42	16.42
I_x (in^4)	30.00	60.00	60.00	60.00
J_{eq} (in^4)	7.33×10^{-3}	34.38	34.38	34.38
L[b] (ft)	6.25	6.25	10.58	6.25
Barrel spacing (ft)	1 at 6.25	1 at 6.25	3 at 12.5	1 at 6.25
Full barrel weight (lb)	800	800	800	800

Note: 1 in^2 = 6.45 cm^2; 1 in^4 = 41.62 cm^4; 1 ft = 30.48 cm; 1 lb = 0.45 kg.
[a]The larger values are appropriate wherever the barrier is operating in the positive moment condition (i.e., the cable is in tension).
[b]Unsupported beam length.

Torsional Stiffness Factor

The torsional stiffness (TS) factor is the equivalent polar moment of inertia (as defined for the determination of torsional rotation in response to an applied torque) divided by the unsupported beam length between attachment points (in cubic inches): $TS = J_{eq}/L$.

Unit Stability Factor

Unit stability (US) is the maximum force that can be applied at the automobile impact level to a 10-ft length of barrier without creating a rotational barrier acceleration (in pounds per 10 ft). It is to be used only on systems not rigidly attached at the base.

Unit Attachment Factor

The maximum force that the attachment of the barrier to the pavement or ground surface generates (in pounds per 10 ft of barrier) is the unit attachment (UA) factor. This includes friction forces and the lateral forces generated by adjacent pavement layers as well as the strength of such positive attachments as dowels, bolts, footings, and the like.

Each of these five factors has been calculated for the three new barrel/W-section designs (SBW1, SBW2, and SBW3) and, for comparison, the standard barrel/W-section barrier. Properties of the barrier systems are listed in Table 2, and the values of the factors for each barrier system are given in Table 3.

Comparison of the factors given in Table 3 shows, in general, relatively high values for the three new designs. MM increases to 1530 lb/10 ft (695 kg/3 m) for SBW1 and SBW3 and to 2080 lb/10 ft (945 kg/3 m) for SBW2. These increases in barrier mass should result in lower barrier deflections.

BS increases radically for SBW1 and SBW3. BS is calculated as I_y/L^3, where I_y was increased from 2.31 in^4 to 16.42 in^4 (96.15-683.45 cm^4) due to the use of the double W-section beam. L remains constant at 6 ft 3 in. BS increases only moderately for SBW2. Although the value of I_y is increased to 16.42 in^4 as in SBW3, the clear span of the beam in SBW2 is increased to 10.58 ft (3.22 m). The adverse effect of L^3 in BS is almost equivalent to the positive effect of increased I_y.

TS is most important to barrier stability. It is the lack of torsional stiffness that allows the first few barrels to be overturned while other barrels remain upright and the connecting single W-section is relatively unstressed. Although TS is calculated by dividing the equivalent section polar moment of inertia (J_{eq}) by the clear span between barrel supports, the major contribution is from the equivalent polar moment of inertia. The value of J_{eq} for the closed double W-section is 4790 times as large as that for the open single section. Cal-

Table 3. Factors that indicate barrier performance.

Design Factors	Barrier Design			
	Standard Barrel/W-Section	SBW1	SBW2	SBW3
MM (lb/10 ft)	1360	1530	2080	1530
BS[a] (in)	5.47×10^{-6}	39.9×10^{-6} (580×10^{-6})	8.04×10^{-6}	39.9×10^{-6} (580×10^{-6})
TS (in^3)	0.098×10^{-3}	0.46 (NC)[a]	0.27	0.46 (NC)[a]
US[b] (lb/10 ft)	1070 (1150)	13 570 (39 170)	9590 (35 190)	8850 (34 450)
UA (lb/10 ft)	680	770	1040	770

Note: 1 lb = 0.45 kg; 1 ft = 30.48 cm; 1 in = 2.54 cm; 1 in^3 = 16.38 cm^3.
[a]The larger values are appropriate wherever the barrier is operating in the positive moment condition (i.e., the cable is in tension). NC = not computed.
[b]Including the torque generated by adjacent beam sections.

culations indicate that the torque necessary to produce a yielding shear stress on the closed section is 22.4 lbf•ft (29 232 N•m) at a rotation in 6 ft 3 in of 2.8° compared with a torque on the open section of 0.13 lbf•ft (169.7 N•m) at a rotation in 6 ft 3 in of 132°. This greater stiffness increase in the torsion mode mobilizes much more of the barrier to resist overturning.

Probably the single most important factor that indicates relative barrier performance is unit stability. This factor, based on the analysis of the structure shown in Figure 6, is a value of force F that can be applied to a 10-ft section of barrier without producing an angular acceleration (i.e., movement that leads to overturning). It can be shown that this force is defined by the barrier weight and barrier dimensions as follows:

Figure 6. Free-body diagram that represents 10 ft of barrier.

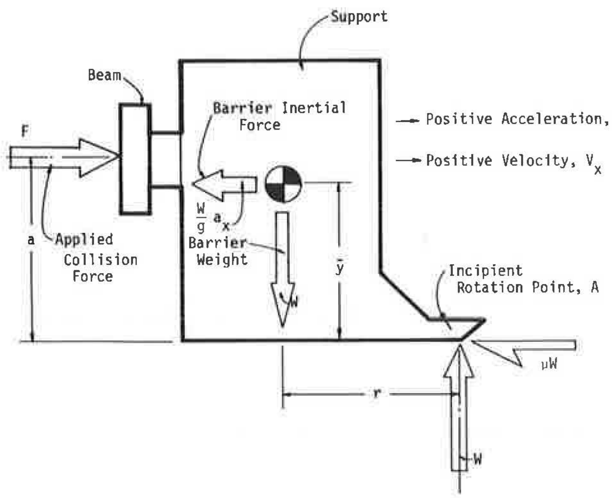
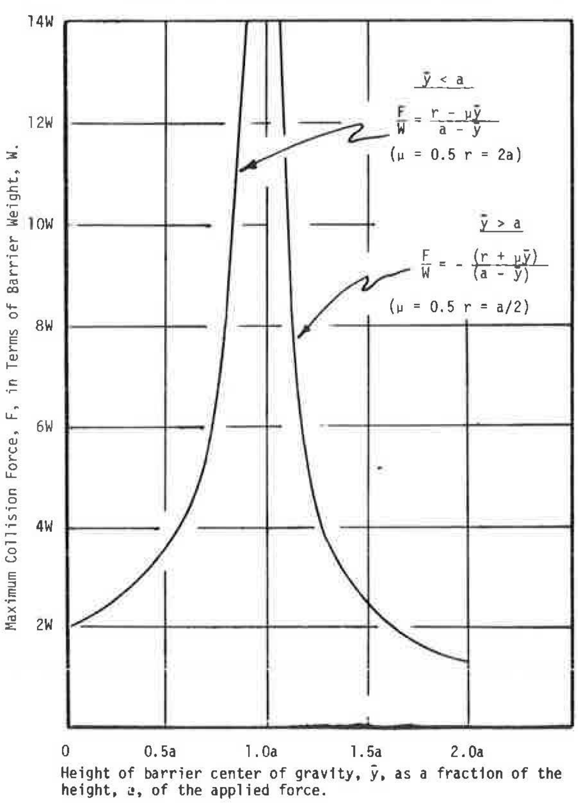


Figure 7. Influence of c.g. height on the unit stability factor.



$$F = W[(r - \mu\bar{y})/(a - \bar{y})] \quad (\bar{y} < a) \tag{1}$$

or

$$F = -W[(r + \mu\bar{y})/(a - \bar{y})] \quad (\bar{y} > a) \tag{2}$$

where

- F = lateral force applied by an impacting vehicle,
- W = barrier weight,
- r = horizontal distance from the barrier center of gravity (c.g.) to the required rotation point for overturning,
- μ = coefficient of friction,
- a = height of force F, and
- $\bar{y}$ = vertical distance from the ground surface to the barrier c.g.

Equations 1 and 2 are the result of eliminating a_x in the equations developed from a summation of moments about the point of incipient rotation A and a summation of forces in the X-direction (where g is acceleration of gravity):

$$\Sigma M_A = 0$$

$$Fa = (W/g)a_x\bar{y} + Wr \tag{3}$$

$$\Sigma F_H = 0$$

$$F = (W/g)a_x + \mu W \tag{4}$$

The force so derived is directly proportional to the weight of the barrier and a nonlinear function of the dimensions a, r, and $\bar{y}$ and the coefficient of friction μ. Equations 1 and 2 must not be taken literally for all imaginable values of a_x. For example, the equations imply that as a approaches $\bar{y}$, F approaches ∞. Consideration of Equations 5 and 6 indicates that this is theoretically true as long as μ is less than the static overturning ratio r/a.

$$\Sigma M_A = 0$$

$$Fa = Wr \tag{5}$$

$$\Sigma F_H = 0$$

$$F = \mu W \tag{6}$$

This is practically impossible, however, since consideration of Equation 3 indicates that a_x must approach ∞ in order for F to approach ∞. It is emphasized that the optimum position of the c.g. of an inertially responding and sliding barrier of this type is on the same vertical level as the applied-force position. Figure 7 illustrates this fact but limits the applied-force level to those practically achievable.

The applicability of Equations 3 and 4 for any value of a_x does depend on whether μ is less than the ratio r/a. If μ is greater than r/a (see Equations 5 and 6), the barrier will tip over before it starts to move laterally (i.e., lateral velocity conditions less than zero). This is why it is of fundamental importance to performance that the barrels skid on the surface rather than dig in.

The values in parentheses for US in Table 3 include the basic US value plus a value of force (2F). This force is the value necessary to place adjacent segments of rail into a yield stress condition of torsion. As an example, adjacent beam segments of SBW1 and SBW3 are double closed W-beam sections 6 ft 3 in long. This beam can accept a torque of 22.4 lbf•ft before the material yields in shear, when a total rotation of one end with respect to the other is 2.8°. By dividing this moment by dimension a (the height of applied collision load), the necessary force F' to produce this torque is calculated. The result is a hybrid stability factor, which to some degree accounts for the tremendous increase in torsional stiffness of all the barriers.

UA will be of great significance to barriers that are mechanically attached to support media, but it is only a reflection of MM in the case of a barrier subject only to friction that acts at the base. In this case, the factors calculated are simply the MM-value multiplied by the coefficient of friction, which is assumed to be 0.5.

TESTS OF SBW3

Based on the analyses of SBW1 and SBW2 and the comparable characteristics of SBW3, a decision was made to test the relatively simple SBW3. These tests were designated 3825-1 through 3825-4 and conducted on the installation shown in Figures 5 and 8. The test installation was placed on unpaved level soil similar to that found in construction zones. The installation was 250 ft (76.2 m) long, which included a 25-ft (7.63-m) end treatment (Figure 8). The details of each test and the subsequent results are summarized in Table 4. The vehicle damage is given in terms of the Traffic Accident Scale Damage Index (TAD), determined from National Safety Council Bulletin 1 (4), and the Society of Automotive Engineers (SAE) damage classification (5).

Test 3825-1

A 1975 Plymouth Grand Fury that weighed 4500 lb including instrumentation was used in this test. Initial impact occurred 1.5 ft (0.46 m) downstream from barrel 6. The rear of the car contacted the rail near the point of initial impact. Contact with the barrier was maintained through barrel 14. The car was exceptionally stable during redirection and left the rail at a 3.5° exit angle. The maximum dynamic rail deflection was 2.1 ft (0.54 m). The rail rebounded 0.3 ft (0.09 m), leaving a 1.8-ft (0.64-m) deflection after collision.

Figure 9 gives sequential photographs of this test. The maximum 50-ms average transverse acceleration was 4 *g*, which is within the acceptable 5-*g* limit given in TRC 191. The lateral acceleration when the vehicle motion became parallel to the barrier was only 1.3 *g*. The longitudinal 50-ms average was a modest -1.4 *g*. Damage to both vehicle and barrier was negligible. The same vehicle was used to conduct test 3825-2.

Figure 8. Test installation and layout for SBW3 tests.

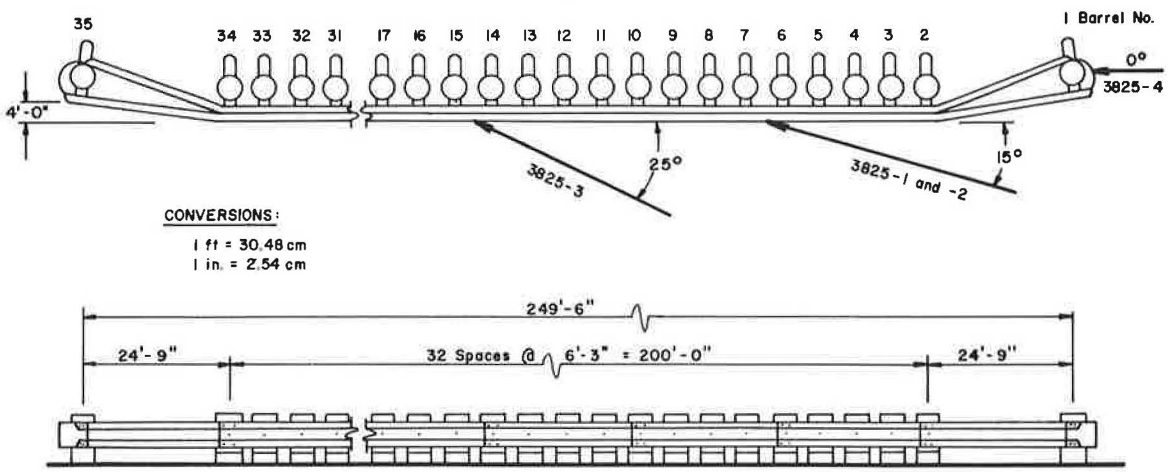


Table 4. Summary of SBW3 test results.

Item	Test Number 3825-1	3825-2	3825-3	3825-4
Parameter				
Vehicle	1975 Plymouth Grand Fury	1975 Plymouth Grand Fury	1974 Plymouth Fury III	1975 Plymouth Grand Fury
Vehicle weight (lb)	4500	4500	4500	4500
Test speed (mph)	44.3	61.7	62.4	61.4
Test angle (°)	15	15.5	22.5	0[a]
Exit speed (mph)	33.3	51.9	45.4	NA
Exit angle (°)	3.5	12.3	18	NA
Vehicle accelerations (maximum 50-ms avg) (*g*)				
Transverse	4.0	4.6	5.43	-3.07
Longitudinal	-1.4	-2.0	-1.36	-15.78
Maximum deflection (m)				
Dynamic	2.1	5.4	11	NA
Permanent	1.8	5.0	10.7	NA
Vehicle damage[b]				
TAD	1-RFQ-1	1-RFQ-2	1-RFQ-3	12-FD-3
SAE	01RFEW1	01RFEW1	01RFEW2	12-FDEW1

Note: 1 lb = 0.45 kg; 1 mph = 1.6 km/h; 1 ft = 0.3 m.
[a]Impact parallel to the barrier at the end terminal.
[b]See Traffic Accident Data Project Bulletin 1 (4) and SAE damage classification document (5).

Figure 9. Test 3825-1.

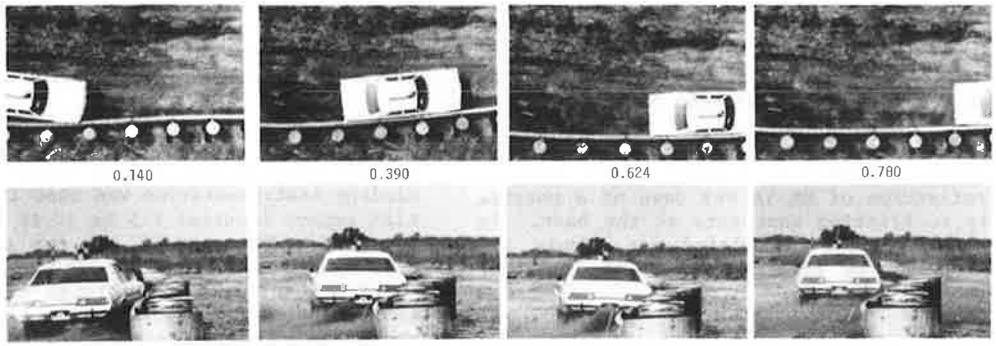


Figure 10. Test 3825-2.

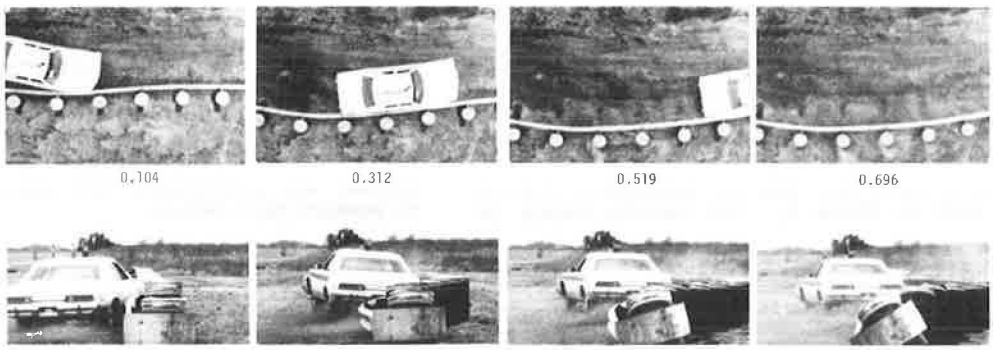


Figure 11. Vehicle before and after test 3825-2.

The barrier was pushed to its original position in 30 min by two men and a forklift. The extent of the permanent deformation was isolated to one 25-ft (7.63-m) rail segment between barrels 6 and 10 that had a 0.5-in (1.27-cm) permanent set. The damage to the rail segment was so slight that replacement was not considered necessary. Four barrels in the immediate area of impact were slightly deformed adjacent to the wooden block. The barrels were not replaced because the deformations were not sufficient to affect performance.

Test 3825-2

In the second test a 1975 Plymouth Grand Fury that weighed 4500 lb including telemetry equipment impacted the barrier at 15.5° and 61.7 mph (99.34 km/h). Figure 10 gives the sequential photographs of this test. The vehicle remained quite stable during redirection; it exhibited no tendency to mount the rail. The vehicle exited the barrier at an angle of 12.3° and a speed of 51.9 mph (83.56 km/h). The maximum 50-ms average transverse acceleration was 4.6 g. This compares favorably with the 5-g acceptable limit from TRC 191. The longitudinal acceleration was -2.0 g, well within the 5-g preferred limit. The maximum rail deflection was 5.4 ft (1.65 m), but the vehicle only penetrated into the protected zone 4.7 ft (1.43 m). The vehicle before and after test 3825-2 is shown in Figure 11.

Two men and a forklift were needed to push the barrier back to its original position. Restoration was completed within 60 min. Significant permanent deformation was confined to the 25-ft rail section between barrels 6 and 10. The maximum permanent set was 3.9 in (9.90 cm) located 2 ft (0.61 m) downstream from barrel 7. This rail section and barrels 6 through 8 were replaced before testing continued.

Test 3825-3

The test vehicle, a 1974 Plymouth Fury, impacted the barrier at 22.5° at a velocity of 62.4 mph (100.4 km/h). The vehicle weighed a total of 4500 lb, which included the telemetry equipment. The vehicle and the barrier before and after the test are shown in Figures 12 and 13.

Sequential photographs of test 3825-3 are presented in Figure 14. Point of impact occurred 3 ft

Figure 12. Vehicle before and after test 3825-3.

Figure 13. SBW3 installation before and after test 3825-3.

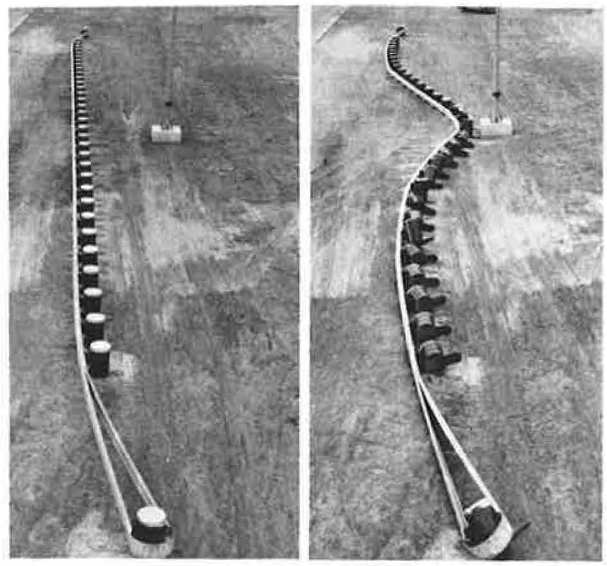


Figure 14. Test 3825-3.

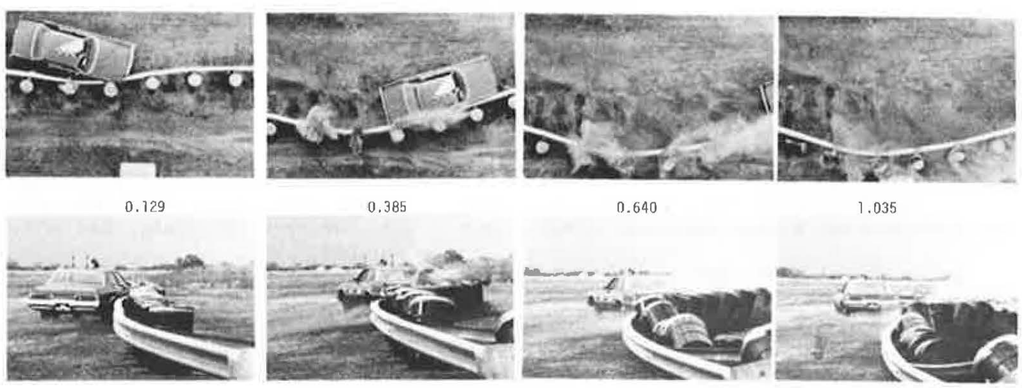


Figure 15. SBW3 installation restored after test 3825-3.

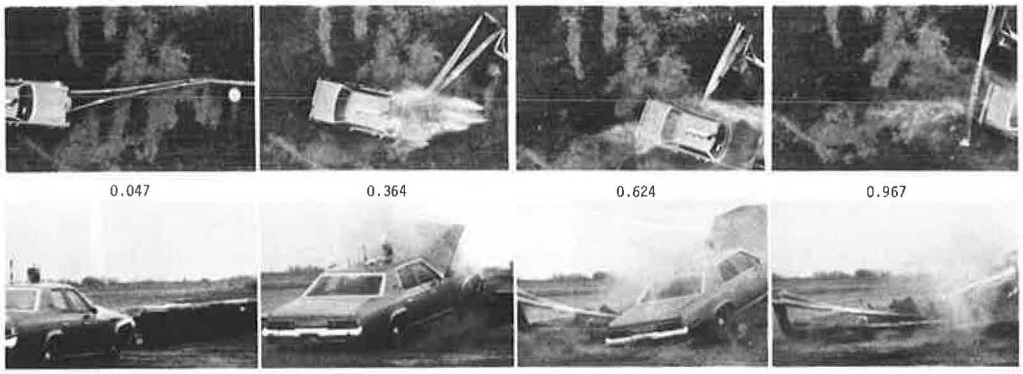
(0.9 m) downstream of barrel 14. At approximately 0.21 s, the vehicle swung into the rail 2.5 ft (0.76 m) downstream of barrel 15. By 0.236 s, the upstream barrels were beginning to rotate. By 0.641 s, the first of the upstream barrels had fallen over and succeeding downstream barrels began to fall. But in the vicinity of the vehicle, the barrels remained upright and resisting throughout the test. The vehicle exited the rail at an angle of 18° and a velocity of 45.4 mph (73.0 km/h). The maximum dynamic deflection of the barrier was 11 ft (3.35 m); this returned to 10.7 ft (3.26 m) after the test.

The barrier was returned to its original position by three men and two forklifts in 90 min. The extent of the permanent deformation after repositioning was between barrels 13-20. The maximum deformation, 5.7 in (0.15 m), occurred at barrel 16. The restored barrier is shown in Figure 15. The 25-ft rail section between barrels 13 and 17 was replaced. Barrels 14 through 18 were also replaced before testing continued.

Test 3825-4

In this test, a 1974 Plymouth Grand Fury impacted the terminal of the barrier at 0° and 61.4 mph (98.9 km/h). The vehicle weighed 4500 lb including telem-

Figure 16. Test 3825-4.



etry equipment. Sequential photographs are presented in Figure 16.

As shown in the sequentials, impact occurred at the end of the terminal. The W-beam began to buckle upstream of barrel 2 and folded inward toward the back of the barrier, which caused the vehicle to ride up and over it. Outward buckling occurred at barrels 2 and 3. The vehicle yawed to the left and came to rest behind the barrier. Damage to the front of the vehicle was extensive.

The peak longitudinal acceleration was high and would have been much too high for a small vehicle. We therefore propose to reduce the sand ballast in the end barrel to roughly 200 lb (90.7 kg) and to elevate the c.g. of this sand to prevent the vehicle from ramping on the end barrel.

Although the barrier was not repaired following test 3825-4, it was severely damaged upstream of barrel 3. Repairs that would have been required to restore the barrier included the replacement of the first two sections of W-beam and the first eight barrels.

CONCLUSION

The technique of comparative structural analysis indicated the high probability that barriers SBW1, SBW2, and SBW3 would perform at a level of impact much more critical than those accepted by the standard barrel/W-section barrier.

This statement has been verified by the first three tests of SBW3. The performance of this design is excellent; there is one major drawback--the relatively large barrier deflection. The barrier is not highly portable and should be considered for use only when it is expected that it will be needed at one point for a considerable period. Unless surplus barrels and the W-section are available, the cost is comparable with that of conventional portable concrete median barriers.

We recommend the use of this barrier design when cost factors warrant it and when deflections during anticipated vehicle collisions can be accommodated.

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The contents of this paper reflect our views and we are responsible for the facts and accuracy of the data. The contents do not necessarily reflect the official views or policy of the U.S. Department of Transportation.

This paper does not constitute a standard, specification, or regulation.

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