Impact Behavior of Small-Highway-Sign Supports

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The results of a series of tests conducted to evaluate the impact performance of widely used and promising new support systems for small roadside signs are presented. All systems were single-post installations. Tests were conducted in accordance with current nationally recognized guidelines, and results were evaluated in terms of American Association of State Highway and Transportation Officials performance specifications. It is concluded that, with the advent of smaller vehicles, small, single-post roadside sign installations can no longer be considered an insignificant hazard. In the tests, many currently used support systems proved acceptable by current performance specifications whereas others were shown to be totally unacceptable and some were what can be termed marginally acceptable. Support systems with breakaway or fracture mechanisms performed much better than base-bending or yielding supports.

A recent survey (1) shows that a variety of systems are used to support small roadside signs. As a result of this survey, it became evident that the crashworthiness of most small-sign supports was unknown. Although many sign-support systems have been crash tested, almost all of the tests have used automobiles that weighed 1453 kg (3200 lb) or more. [A summary of crash tests of sign supports conducted prior to the work reported in this paper is given by Ross and others (1, Appendix B).] Current guidelines (2) recommend that the impact performance of a sign support be evaluated by using a compact vehicle, or its equivalent, with a weight of approximately 1022 kg (2250 lb). The use of smaller automobiles in crash-test evaluations was precipitated by the current trend to smaller and more economical vehicles.

To evaluate currently used sign-support systems and promising new systems, a series of test programs have been undertaken. This paper presents the condensed results of 22 tests sponsored by the Federal Highway Administration (FHWA) (3, 4) and 13 tests conducted by others (5-9). All tests involved installations that had a single support (single-post installations represent approximately 75 percent of all roadside sign installations).

Use of the results of these tests is not limited to state highway or transportation agencies. Although vehicle operating speeds are generally lower in city and county jurisdictions, a sign support can still be hazardous in these areas, especially to occupants of small vehicles. It is important to note that a sign support can be more hazardous at low than at high vehicle speeds. Supports that fracture or break away on impact are generally more hazardous at low speeds, whereas those that yield or bend are generally more hazardous at high speeds. This does not mean, however, that yielding supports are necessarily safer at low speeds than systems that break. Clearly, an agency should be aware of the impact performance of candidate support systems for expected operating speeds.

SUMMARY OF CURRENT SIGN-SUPPORT SYSTEMS

The steel U-post, or flanged channel post, is the most widely used sign support in the United States (1). The next most popular types are the wood post, the steel pipe, and the steel tube post, respectively. Together these four types comprise more than 95 percent of all systems used. An extruded aluminum type X post is also being used to a limited degree. Cross-sectional views of the five basic post types are shown in Figure 1. Rolled-steel shapes with breakaway slip bases are used to some extent, primarily on Interstate systems with controlled access.

Promising new systems have also evolved during the past few years. These include a frangible coupling for use with the steel U-post and a lap-spliced, bolted-base design for the steel U-post that uses a post-stub combination.

TESTING AND EVALUATION

Performance Specifications

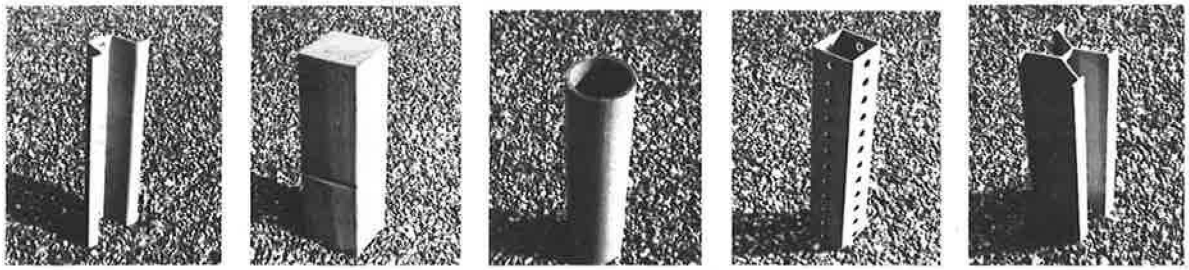
According to the American Association of State Highway and Transportation Officials (AASHTO) (10), "Satisfactory dynamic performance is indicated when the maximum change in momentum for a standard 1020-kg (2250-lb) vehicle, or its equivalent, striking a breakaway support at speeds from [32 km/h to 97 km/h] 20 mph to 60 mph does not exceed [5 kN·s] 1100 pound-seconds, but desirably does not exceed [3.4 kN·s] 750 pound-seconds." In the AASHTO specification, "breakaway supports" is used as a generic term to include all types of sign supports, whether the release mechanism is a slip plane, plastic hinges, fracture elements, or a combination of these. The specification states that "breakaway structures should also be designed to prevent the structure or its parts from penetrating the vehicle occupant compartment" (10). It also alludes to the unacceptability of vehicle rollover after impact.

Transportation Research Circular 191 (2) provides recommended guidelines for crash-test evaluation of a given highway safety appurtenance. With regard to sign supports, it contains recommended test-site soil conditions, vehicle size and impact conditions, procedures for data acquisition and reduction, and performance criteria. The performance criteria given in the circular for sign supports are essentially the same as those given by AASHTO (10). The procedures recommended in the circular were closely followed in the crash tests reported here.

Test Results

Table 1 gives a summary of 22 crash tests sponsored by FHWA (3), and Table 2 gives a summary of recent crash tests of single-post installations sponsored by other agencies. With the exception of test M-13 in Table 2, test vehicles consisted of 1971-1973 Chevrolet Vegas that weighed approximately 1022 kg (2250 lb). In each test, the lower edge of the sign panel was approximately 1.83 m (6 ft) above grade. Soil at the test site conformed to recommended guidelines (2). The types of posts evaluated are categorized as follows.

Figure 1. Five basic types of support posts for small highway signs.



Steel U-Post Wood Post Standard Steel Pipe Post Square Steel Tube Post Aluminum Type X

Table 1. Results of single-post crash tests sponsored by FHWA.

Test	Material and Type of System	Impact Speed (km/h)	Size of Post	Windshield Broken	Change in Vehicle Momentum (kN·s)
1	Wood, southern pine	34.1	10.2x10.2 cm	No	2.20
2	Wood, southern pine	104.3	10.2x10.2 cm	Yes, by panel	2.17
3	Steel U-post, billet steel	33.5	4.5 kg/m	No	1.44
4	Steel U-post, billet steel	98.5	4.5 kg/m	No	4.31
5	Steel U-post and stub (billet steel) with frangible coupling	35.2	4.5 kg/m	No	1.21
6	Steel U-post and stub (billet steel) with frangible coupling	106.4	4.5 kg/m	Yes, by panel	1.30
7	Square perforated steel tube, post and stub	98.8	6.4x6.4x0.34 cm	Yes, struck by hood	2.54
8	Aluminum type X	102.5	3X	No	1.88
9	Steel U-post, back to back (billet steel)	98.5	8.9 kg/m	Yes, struck by hood	10.21
10	Standard steel pipe	30.4	6.4-cm diameter	No	4.01
11	Standard steel pipe	98.8	6.4-cm diameter	Yes, due to rollover	5.68[a]
12	Wood, southern pine	33.3	10.2x15.2 cm, nominal	No	2.38
13	Steel U-post (rail steel)	102.7	4.5 kg/m	Yes, by panel	1.16
14	Standard steel pipe, post and stub, with breakaway collar	32.7	6.4-cm diameter	No	3.64
15	Standard steel pipe, post and stub, with breakaway collar	101.9	6.4-cm diameter	No	1.72
16	Standard steel pipe, post and stub, with breakaway collar	30.9	6.4-cm diameter	No	2.90
17	Steel U-post, braced-leg design (billet steel)	32.0	3-kg/m post, 3-kg/m brace	No	3.55
18	Standard steel pipe	90.9	5.1-cm diameter	No	2.10
19	Steel U-post, braced-leg design (billet steel)	97.5	3-kg/m post, 3-kg/m brace	Yes	2.40
20	Steel U-post, back to back (rail steel)	108.3	8.9 kg/m	Yes	3.18
20A	Steel U-post, back to back (rail steel)	101.2	8.9 kg/m	Yes	3.04[a]
21	Steel U-post, back to back (experimental billet steel)	93.2	8.9 kg/m	Yes	1.95

Note: 1 km = 0.62 mile; 1 kN·s = 223 lbf·s; 1 cm = 0.39 in; 1 kg/m = 0.67 lb/ft.

[a] Vehicle rolled after impact.

Table 2. Results of single-post crash tests sponsored by agencies other than FHWA.

Source	Test	Material and Type of System	Impact Speed (km/h)	Size of Post	Windshield Broken	Change in Vehicle Momentum (kN·s)
Effenberger and Ross (5)	3491-1	Steel U-post and stub (rail steel) with bolted connection	36.5	4.5 kg/m	No	0.86
	3491-2	Steel U-post and stub (rail steel) with bolted connection	95.9	4.5 kg/m	No	0.81
	3491-3	Steel U-post and stub (rail steel) with bolted connection	27.7	4.5 kg/m	No	1.67
	3491-4	Steel U-post and stub (rail steel) with bolted connection	26.7	4.5 kg/m	No	1.63
Ross and Walker (6)	3636-1	Steel U-post back to back (rail steel)	30.3	8.9 kg/m	No	3.67
	3636-3	Steel U-post back to back (rail steel)	101.4	8.9 kg/m	Yes	4.52
Mohrig and Ross (1)	3683-1	Aluminum type X post	33.0	6X	No	3.73
	3683-2	Aluminum type X post	96.7	6X	Yes	1.83
Walker and Ross (8)	3775-1	Square perforated steel tube, post and stub	31.1	5.1x5.1x0.27 cm	No	1.11
	3775-2	Square perforated steel tube, post and stub	97.5	5.1x5.1x0.27 cm	Yes	0.48
	3775-3	Square perforated steel tube, post and stub	32.8	6.4x6.4x0.34 cm	No	2.87
	3775-4	Square perforated steel tube, post and stub	101.2	6.4x6.4x0.34 cm	No	0.75
Kimball and Michie (9)	M-13ᵃ	Wood post with weakened section (drilled holes)	32.2	15.2x20.3 cm, nominal	N/A	1.28

Note: 1 km = 0.62 mile; 1 kN·s = 223 lbf·s; 1 kg/m = 0.67 lb/ft; 1 cm = 0.39 in.

ᵃTest conducted with soft-nose pendulum.

Wood Posts

Tests 1, 2, 12, and M-13 involved wood posts. In tests 1, 2, and 12, the posts had no breakaway or weakening devices. In tests 1 and 2, the posts were "rough cut" and had full cross-sectional dimensions. In test 12, the post had standard dressed size dimensions of 14.0x8.9 cm (5.5x3.5 in). In test M-13, holes were drilled in the post near the groundline to effect breakaway on impact.

Steel U-Posts

Tests 3, 4, 9, 13, 20, 20A, and 21 involved full-length steel U-posts. There were two basic types of post material and two basic designs. In tests 3, 4, 9, and 21, the posts were hot rolled from billet steel. Of these, the material used in tests 3, 4, and 9, taken from commercially available stock, was considerably more impact resistant than that used in test 21. Post material in test 21 was of an experimental nature and was provided by Armco Steel Corporation of Middletown, Ohio, a producer of billet-steel U-posts. Use of the "experimental posts" in test 21 was precipitated by adverse results in tests 4 and 9. Further discussions of the material properties of yielding or base-bending metal posts are presented in subsequent sections of this paper.

Posts in tests 13, 20, 20A, 3636-1, and 3636-2, taken from commercially available stock (Franklin Steel Company of Franklin, Pennsylvania), were hot rolled from rail steel. In test 20, the intended impact speed was 96.5 km/h (60 miles/h), and the actual speed was approximately 107.8 km/h (67 miles/h). Test 20A was a repeat of test 20 at a lower speed.

The support in tests 3, 4, and 13 consisted of a single 4.5-kg/m (3-lb/ft) post. In tests 9, 20, 20A, 21, 3636-1, and 3636-3, the support consisted of 4.5-kg/m (3-lb/ft) posts bolted together to form a single back-to-back design that weighed 8.9 kg/m (6 lb/ft).

Steel U-Posts with Special Features

Three designs in which the steel U-post was used as a basic component were evaluated. In the first of these, a frangible breakaway coupling was used as a connection between a steel U-post stub and a steel U-post signpost. This coupling was evaluated in tests 5 and 6. In tests 17 and 19, an installation with a vertical U-post and a U-post back or knee brace was evaluated. This design is widely used in the state of Arkansas.

In tests 3491-1 through 3491-4, a stub-signpost design was evaluated. The main feature of this system is a lap-spliced bolted connection at the stub-signpost interface and a retainer-spacer strap. Tests of this concept have also been conducted on multiple-post sign installations (6).

Standard Steel Pipe

Tests 10, 11, and 18 involved full-length standard steel pipe. An anti-twist plate was welded to the base of the post in each case.

Standard Steel Pipe with Breakaway Coupling

Tests 14, 15, and 16 involved standard steel pipe with a standard threaded pipe collar at the base. The collar and a short pipe stub were embedded in a concrete footing. This support system is used primarily by the state of Texas. In test 16, a slight change in the embedment depth of the collar reduced damage to the installation from impact.

Square Steel Tubing

Tests 7 and 3775-1 through 3775-4 involved a square perforated steel tube stub-signpost design.

Aluminum Post

Tests 8, 3683-1, and 3683-2 involved an aluminum post with a cross section similar to that in a back-to-back steel U-post design. The post in test 8 was a type 3X, and in tests 3683-1 and 3683-2 the post was a type 6X (the size designations of the manufacturer, Magnode Products, Inc., of Trenton, Ohio).

Analysis of Tests

Analyses of the test results show that two systems clearly do not meet AASHTO performance specifications: namely, the 6.35-cm (2.5-in) diameter standard steel pipe and the 8.9-kg/m (6-lb/ft) back-to-back billet-steel U-post. Both are the base-bending or yielding type of post with no breakaway mechanism. In the past, when large automobiles were more predominant, this type of sign could be easily ridden down. Now that the small-automobile population has become significant, the base-bending type of post is of much greater concern, especially at higher impact speeds.

To improve the impact behavior of the billet-steel U-post, a steel alloy that exhibited brittle fracture during laboratory impact load tests was developed. The mechanical and chemical properties of this material, and all other metal posts tested, are described by Ross and others (3). Test 21 was scheduled to evaluate the impact behavior of this material under full-scale conditions. The post in test 21 was identical to that in test 9 except for the alloy. Comparison of tests 9 and 21 shows that severity of impact was significantly reduced by the new material: The post fractured in test 21 but did not in test 9. Research is still under way to determine an alloy that not only meets safety performance specifications but also is cost effective in terms of production and field application.

Four supports had a change in momentum above the desirable limit but below the upper limit. These were the 6.35-cm (2.5-in) standard steel pipe with a breakaway coupling (test 14), a 2.98-kg/m (2-lb/ft) steel U-post system composed of a vertical post and a back brace (test 17), a 4.5-kg/m (3-lb/ft) full-length steel U-post (test 4), and an aluminum type 6X (test 3693-1).

Test 16, a test of the same design as test 14, involved a minor change in the embedment procedure (3). The change in momentum in test 16 was well below the desirable limit. The change in momentum for this system at a high-speed impact (test 15) was also well below the desirable limit.

For the steel U-post system with a vertical back brace, change in momentum was only slightly greater than the desirable limit. The change in momentum for this system for a 96.5-km/h (60-mile/h) impact was considerably below the desirable limit. Note that posts in this system were from the same type of billet steel used in posts evaluated in tests 3, 4, and 9.

The steel in the U-post evaluated in test 4 was identical to that used in test 9. The comments made on test 9 would therefore be applicable to test 4.

The other system in the "gray area" was the aluminum type 6X post. In this case, change in momentum was above the desirable limit for the low-speed impact and well below the desirable limit for the high-speed impact. Acceptance of this system from the standpoint of safety performance would seem appropriate, since the difference between the actual change in momentum and the desirable limit in the low-speed test is not believed to be excessive.

With regard to trajectory hazard, there were no penetrations into the passenger compartment of the test vehicle by panel or post in any test. In several tests, however, the windshield was broken, usually when the panel and post rotated down into the windshield. In some cases, the hood of the vehicle was pushed back into the windshield. In some tests, the windshield was only cracked, whereas in others it was shattered and dished. In test 20, the panel and post struck the roof and left a considerable dent in the passenger side of the vehicle. However, the impact speed in test 20 was higher than that called for in current test procedures (2).

Many factors influence the trajectory of a sign-support system. These include type and size of vehicle, impact speed, soil conditions, type of support, mounting height of panel, type of panel, and type of post-to-panel attachment. The sequential photographs of the tests indicate that, if a full-sized rather than a compact-sized automobile had been used, windshield contact would have occurred in some tests. The converse of that is true in other tests. Likewise, if the panel had been mounted higher, the windshield of the compact automobile would probably not have been contacted in certain tests but probably would have been with a full-sized automobile.

The above factors notwithstanding, it was concluded after careful analysis of each test that the penetration problem can be minimized by adequately attaching the panel to the post. In general, impact will accelerate the post and panel, causing the post to bend and the panel to rotate downward toward the hood. If the post fractures or a breakaway device releases, the post and panel are also accelerated in the direction of vehicle travel. To reduce the chance of penetration, it is important that the panel remain with the post during this initial contact so that its velocity relative to that of the vehicle is minimized. It should be noted that keeping the panel on the post will not necessarily prevent windshield breakage.

For some designs, the trade-off for a low change in momentum may be a broken windshield. This can be seen by comparing the results of tests 4 and 13. Although the test conditions and post designs and sizes were very similar, the windshield was shattered and dished in test 13 and unbroken in test 4. The change in momentum was 1.16 kN·s (255 lbf·s) in test 13 and 4.3 kN·s (950 lbf·s) in test 4. In test 13, the post fractured and the post and panel rotated down into the windshield. In test 4, the post wrapped around the hood of the vehicle before being ridden down, without fracturing.

Sign-panel accelerations were approximated by analysis of high-speed film. Combined accelerations up to 40 *g*, acting both perpendicular and parallel to the face of the sign, were calculated. The highest acceleration occurred in the base-bending posts that did not fracture. Even with a factor of safety of two, design of an adequate attachment should not be difficult, especially with lightweight aluminum panels. Attachment load is determined by simply multiplying the weight of the panel by 40 and that by the desired factor of safety. Tensile and shear load per fastener would equal the attachment load divided by the number of fasteners. Washers should be used as needed to prevent pullout of the nut and bolted head through the panel and post.

Vehicle rollover occurred in tests 11 and 20A. Before these two tests are discussed, it should be noted that in each test the initial contact point on the vehicle was approximately 38.1 cm (15 in) either left or right of the center of the bumper. In addition to a longitudinal force, this produced a moment on the vehicle about the yaw axis. In test 11, impact caused the vehicle to pitch down, yaw, and roll. After loss of post contact, the vehicle went into a significant yaw and roll motion that resulted in complete loss of stability. It rolled three times before coming to a stop and was a total loss. In test 20A, the post fractured and was carried along with the vehicle for a distance. When the brakes were applied, the panel slid off the hood onto the ground in front of the vehicle. Applying the brakes also caused the vehicle to begin a yawing motion. When the panel and post were hit by the front of the vehicle, the panel dug into the soil, resisting vehicle motion. This tripped the vehicle, and it rolled over twice.

Analysis shows that the rollover in test 11 was initiated during impact with the post and was therefore what may be termed repeatable, whereas the rollover in test 20A was caused by events that occurred after impact—i.e., the panel tripping the vehicle after hitting the ground. One can only speculate about the probability of occurrence of the test 20 A type of rollover, but it is believed to be very low. Note that tests 20 and 20A were very similar except that in test 20 the impact speed was higher. The vehicle did not roll in test 20.

Although rollover did not occur in test 4, the vehicle appeared to be unstable. After impact, the vehicle began to yaw and roll; then the cable guidance applied a steer correction that stabilized the yaw and roll motions and apparently prevented rollover.

Toughness or ductility during impact was found to be a key factor in the severity of impact for base-bending posts. Posts that exhibited brittle fracture during impact offered considerably less resistance than those that underwent large deformations and yielding without fracturing. Good correlation was found between the impact behavior measured by Charpy impact tests and that observed in the full-scale crash tests. It was found that posts that fractured during full-scale tests had Charpy fracture energy values less than 28 J/cm^2 (1600 in·lbf/in^2), and posts that did not fracture had energy values greater than 44 J/cm^2 (2500 in·lbf/in^2). The details of post material properties and Charpy test results are given elsewhere (1).

CONCLUSIONS

The following conclusions can be drawn based on the tests described in this paper:

1. With the advent of smaller vehicles, the small, single-post roadside sign installation can no longer be considered an insignificant hazard. Although many currently used support systems were proved acceptable by current change-in-momentum performance specifications, others were shown to be totally unacceptable. Some were what can be termed marginally acceptable. Support systems with breakaway or fracture mechanisms performed much better from a change-in-momentum standpoint than the base-bending or yielding supports.

2. In the 22 full-scale tests conducted in this study and 13 tests conducted by other agencies and summarized here, there was no clear intrusion by the test article or the vehicle structure into the passenger compartment. However, in several tests, the windshield was struck by either the sign panel or the vehicle hood (as it was pushed back), and damage ranged from only cracks to a large dish in the windshield. Breakage occurred in high-speed tests only. It is concluded that trajectory hazard can be minimized by designing the panel-to-support attachment so that the panel remains with the sign support after impact. Even so, for some support systems the trade-off for a low change in momentum may be a broken windshield.

3. Vehicle rollover occurred in two tests, and in another test the test vehicle appeared near rollover. In all tests the contact point was either left or right of the center of the front bumper. In addition to a longitudinal force, this eccentricity of loading produced a twisting moment on the vehicle that tended to spin it sideways. Since off-center hits undoubtedly occur in practice, careful consideration should be given to off-center impacts in future tests of sign and luminaire supports. For a given size of post, the potential for rollover increases as vehicle size decreases.

4. Charpy impact tests were conducted on specimens from base-bending posts to determine why some posts fractured during full-scale tests and others did not. Posts that did not fracture caused considerably higher changes in momentum than posts of comparable size that did fracture. Based on the Charpy tests, post fracture can be anticipated for a high-speed impact if the fracture energy is less than 35 J/cm^2 (2000 in·lbf/in^2) at 65.6°C (150°F), provided, of course, the post is not larger than the limits determined here.

5. Adequate panel-to-post attachment can be achieved if the fasteners can carry a total tensile and shear working load equal to 40 times the weight of the panel. Tensile and shear load per fastener should equal the total force divided by the number of fasteners.

A breakdown of the crash-test performance of widely used single-support systems, as well as promising new systems, is given in Table 3 in terms of the following AASHTO change-in-momentum limits:

1. Acceptable—change in momentum of less than 3.4 kN·s (750 lbf·s),
2. Marginally acceptable—change in momentum greater than 3.4 kN·s (750 lbf·s) but less than 5 kN·s (1100 lbf·s), and
3. Unacceptable—change in momentum greater than 5 kN·s (1100 lbf·s).

Note that the limiting sizes in the acceptable category in Table 3 are not necessarily the maximum sizes that will satisfy the AASHTO specification. These limits are based on current test results. Future tests—if and when they are performed—may show that larger sizes of some designs are acceptable.

Crash tests of the slip-base breakaway design (11-13) and the load-concentration-coupler design (14, 15) have shown that these systems can easily meet current performance specifications for single-post installations. Most of the referenced tests involved installations with multiple supports much larger than those that would typically be used in a single-post installation. Slip bases are commonly used with standard steel pipe and rolled-steel shapes. The load-concentration coupler is typically used with rolled-steel shapes.

Table 3. Acceptability of various single-post systems according to AASHTO change-in-momentum specifications.

Acceptibility Category	Type of Post	Maximum Dimensions	Test No.
Acceptable	Steel U-post		
	Rail steel with lap-spliced bolted-base assembly	6 kg/m^a	3491-1, 3491-2, 3491-3, 3491-4
	Post with frangible coupling at base	4.5 kg/m^b	5, 6
	Full-length rail steel	4.5 kg/m	13
	Full-length "experimental" billet steel	8.9 kg/m, two 4.5-kg/m posts back to back	21
	Wood, grade 2, southern pine (or equivalent)		
	No breakaway or weakening device	10.2x15.2 cm, nominal	1, 2, 12
	Holes at base for breakaway mechanism	15.2x20.3 cm, nominal	
	Pipe		
	Full-length standard steel with no breakaway or weakening device	5.1-cm inside diameter	18
	Standard steel with breakaway coupling	6.35-cm inside diameter	14, 15, 16
	Square steel tube	6.35x6.35x0.34 cm	7, 3775-1, 3775-2, 3775-3, 3775-4
	Aluminum, full-length	Type 3X	8
Marginally acceptable	Steel U-post		
	Full-length rail steel	8.9 kg/m, two 4.5-kg/m posts back to back	20, 20A, 3636-1, 3636-2,
	Billet-steel vertical post and billet-steel back brace	3 kg/m each	17, 19
	Full-length billet steel	4.5 kg/m	3, 4
	Aluminum, full-length	Type 6X	3683-1, 3683-3
Unacceptable	Steel U-post, full-length billet steel	8.9 kg/m, two 4.5-kg/m posts back to back	9
	Pipe, full-length standard steel	6.35-cm inside diameter	11

Note: 1 kg/m = 0.67 lb/ft; 1 cm = 0.39 in.

[a] Maximum size crash tested.

[b] Maximum size for which couplings have been crash tested.

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