Small Sign Support Investigation

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The Arizona Department of Transportation (ADOT), in an effort to comply with FHWA and NCHRP 230 guidelines, and in cooperation with the Texas Transportation Institute (TTI) developed a generic breakaway small sign support system that was implemented in the summer of 1991. The system consists of two 4.5 kg/m (3 lb/ft), 551 MPa (80 ksi) U-channel posts with a 102-mm (4-in.) ground-level splice, (sign post behind the base and separated by two hexagonal spacers) and two Grade 9 bolts 8-mm (5⁄16-in.) in diameter spaced at 760 mm (3 in.). Shortly after the first installations some single post sign supports reported failed due to winds of approximately 64 km/hr (40 mph). The investigation of the failures involved meetings with ADOT maintenance personnel, U-channel post suppliers, and TTI. Field evaluations of the generic U-channel system were performed. Material property tests were performed on the U-channel posts (purchased as part of the implementation of the generic small sign support). Static and dynamic testing of the U-channel small sign support system were performed as well. Field evaluations indicate that contractor-installed signs have used a variety of spacers. Material property tests indicate that at least some of the U-channels did not meet the 551-MPa (80-ksi) minimum yield point. Static testing indicates that the system should be able to withstand a static load of 160.9 km/hr (100 mph). Dynamic testing, developed specifically for this project by TTI, could not prove that the ADOT generic U-channel single-post sign support can perform satisfactorily under fluttering caused by high winds. Pilot studies, or sign test sites, have been installed in two ADOT maintenance yards and on one ADOT highway. These pilot studies will give field performance data upon which management can make a decision about what ADOT's small sign support of the future will be. In the interim ADOT either will use a minimum of two supports per sign or will specify that square steel tube be used for breakaway small sign supports.

In October 1984 the Arizona Department of Transportation (ADOT) began a research project with the Texas Transportation Institute (TTI) to determine which of the small sign support systems then used by ADOT met FHWA criteria for breakaway sign supports. The project scope was expanded several times and eventually included three phases: Phase 1—crash test program, Phase 2—development of a new small sign support, and Phase 3—benefit/cost analysis.

The results of Phase 1 were that several of the systems ADOT used were in compliance and several were not (*1*). During testing at TTI, FHWA made the recommendation that breakaway small sign supports should conform to the 1985 AASHTO publication *Standard Specifications for Structural Supports for Highway Signs, Luminaries, and Traffic Signals*.

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In particular, breakaway small sign supports should have a base that extends no higher than 102 mm (4 in.) above ground level (*2*). The 102-mm stub height is called out in order to prevent the base post from rupturing fuel lines or penetrating the passenger compartment after the sign post has been hit by an errant vehicle. The 102-mm stub height requirement eliminated from consideration the previously used mid-height splice U-channel.

In response to the FHWA requirement ADOT embarked on the second phase of the TTI study: the development of a generic U-channel small sign support system with a ground-level lap splice. In addition to being able to withstand wind loads and meet federal safety standards for crash testing, some of the desired features of the generic small sign support included use of off-the-shelf hardware and easy installation procedures. Several combinations of U-channel unit weights and strengths were considered—4.5-kg/m (3-lb/ft) and 5.9-kg/m (4-lb/ft) U-channel posts, both at 413.4 MPa (60 ksi) and 551.2 MPa (80 ksi)—along with many possible splice configurations. Static and crash testing was performed as part of the generic small sign support development. Static testing was used to verify performance with respect to wind loading and crash testing was used to verify performance with respect to safety. In order to make the installation as easy as possible, a 76.5-mm (3-in.) bolt spacing was used. With a maximum 102-m (4-in.) stub height, the maximum bolt spacing possible (without excavation) is 76 mm.

Upon the conclusion of the second phase of the TTI study, ADOT chose the 4.5-kg/m, 551.2-MPa U-channel system, with a nested lap splice, and the post behind the base. Two Grade 9 bolts 8.0-mm (5⁄16 in.) in diameter spaced at 76 mm were selected to fasten the splice. A standard drawing and standard specification for the system were then developed. The U-channel small sign support installation drawing is shown in Figure 1.

PROBLEM DESCRIPTION

The U-channel small sign support standard specification was adopted and implemented in 1991. Failures of single support, small sign support installations occurred in large numbers soon after they were installed as part of construction projects. No reports of failures of installations with two or more supports were reported. Reports of single support sign post failures included the following:

- Within 3 months after installation, at a construction project near Phoenix, 32 of the 85 sign supports had failed due to winds that reportedly did not exceed 64.4 km/hr (40 mph);

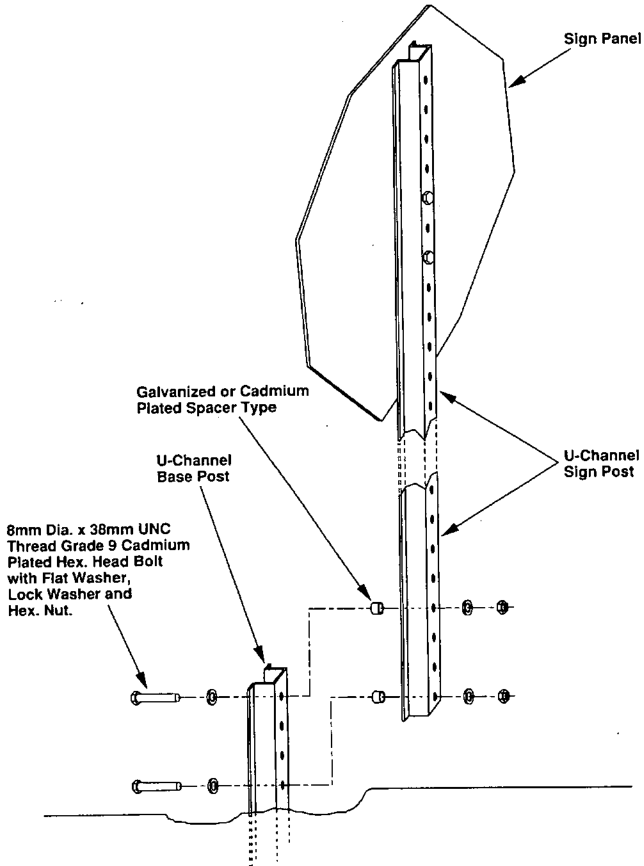

FIGURE 1 U-channel installation pictorial.

- In an airport road project, the U-channel small sign support system was installed without spacers and 40 percent of sign supports failed;
- Seven stop sign supports failed at a construction project south of Phoenix;
- All stop sign supports failed at a construction project in southern Arizona; and
- Some of the stop sign supports failed in a project near Tucson.

For the majority of failures, evidence indicated that the top bolt failed first followed by the U-channel post in the vicinity of the splice. Some posts ruptured with a zipper pattern along the back center line. A number of posts were torn diagonally as though they failed due to torsion stresses.

The couple formed by the two bolts is transferred to the posts through the bearing area of the spacers. Spacers used by some contractors (various diameters of galvanized water pipe and others) have had minimum bearing areas and have deformed easily allowing the connection to become loose. Once the connection is loose the bolts become subject to fatigue failure (*3*).

The U-channel selection chart, which is part of the ADOT U-channel small sign support standard drawing, is shown in Figure 2. The selection chart is used to determine support configurations for a given sign panel. The selection chart is based on a 96.5-km/hr (60-mph) wind speed. AASHTO specifications state that for roadside supports a 10-year mean recurrence interval should be used (*2*). A U.S. map indicating that for a 10-year mean recurrence interval the wind speed is 112.6 km/hr (70 mph) for most of Arizona is also given by

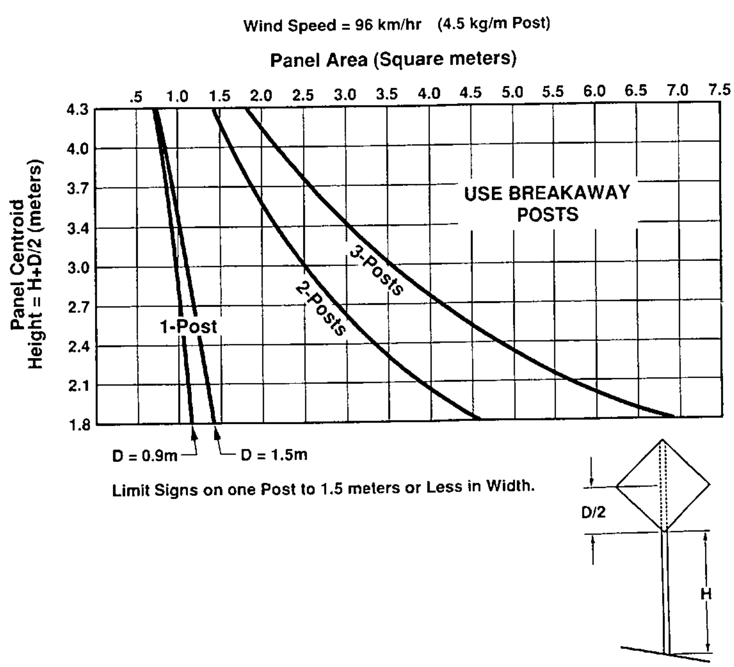

FIGURE 2 U-channel selection chart.

AASHTO. The ADOT selection chart was developed considering only the cross-section of the U-channel posts and not the structural capacity of the splice. The splice has proven to be the critical component of the U-channel small sign support system.

PROJECT APPROACH

The investigation began with a meeting with ADOT maintenance personnel and an assessment of the mode of the small sign support failures. The initial indication was that the U-channel sign post material was too brittle. Therefore, it was decided to conduct physical property tests. Tensile coupon testing was conducted along with chemical analysis of the U-channels that were purchased for use by ADOT maintenance personnel as part of the implementation of the new small sign support standard. These tests indicated that the yield point of some of the U-channel posts was slightly less than the required 551.2 MPa and that the chemistry of the steel was adequate.

The splice was the next target of the investigation. In the original TTI study, when the generic small sign support was developed, static bending, torsion, and combined bending and torsion tests were used to verify the wind load capacity of the system (*4*). Therefore, combined bending and torsion, and static testing was conducted to verify the results of the original study and to compare the effects of various spacers that had been used by contractors. The static testing was conducted in a factorial experiment that included tightness of the connection as a factor. Some of the test specimens with the hexagonal spacers had the bolts secured loosely in order to study the effect.

Structural analysis was performed to determine the wind speed equivalent of the static testing. Indications were that even the loose connection of the U-channel sign supports could withstand a static wind load of approximately 160.9 km/hr (100 mph). At this point, attention shifted to dynamic testing with the intention of simulating the flutter experienced by single sign supports in strong winds.

Vendor Participation

As part of the investigation U-channel post suppliers (Franklin Steel Company and Marion Steel Company) were contacted for their input. U-channel specimens were sent to Marion Steel and Franklin Steel. Franklin Steel representatives came to Arizona and gave a presentation to ADOT in October 1991. They believed that the 551.2-MPa steel was too brittle and that the lap splice was not sufficient to transfer torsion. A Marion Steel Representative came to Arizona in November of 1991 and discussed the problems with ADOT. The Marion Steel representative believed that improper installation was the major problem and offered to conduct training in each of the four ADOT districts.

Tensile Testing

The purpose of the tensile testing was to determine whether the yield point of the Marion Steel 4.5-kg/m (3-lb/ft) U-channel posts met the 551.2-MPa (80-ksi) minimum. Twelve Marion Steel post specimens were selected randomly and shipped to TTI for testing. Four Marion Steel post specimens taken from the TTI scrap yard were also tested for comparison purposes. Table 1 shows the test data.

Coupon tensile tests of the U-channel posts (rated at 551.2 MPa) used by TTI in the development of the generic small sign support system found a yield point of approximately 737.2 MPa (107 ksi) (*4*).

Cross-Section Variability

As stated, all U-channel small sign support failures that have occurred have been single-support installations. Single sign supports are subject to flutter and subsequently torsion. The contact between base post and sign post sides is required if torsion is to be carried by the U-channel posts.

A field evaluation was performed to determine whether contractor-installed sign supports had any contact between the base and sign post. Measurements were taken to determine the variability of in-service U-channel sign supports.

To determine whether the variability inherent in U-channel posts was such that the nesting concept was infeasible, a random sampling of U-channel posts were selected for measurements. Manufacturers of U-channel posts were contacted to determine mill tolerances.

Representatives of Franklin Steel stated that the U-channel posts are formed by rollers. These rollers are constantly wearing and may need to be changed even over the course of 1 day. After the steel is rolled at temperatures of approximately 1,038°C (1,900°F), it is placed on a notched bed for cooling at a temperature of between 206°C and 316°C (500°F and 600°F). Any differential cooling that takes place will induce variations in section dimensions. The U-channel posts are rolled when cool to straighten them. After the section is straightened it is sheared to length.

When asked to send a cross-section drawing that gave the tolerances for each dimension of the cross section, Franklin Steel stated: "it has been difficult to determine the range of variability you asked for, but I have shown on the drawing the internal tolerances we use on overall width, flange to flange. The other dimensions should be considered nominal and will vary slightly from rolling to rolling. The weight per foot of the section is the normal control element from a rolling standpoint and that tolerance for Franklin is plus or minus five percent." The tolerance on the flange-to-flange width mentioned is plus or minus 3 percent. Franklin Steel also stated that cross-section tolerances are not small enough to allow side-to-side contact in all cases. Therefore, it is not reasonable to expect torsion to be carried by side-to-side contact. Information supplied by Marion Steel indicates that their rolling process is similar. The cross-section variability indicated is approximately the same.

Chemical Analysis

A laboratory chemical analysis was conducted for the purpose of investigating chemical composition of the U-channel posts, and to see whether the chemical composition of these posts

TABLE 1 U-Channel Coupon Tensile Test Data (TTI)

Specimen Number	Width (mm)	Thickness (mm)	Load (kN)	Maximum Stress (MPa)
M1	12.672	3.510	40.72	914.99
M2	12.713	3.597	41.30	901.83
M3	12.685	3.708	42.14	895.01
M4	12.680	3.620	41.30	899.28
M5	12.738	3.579	41.25	903.42
M6	12.774	3.660	42.28	902.80
M7	12.700	3.647	42.14	908.72
M8	12.700	3.592	41.21	902.45
M9	12.771	3.617	41.61	899.77
M10	12.692	3.680	41.79	893.63
M11	12.703	3.683	41.30	878.27
M12	12.728	3.581	41.12	900.45
M13	12.664	4.318	45.88	837.69
M14	12.659	4.082	43.30	836.93
M15	12.700	4.293	50.02	916.51
M16	12.713	4.067	48.15	930.70

NOTES:
1) Test Procedure: ASTM 370
2) Specimens M1 through M12 are Marion 4.5 kg/m post specimens and were galvanized.
3) Specimens M13 through M16 were taken from the TTI scrap yard and were painted.
4) M13 and M14 are Marion 4.5 kg/m post specimens.
5) M15 and M16 are Marion 5.95 kg/m post specimens.
6) Thickness includes galvanizing or paint.

met the requirements stated in Article 607-2.04 of the 1990 ADOT Standard Specifications for Road and Bridge Construction (5). Eleven post specimens were analyzed. The following table presents the ADOT chemical composition requirements:

Element	*Composition (%)*
Carbon	0.67–0.82
Manganese	0.70–1.10
Phosphorus (maximum)	0.04
Sulfur (maximum)	0.05
Silicon	0.10–0.25

Table 2 gives the chemical analysis results. Except for the silicon content in Specimen 10, which is slightly above the maximum amount allowed, all the specimens met the chemical composition requirements.

Static Testing (Bending and Torsion)

The static testing was performed with the sign support in the horizontal position, by placing the base post in a large clamp so that the bottom of the splice was 76 mm (3 in.) from the clamp. The load was applied 2.7 m (9 ft) from the clamp with a 183-mm (7.2-in.) eccentricity. The testing was conducted with the U-channel flanges facing down. Figure 3 shows a schematic of the U-channel clamping and loading configuration for static testing. The load was applied by a two-speed motor (attached to an overhead I-beam) at a rate of 10.3 mm/sec (0.404 in./sec). A load cell was placed between the post and the motor for continuous monitoring of load. Loading was continued until failure.

All bolts used for the testing were Grade 9, 7.9-mm (5/16-in.) in diameter, and spaced at 76 mm (3 in.). Twenty-eight sign support specimens were tested from six spacer groups:

1. Steel bar stock spacer, 13-mm (½-in.) thick × 19-mm (¾ in.) wide × 127-mm (5-in.) long,
2. Hexagonal threaded spacers with bolts tightly fastened,
3. Hexagonal threaded spacers with bolts loosely fastened,
4. Spacers cut from a galvanized water pipe with a 13-mm (½-in.) inside diameter,
5. Spacers cut from a galvanized water pipe with a 19-mm (¾-in.) inside diameter, and
6. Spacers 19 mm in diameter and 13 mm thick (as used in the original TTI testing).

All sign support specimens failed by tensile failure of the top bolt. Table 3 shows the test results. Structural calculations indicate that the minimum load at failure of 1,469 N (330 lb) was equivalent to a "static" wind load of approximately 160.9 km/hr (100 mph) speed on a sign 762 × 762 mm (30 × 30 in.). Therefore, if the wind speed were 112.6 km/hr (70 mph), the factor of safety of the sign support against wind load would be about two. Also, maximum bending stress in the base post was larger than the specified yield stress of 551.2 MPa (80 ksi), which confirms the statement from TTI in their report

TABLE 2 Results of Chemical Analysis of U-Channel Posts

	ELEMENTAL COMPOSITION								
Specimen Number	C	Mn	P	S	Si	Cr	Ni	Mo	Cu
1	0.68	0.84	0.012	0.023	0.16	0.03	0.01	0.01	0.05
2	0.73	0.84	0.023	0.034	0.21	0.03	0.01	0.01	0.01
3	0.78	0.98	0.025	0.014	0.23	0.18	0.02	0.01	0.01
4	0.76	1.02	0.014	0.046	0.25	0.13	0.16	0.03	0.47
5	0.75	0.94	0.012	0.040	0.21	0.09	0.11	0.02	0.34
6	0.75	0.94	0.012	0.040	0.21	0.09	0.11	0.02	0.34
7	0.75	0.91	0.011	0.041	0.21	0.09	0.11	0.02	0.33
8	0.67	0.95	0.014	0.042	0.23	0.10	0.12	0.02	0.37
9	0.71	0.92	0.012	0.040	0.22	0.09	0.11	0.02	0.34
10	0.70	0.86	0.013	0.029	0.26	0.09	0.17	0.02	0.39
11	0.76	0.91	0.022	0.045	0.23	0.12	0.12	0.02	0.42

NOTES: 1) Specimen Numbers 1 through 3 are Franklin Post specimens.
2) Specimen Numbers 4 through 11 are Franklin Post specimens.

on Phase 2 of the original research, that for Marion Steel 4.5-kg/m (3-lb/ft) posts with Grade 9 bolts spaced at 76 mm (3 in.), the splice will develop the nominal yield stress of the posts.

Dynamic Testing

Dynamic testing was conducted to compare the endurance limits of several types of lap splices. Torsional vibration plus bending was induced by a shaker. The shaker consisted of a single-speed motor that drove two counter-rotating masses, one on each side of the motor, 180 degrees out of phase. Each sign support specimen for dynamic testing was installed as shown in Figure 4. The specimen was laid horizontally, with the base post clamped near the splice and the shaker attached to the sign post, 2.7 m (9 ft) away from the clamp that secured the base post. The shaker weighed approximately 445 N (100 lb) and was oscillated at 4 cycles a second.

The level of the dynamic load acting on the post was adjusted by changing the weight of the masses. Three levels of dynamic load were applied. The dynamic testing was intended to simulate wind induced flutter and therefore could not be correlated to wind speed.

Thirty-five sign post specimens were tested from five groups:

1. Marion Steel posts (from ADOT's supply) with two hexagonal threaded spacers and two Grade 9 bolts 7.9 mm (5⁄16 in.) in diameter, at 76-mm (3-in.) spacing;
2. Marion Steel posts (from ADOT's supply) with one steel bar spacer 13 mm (½ in.) thick, 19 mm (¾ in.) wide, 152 mm (6 in.) long and two Grade 8 bolts 7.9 mm (5⁄16 in.) in diameter, at 102-mm (4-in.) spacing;

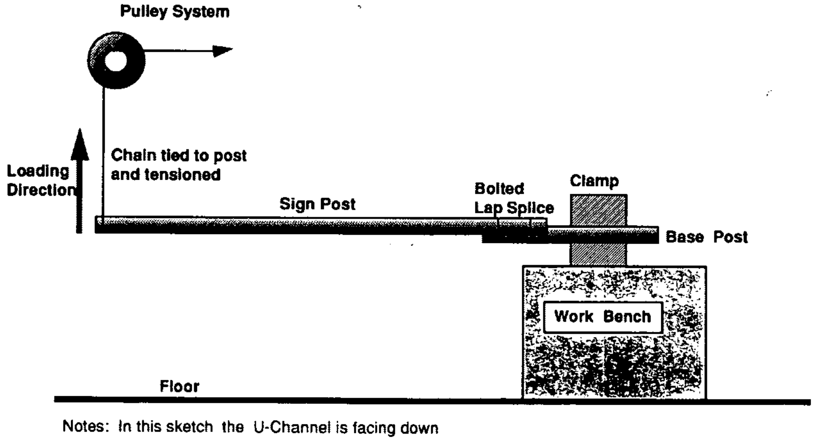

FIGURE 3 Schematic of U-channel post assembly and load application for static testing.

TABLE 3 Static Test Results

Post Group	Number of Specimens	Load at Failure (N)	Average Load at Failure (N)	Deflection at Loaded End (mm)	Avg. Deflection at Loaded End (mm)
1	8	1900.15	1851.20	85.34	72.90
		1659.85		60.96	
		2024.75		77.72	
		1726.60		67.56	
		2011.40		73.15	
		1811.15		69.60	
		1766.65		73.66	
		1909.05		75.18	
2	4	1650.95	1610.90	74.68	71.37
		1659.85		72.14	
		1504.10		65.53	
		1624.25		72.64	
3	4	1504.10	1530.80	73.15	73.41
		1637.60		75.69	
		1495.20		72.14	
		1490.75		72.64	
4	4	1593.10	1575.30	73.15	71.88
		1468.50		68.58	
		1615.35		71.12	
		1615.35		74.17	
5	4	1642.05	1579.75	69.60	
		1570.85		59.94	
		1477.40		67.56	
		1624.25		70.10	
6	4	1557.50	1619.80	64.10	66.29
		1628.70		67.56	
		1619.80		67.06	
		1673.20		66.55	

NOTES:
1. 13 mm (½ in.) thick x 19 mm (¾ in.) wide x 127 mm (5 in.) steel bar stock spacer.
2. hexagonal threaded spacers with bolts tightly fastened.
3. hexagonal threaded spacers with bolts loosely fastened.
4. spacers cut from 13 mm (½ inch) inside diameter galvanized water pipe.
5. spacers cut from 19 mm (¾ inch) inside diameter galvanized water pipe.
6. 19 mm diameter x 13 mm thick spacers (as used in the original TTI testing).

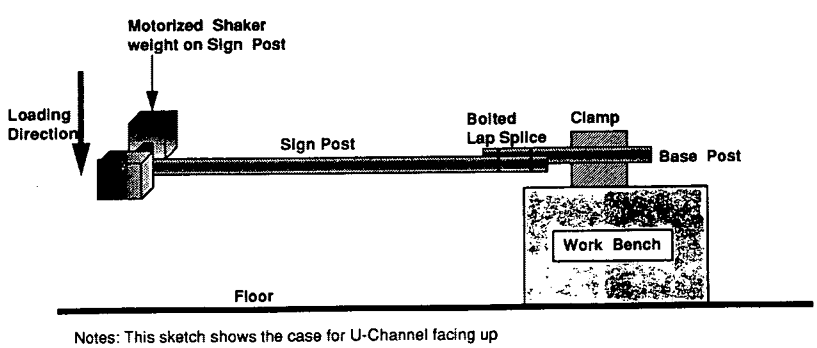

FIGURE 4 Schematic of U-channel post assembly and load application for dynamic testing.

3. Marion Steel posts (from ADOT's supply) with one steel bar spacer 13 mm (½ in.) thick, 19 mm (¾ in.) wide and 152 mm (6 in.) long and two Grade 8 bolts 9.5 mm (⅜ in.) in diameter, at 102-mm (4-in.) spacing;
4. Franklin EZE-ERECT; and
5. Marion Steel post with no splice.

Sign post specimen groups 4 and 5 were included to establish a baseline performance. Group 4, the Franklin EZE-ERECT, is a proprietary lap-splice system that has a 15-year service record. Group 5 was a single test with a continuous Marion Steel 4.5-kg/m (3-lb/ft) post.

The ratio of load cycles (number of revolutions of the sprocket that drives the rotating masses) to observed response cycles (number of oscillations of the sign support) at a given time varies with the level of load. Approximate observed ratios were 1:1 for the low level; 3.87:1 for the medium load level; and 4.32:1 for the high load level. Table 4 presents the results of the dynamic testing.

Pilot Studies

Pilot studies, or field installations, of various U-channel lap splices have been conducted in Arizona in an effort to gain field performance data. To date, two pilot studies have been installed in ADOT maintenance yards and one on an ADOT highway.

The pilot studies consist of a set of signs with four or five lap-splice configurations (including the Franklin EZE-ERECT) at three load levels. To obtain the load levels, the height to the centroid of the sign is held constant at 2.6 m (8.5 ft) and the sign panel size is varied.

Each of the maintenance yard pilot studies has been instrumented with a wind gauge. The maximum peak gust information is captured and stored by the gauges. The wind speed information is gathered periodically and incorporated into the test results data base for the small sign support investigation.

To date, one of the maintenance yard pilot studies, with signs facing west, has had a maximum peak gust speed of 66 km/hr (41 mph) east-southeast. The other maintenance yard pilot study, with signs facing northeast, has had a maximum peak gust speed of 120.7 km/hr (75 mph) south-southeast. All sign supports are still standing at both maintenance yards.

The highway pilot study originally consisted of 10 stop signs. Five had the hexagonal spacer splice and five had the bar spacer splice. Two of the signs had to be removed. None of these signs has failed.

TABLE 4 Dynamic Test Results

Dynamic Load Level	Post Group[a]	Channel Facing Down/up	N[b]	Range of Load Cycles to Failure	Avg. Number of Load Cycles to Failure	Avg. Number of Response Cycles to Failure
High	1	Down	4	4,880 - 10,280	7,280	1,685
High	1	Up	3	2,640 - 7,240	5,170	1,197
High	2	Down	3	5,560 - 10,360	17,050	3,947
High	2	Up	3	3,360 - 9,640	6,510	1,507
High	3	Up	3	11,040 - 13,920	12,240	2,833
High	4	Down	3	10,680 - 16,560	13,960	3,231
High	4	Up	3	20,320 - 71,640	38,560	8,926
High	5	Down	1	Test was halted at 187,480	Test was halted before Failure	Only one test was conducted
Medium	3	Up	3	22,800 - 40,320	31,920	8,248
Medium	4	Down	3	29,760 - 111,360	79,360	20,506
Low	3	Up	3	13,440 - 44,160	25,920	25,920
Low	4	Down	3	42,000 - 191,520	92,240	92,240

NOTES: (a) 1. Marion Steel posts (from ADOT's supply) with two hexagonal threaded spacers and two 7.9 mm (5/16 inch) diameter, Grade 9 bolts at 76 mm (3 inch) spacing.
2. Marion Steel posts (from ADOT's supply) with one 13 mm (½ inch) thick x 19 mm (¾ inch) wide x 152 mm (6 inch) steel bar spacer and two 7.9 mm (5/16 inch) diameter, Grade 8 bolts at 102 mm (4 inch) spacing.
3. Marion Steel posts (from ADOT's supply) with one 13 mm thick x 19 mm wide x 152 mm steel bar spacer and two 9.5 mm (⅜ inch) diameter, Grade 8 bolts at 102 mm spacing.
4. Franklin EZE-ERECT.
5. Post with no splice (Marion Steel Post).
(b) N = Number of Specimens

STRUCTURAL ANALYSIS

Effect of Cross Sections

Two cross-section drawings have been received by ADOT from Marion Steel, one dated January 20, 1983, and one dated November 30, 1983. A structural analysis was performed using the January 20, 1983, cross section. A 0.9-m × 0.9-m (3-ft × 3-ft) diamond-shaped sign mounted on a single post, with a 3.5-m (11.5-ft) height to the center of the sign, was used for the analysis since similar signs have been reported failed due to wind. Also signs of this size and height are on the acceptable limit of the current selection chart.

The sign support was analyzed for both 72.4 km/hr (45 mph) and 96.5 km/hr (60 mph) wind speeds (see Table 5). The analysis was performed according to the methodology given by AASHTO (*2*). AASHTO calls for a 40 percent increase in allowable bending stress for wind loading. The 40 percent increase was applied to all bending stress terms in the combined stress ratio (CSR) equation except for the axial compressive stress (F_a), which appears in the denominator of the second term of the equation. The 40 percent increase was not applied to this term in the interest of being conservative.

The analysis considered only the cross-sectional properties and yield point of the U-channel post steel. A yield strength of 551.2 MPa (80 ksi) was used. When subjected to 96.6 km/hr (60 mph) wind, the post is over stressed. However, the post is within the allowable range in the ADOT U-channel selection chart (Figure 2). This is because the U-channel selection chart was developed using the cross section of the U-channel posts supplied to TTI for the development of the generic small sign support.

In January 1992 ADOT received another 4.5-kg/m (3-lb/ft) post cross-section drawing, dated November 30, 1983, from Marion Steel Company. Marion Steel stated that the November 30, 1983, cross section is its final pass design and the January 20, 1983, cross section was sent to ADOT in error. The November 30, 1983, section is slightly weaker than the January 20, 1983, section and has a section modulus that is 23 percent smaller than the posts used in the development of the ADOT U-channel selection chart.

It is very important that in the development of the U-channel selection chart, the weakest possible section from all potential suppliers be used for structural calculations.

Bolt Stresses

An analysis was performed to determine the loads on the bolts at the splice. The splice strength is related to the bolts. The maximum loads on the bolts at the splice, using different wind speeds, are given here:

	Wind Speed (km/hr)	
	72.40	*96.50*
Maximum load on bolt (KN)	18.50	32.90
Factor of safety (based on 33.38-KN proof load)	1.80	1.01

It can be seen that for a 96.5-km/hr (60-mph) wind, the bolts do not have an adequate factor of safety.

Effect of Size and Spacing of Spacers on Stresses in Posts

A structural analysis was performed to check the stresses in the back of the post at the splice using the January 20, 1983, Marion Steel cross section. A wind speed of 72.4 km/hr (45 mph) was used for the wind load. The analysis was performed for spacers 19 mm (¾ in.) in diameter, 16 mm (⅝ in.) in diameter, and 13 mm (½ in.) in diameter, with bolt spacings of 51 mm (2 in.), 76 mm (3 in.), and 102 mm (4 in.). The back of the post was treated as a structural member spanning the sides. Table 6 shows the results of the analysis.

Some of the theoretical stresses shown in Table 6 are not attainable because they are far beyond the failing stress of the steel. The actual stresses would generally be lower because of the effect of local yielding and stress redistribution. How-

TABLE 5 Results of Structural Analysis on U-Channel Posts

	Wind speed (km/hr)	
	72.40	96.50
Axial compressive stress f_a (kPa)	558.10	558.10
Allowable axial compressive stress F_a (kPa)	8336.90	8336.90
Bending stress f_b (MPa)	228.67	405.61
Allowable bending stress F_b (MPa)	463.00	463.00
Shear stress from shear and torsion f_v (MPa)	127.53	226.48
Allowable shear stress F_v (MPa)	254.65	254.65
Combined stress ratio (CSR) $= \frac{f_a}{F_a} + \frac{f_b}{(1-f_a/F_a)F_b} + \frac{f_v^2}{F_v^2}$ (should be < or = 1)	0.863	1.824

TABLE 6 Maximum Flexural Stresses in Back of Post at Splice

	Maximum flexural stress (MPa) in back of post		
Bolt Spacing (mm)	19 mm diameter spacer	16 mm diameter spacer	13 mm diameter spacer
5.1	1149.3	1485.5	1816.2
7.6	685.6	877.1	1065.9
10.2	556.0	705.5	853.7

ever, it can be seen that the stress decreases as the size of spacer and bolt spacing increase. The optimum diameter of the spacer is 19 mm (¾ in.).

CONCLUSIONS

ADOT developed a generic U-channel small sign support system with a breakaway ground-level lap splice. Shortly after implementation of the new system, failures of single-support sign installations occurred. The failures have been associated with the splice.

The investigation into the failures began by ensuring that the U-channel steel met specifications. The chemistry of the steel met specifications but the yield point of some of the specimens tested was slightly less than the required 551.2 MPa (80 ksi). On reviewing the original TTI work, it was determined that the U-channel posts that they used were rated 551.2 MPa (80 ksi) but that the as-tested strength was 737.2 MPa (107 ksi). However, the U-channel posts purchased by ADOT (from the same vendor who supplied the original U-channel posts) that were rated at 551.2 MPa (80 ksi) were actually much closer to 551.2 MPa.

The combined bending and torsion static testing was conducted next. The purposes of this testing were to verify the original work done by TTI and to determine whether various spacers used by contractors had caused the failures. The results of the static testing indicated that all the spacers were sufficient from a static loading standpoint.

A dynamic test conducted at the TTI laboratory was used to induce flexural and cyclic torsional stresses on the sign support system. The test indicated that the proprietary Franklin EZE-ERECT performed better than any of the other systems tested. This was presumably due to the four bolts and special strap used in that system. Although the dynamic test was meant to simulate sign flutter caused by wind, the simulated flutter could not be correlated with real system flutter because there were no wind data for the analysis.

All failures during the testing occurred at one of the two splice bolts. The failure of only single sign support installations in the field led to a study of the effects of torsion. For torsion to be carried efficiently, it is necessary for the sides of the U-channels to be in constant contact. If they are not, the bolts will have to carry all the torsion. The results of variability studies of the U-channel post cross sections indicated that side-to-side contact is not a reasonable expectation. The result of this work, for ADOT, is that sign supports previously scheduled (designed) for a single post will now be installed with two posts. ADOT will explore other options for small sign support in the future.

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