Dynamic Testing of Malleable Aluminum Transformer Bases for Highway Luminaires

John E. Haviland, New York State Department of Transportation
David J. Segal, Calspan Corporation, Buffalo, New York

The purpose of the reported test program was to develop modifications to existing malleable aluminum transformer bases for highway luminaires that could be performed in the field with minimal equipment and labor expenditure. The evaluation consisted of two phases; first, determining whether the modifications resulted in acceptable breakaway performance as indicated by the momentum change of the impacting vehicle, and, second, determining whether the modifications could result in a serious degradation of expected service life as indicated by results of a limited accelerated fatigue study. The dynamic tests were conducted in accordance with NCHRP Report 153 and used a 1020-kg (2250-lb) car impacting at 9 and 18 m/s (20 and 40 mph). Fatigue tests consisted of vibrating a horizontally mounted base and pole shaft at the resonant frequency of the pole until failure occurred. The tests indicated that a base saw cut, made horizontally to leave 76.2 mm by 4.76 mm (3 x $^{3}/_{16}$-in) thick metal on each side, would induce approximately 362 kg·s (800 lb·s) momentum transfer and 6 *g* 50 millisecond maximum average deceleration in the test vehicle. Terminating the saw cut in 38-mm (1½-in) diameter holes proved sufficient to induce fatigue failure in the unmodified pole instead of the base.

The highway appurtenances tested during the reported program were fabricated aluminum transformer bases and mercury luminaire aluminum lamp posts of the New York City type 8S. During the 1960s the transformer bases were fabricated by various manufacturers to New York City drawings J-3739 and J-3793. The bases were 457 mm (18 in) square at the bottom, 330 mm (13 in) square at the top, 660 mm (26 in) high, and were fabricated with a 3003-H14 aluminum skirt welded to 356T6 bolt rings top and bottom. The skirt was 4.76 mm ($^{3}/_{16}$ in) thick.

Three basic configurations, and derivations thereof, were tested. An unmodified transformer base provided a baseline with which to compare both impact and fatigue testing. The two modified configurations were produced by making horizontal saw cuts near the bottom of the bases. One configuration involved leaving uncut material on each flat side; the other, uncut material on each corner.

For the impact tests, the bases were mounted to a 25.4-mm (1-in) thick steel plate, drilled and tapped to accept four 25.4-mm (1-in) hex-head cap screws. The cap screws secured the transformer base to the mounting plate by means of cast aluminum washers and were tightened to 271 N•m (200 lb•ft) of torque. The steel plate was, in turn, mounted to the concrete test track with ten concrete anchors and bolts. The bases and poles were mounted in such a way that the luminaire arm was at a right angle to the center line of the test track, and the access door on the transformer base was on the opposite side of the point of impact.

Photographs of a typical installation are shown in Figure 1.

TEST CONDITIONS

Full-Scale Impact Tests

Five full-scale impact tests were conducted on the unmodified and modified aluminum transformer bases. All tests were conducted with small (compact or subcompact) vehicles with a nominal test weight of 1020 kg (2250 lb). The test conditions are summarized in Table 1.

The vehicles were prepared for testing by removing nonessential components (e.g., seats, gas tank) or by adding ballast to obtain a test weight of 1020 kg (2250 lb) ± 9 kg (20 lb). Instrumentation installed in the vehicles consisted of two triaxial accelerometer packages, one located on the drive shaft tunnel at the longitudinal center of gravity position and the other on the rear deck along the vehicle longitudinal center line. In addition to the acceleration transducers, signal conditioning and amplification equipment were installed in the vehicle trunk area. [See the complete report, Appendix A, for detailed descriptions of the data acquisition and reduction systems.]

Lateral guidance of the test vehicle was provided by the test track guide rail and a pair of large-diameter flanged aluminum wheels arranged so as to restrict vertical and lateral motion of the vehicle. It was noted in the first two tests (with the Pinto and a Vega) that the required mounting location of these guide wheels on the available vehicle substructure resulted in contact between the wheels and the transformer base. Consequently, a guide slipper that could be mounted further aft on the vehicle understructure and therefore avoid contamination for the test results was fabricated for the third and fifth tests. The guide wheels were used on the Maverick in the fourth test since they could be mounted sufficiently aft to avoid contact with the base. The tow cable was connected to the vehicles by means of a quick-release cable clamp. This clamp was located 229 mm (9 in) to the left of the vehicle center line so as to avoid cable rub on the transformer base.

Speed measurements were made at three locations for each test. The first location was the abort window station located at a distance ahead of the impact point as determined by the test speed. The vehicle speed at this location was automatically compared to preprogrammed limits and, if outside these limits, the test was aborted and the vehicle was stopped prior to impact. The second location determined vehicle speed at impact; the last location measured the vehicle speed at a predetermined distance after impact to obtain velocity (and therefore momentum) change.

Photographic documentation of the tests included 102 × 127-mm (4 × 5-in) black-and-white still photographs, standard-speed documentary motion pictures, and high-speed motion pictures. High-speed camera frame rates for each of the five tests are given in Table 2.

Fatigue Tests

In conjunction with the full-scale impact test program, accelerated fatigue tests were conducted on six base and pole assemblies in order to evaluate the extent of fatigue life degradation resulting from the base modifications. Tests were conducted on horizontally mounted trans-

Figure 1. Typical installation of pole and base for impact testing.

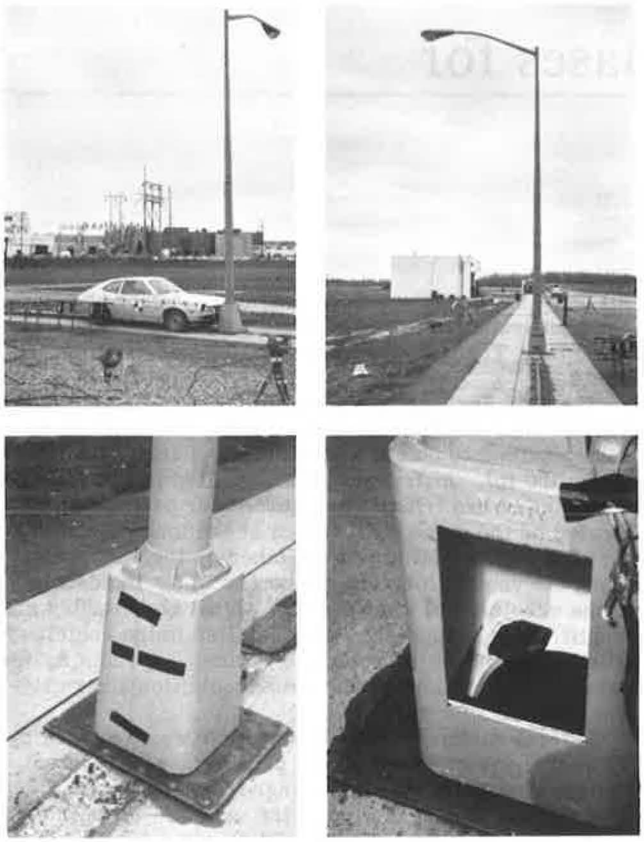

Table 1. Summary of full-scale impact test conditions.

Test No.	Target Impact Speed (m/s)	Vehicle	Vehicle Weight (kg)	Transformer Base Configuration
1	9	1971 Pinto	1020	Unmodified
2	9	1971 Vega	1020	Cut with 102 mm of wall material remaining
3	9	1971 Vega	1010	Cut with 76 mm of wall material remaining
4	18	1971 Maverick	1030	Cut with 76 mm of wall material remaining
5	9	1973 Vega	1020	Cut with 76 mm of wall remaining around base corners

Note: 1 m/s = 2.24 mph, 1 kg = 2.2 lb, 1 mm = 0.04 in.

former bases and pole assemblies with sinusoidal excitation provided by a rotating eccentric mass located at the approximate midpoint of the pole. Rotational speed of the eccentric mass was varied to excite the pole at its second natural frequency by means of a variable-speed electric motor. The mass weighed 1.18 kg (2.59 lb) and its eccentricity was 63.5 mm (2.49 in). The total weight of the vibratory assembly was 17.8 kg (39.3 lb).

The number of cycles to failure was determined by timing the duration of the test with a stop watch and measuring the vibration frequency with a General Radio Company Strobotac Type 1531-A. Although this method lacks a high degree of precision, it was deemed sufficiently accurate for comparative purposes.

It should be noted that only one sample of each configuration was tested using this procedure. Therefore, the possibility exists that these results would not be typical of the mean performance if a number of samples had been subjected to fatigue testing.

TEST RESULTS

Full-Scale Impact Tests

The first impact test was conducted on April 23, 1976, using a 1971 Ford Pinto to impact an unmodified transformer base and lamp post assembly. The car weight was 1020 kg (2250 lb), and the impact speed was 9 m/s (20.01 mph). Test data are summarized for this and all other impact tests in Table 3.

In this test, the unmodified transformer base did not break away during the impact. The maximum x component deceleration (positive forward) recorded at the tunnel was 32.8 *g*, and, at the rear deck, 23.75 *g* with an average of 28.3 *g*. The maximum average deceleration over a 50-ms time period was 16.8 *g* occurring between 55 and 105 ms at the rear deck location. Vehicle speed changes resulting from integration of the tunnel x acceleration and rear deck x acceleration were 11 and 10.6 m/s (24.5 and 23.75 mph) respectively. Analysis of the high-speed film coverage resulted in a speed change of 10.2 m/s (22.8 mph). The corresponding momentum changes were 1145, 1105, and 1060 kg•s (2513, 2436, and 2339 lb•s) respectively. Vehicle damage consisted of 495 mm (19.5 in) of frontal crush with a vehicle damage identification or impact code(VDI) of 12-FCEN-2. Damage to the transformer base consisted of a dented forward (struck) face and a cracked weld at the joint between the forward face and bottom.

In the second impact test, a 1971 Chevrolet Vega was used to impact a modified transformer base and lamp post assembly. The base was modified by saw cuts located 51 mm (2 in) above the bottom of the assembly and extending around each corner so that 102 mm (4 in) of panel material were left uncut on each of the four sides. The weight of the test vehicle was 1020 kg (2250 lb) and the impact speed was 9 m/s (19.96 mph). (See Table 3.)

The impact precipitated a breakaway of the transformer base resulting from an apparent combination shear and tensile failure of the uncut portion of the struck transformer base panel, a shear failure of the left panel, and tensile failure of the welds securing the right and rear panels to the base plate.

The peak x decelerations recorded at the tunnel and rear deck locations on-board the vehicle were 23.25 *g* and 20 *g* respectively, and the maximum average deceleration over 50 ms was 7.87 *g* occurring between 40 and 90 ms at the rear deck location. Vehicle speed changes resulting from integration of the tunnel and rear deck accelerations were 4.9 m/s (10.8 and 10.72 mph respectively). Analysis of high-speed film coverage indicated a speed change of 5.0 m/s (11 mph); speed trap measurement indicated a change of 4.6 m/s (10.2 mph) at a location 1.52 m (5 ft) beyond impact. The computed changes in momentum for these speed changes are 492, 487, 500, and 464 kg•s (1108, 1100, 1128, and 1046 lb•s) respectively. Damage to the vehicle consisted of frontal crush of 343 mm (13.5 in) with a VDI of 12-FCEN-2.

The third impact test was conducted on May 12, 1976, using a 1971 Chevrolet Vega weighing 1010 kg (2230 lb). The transformer base used in this test was modified with saw cuts located 51 mm (2 in) above the bottom of the assembly and extending around each corner so that 76 mm (3 in) of panel material were left uncut on each of the four sides. The vehicle impact speed was 9 m/s (19.78 mph). (See Table 3.) As a result of the impact, the transformer base broke away through failure of the 76 mm (3 in) of panel material remaining on the front and two sides and of the weld at the rear of the assembly.

The peak x decelerations recorded at the tunnel and rear deck locations on board the vehicle were 20 *g* and

14.5 *g* respectively, and the maximum average deceleration over 50 ms was 6.2 *g* occurring between 10 and 60 ms at the tunnel location. Vehicle speed changes resulting from integration of the tunnel and rear deck x accelerations were 3.4 and 3.50 m/s (7.6 and 7.8 mph) respectively. Analysis of high-speed film coverage indicated a speed change of 3.4 m/s (7.58 mph), and speed trap measurement indicated a change of 3.4 m/s (7.74 mph) at a location 1.52 m (5 ft) beyond impact. The computed changes in momentum for these speed changes are 350, 360, 350, and 357 kg·s (771, 793, 771, and 787 lb·s) respectively.

The front of the vehicle was crushed 381 mm (15 in), and the VDI for this test was 12-FCEN-2. Rotation of the pole after impact also resulted in contact with the vehicle roof on the driver's side and a cracked windshield.

The fourth impact test was conducted on June 10, 1976, using a 1970 Ford Maverick weighing 1030 kg (2270 lb). The transformer base used in this test was modified with saw cuts located 51 mm (2 in) above the bottom of the assembly and extending around each corner so that 76 mm (3 in) of panel material were left uncut on each of the four sides. The vehicle impact speed was 18 m/s (40.91 mph). (See Table 3.)

As a result of the impact, the transformer base broke away through failure of the 76 mm (3 in) of panel material remaining on the front and two sides and of the weld at the rear of the assembly.

The peak x decelerations recorded at the tunnel and rear deck locations on board the vehicle were 22.5 *g* and 17 *g* respectively, and the maximum average deceleration over 50 ms was 6 *g* occurring between 10 and 60 ms at the rear deck location. Vehicle speed changes resulting from integration of the tunnel and rear deck x accelerations were 3.22 and 3.33 m/s (7.2 and 7.44 mph) respectively. Analysis of high-speed film coverage indicated a speed change of 3.69 m/s (8.26 mph). The computed changes in momentum for these speed changes are 338, 349, and 388 kg·s (745, 770, and 855 lb·s).

An apparent malfunction in the speed trap measurement system, used to determine postimpact speed, resulted in an erroneous value of 6.7 m/s (14.94 mph).

Table 2. High-speed camera frame rates per second.

	Test Number				
Camera Location	1	2	3	4	5
South, wide	978	950	1001	925	880
South, medium	NA	NA	952	895	1100
East	1059	979	960	1034	860
Southeast, close	2820	2900	3480	2560	1100
Northeast, close	NTL	NTL	NTL	NTL	1300

Note: NA = not applicable, NTL = no timing light.

Therefore, no momentum transfer value is given in Table 3 for test 4.

The vehicle crush measured was 394 mm (15.5 in) and the VDI for this impact was 12-FCEN-2. Pole kinematics after impact resulted in contact with the vehicle roof causing a dent of about 76-102 mm (3-4 in) in depth.

The fifth impact test was conducted on September 8, 1976, using a 1973 Chevrolet Vega weighing 1020 kg (2260 lb). The transformer base used in this test was modified with saw cuts on each of the four sides 95 mm ($3\frac{3}{4}$ in) above the bottom of the assembly. The cuts were terminated with 25-mm (1-in) diameter stress relief holes so that 76 mm (3 in) of uncut material remained at each of the four corners. The vehicle speed at impact was 9 m/s (20.16 mph). (See Table 3.) As a result of the impact, the transformer base broke away through failure of the material remaining at the corners.

The peak decelerations recorded at the tunnel and rear deck locations on board the vehicle were 16 and 13.5 *g* respectively, and the maximum average deceleration over 50 ms was 5.86 *g* occurring between 20 and 70 ms at the tunnel location. Vehicle speed changes resulting from integration of the tunnel and rear deck x acceleration components were 4.3 and 4.0 m/s (9.68 and 8.96 mph) respectively. Analysis of high-speed film coverage indicated a speed change of 4.1 m/s (9.28 mph). Speed trap measurements at impact and 2.44 m (8 ft) after impact resulted in a speed change of 4.8 m/s (10.85 mph).

Examination of the computerized data for this test disclosed that the 50-ms maximum average deceleration, speed change, and the momentum transfer values were not consistent with data from tests 2, 3, and 4 in that momentum transfer appeared about 91 kg·s (200 lb·s) high, and speed change appeared 0.9-1.3 m/s (2-3 mph) high as shown below for the tunnel "X" accelerometer (1 m/s = 2.24 mph, 1 kg = 2.2 lb, and 1 mm = 0.04 in).

	Test Number			
Item	2	3	4	5
Maximum 50-ms avg deceleration, *g*	7.9	7.6	6.0	5.9
Speed change, m/s	4.8	3.5	3.2	4.3
Speed change time, m/s	75	70	50	100
Tunnel momentum change, kg·s	504	351	338	452
Metal remaining, mm	102	76	76	76
Test speed, m/s	9	9	18	9

Review of the high-speed photography disclosed that the left front wheel rose several centimeters off the ground shortly after impact. Inspection of the lower portion of the transformer base disclosed that there were two secondary impacts that were caused by the towing attachment and the guide slipper used to maintain lateral placement. As shown here, a comparison of the velocity change plots indicated that test 5 extended at least 20 ms

Table 3. Summary of test results.

			Speed Trap Measurement		Integration of Tunnel Acceleration		Integration of Rear-Deck Acceleration		High-Speed Film Analysis		Vehicle Damage	
Test No.	Maximum 50-ms Avg Deceleration (*g*)	Peak Deceleration (*g*)	Speed Change (m/s)	Momentum Change (kg·s)	Speed Change (m/s)	Momentum Change (kg·s)	Speed Change (m/s)	Momentum Change (kg·s)	Speed Change (m/s)	Momentum Change (kg·s)	VDI	Permanent Deformation (mm)
1	16.8	32.8	NM	NM	10.9	1145	10.6	1105	10.2	1060	12-FCEN-2	495
2	7.9	23.25	4.6	485	4.8	504	4.8	499	4.8	499	12-FCEN-2	343
3	6.2	20.0	3.45	358	3.50	351	3.48	360	3.48	350	12-FCEN-2	381
4	6.0	22.5	-	-	3.2	338	3.3	349	3.7	388	12-FCEN-2	394
5	5.86	16	4.8	506	4.3	457	4.0	418	4.1	457	12-FCEN-2	343

Notes: 1 m/s = 2.24 mph, 1 kg = 2.2 lb, 1 mm = 0.04 in.
NM = not measured for this test.

Table 4. Summary of accelerated fatigue test data.

Test No.	Base Configuration	No. of Cycles to Failure
1	Unmodified	15 060
2	Saw cut 45 mm up from bottom with 76 mm of material remaining uncut on each side; saw cuts terminated with 6-mm stress relief holes	930
3	Saw cut 91 mm up from bottom with 76 mm of material remaining uncut around each corner; saw cuts terminated with 13-mm stress relief holes	1 350
4	Saw cut 95 mm up from bottom with 76 mm of material remaining uncut around each corner; saw cuts terminated with 25-mm stress relief holes	1 840
5	Saw cut 111 mm up from bottom with 76 mm of material remaining uncut around each corner; saw cuts terminated with 38-mm stress relief holes	6 900
6	Saw cut 64 mm up from bottom with two 38-mm sections of uncut material left on each side; saw cuts terminated with 38-mm stress relief holes	11 650

Note: 1 mm = 0.04 in.

longer than the other tests. Since the maximum average 50-ms deceleration values of tests 3, 4, and 5 are approximately equal and consistent with the value of test 2—where the only difference was an additional 25 mm (1 in) of metal on each side—we believe that the computed momentum transfer value for test 5 is excessive by approximately 91 kg•s (200 lb•s) because of the extended velocity change time.

The computed momentum changes from these speed changes are 457, 418, 457, and 506 kg•s (997, 923, 956, and 1118 lb•s) respectively. Film analysis also indicated a secondary impact between pole and car prior to the second speed trap, which accounts for the higher speed change obtained by that method.

The vehicle crush was 343 mm (13.5 in). The VDI for this impact was 12-FCEN-2.

Fatigue Tests

The accelerated fatigue test series consisted of six tests involving five modified bases and one unmodified base with which comparisons of the relative fatigue life (in terms of cycles to failure) could be made. The excitation was provided by a rotating eccentric weight located at approximately the midpoint of the horizontally mounted pole as discussed in an earlier section of this paper. The excitation frequency corresponded to the second natural frequency of the pole as determined by visual observation and was 6.9 Hz. The resulting sinusoidal excitation force due to the rotating eccentric weight had a magnitude of 17.8 kg (39.3 lb).

The fatigue test results are summarized in Table 4. The first test of the unmodified transformer base and pole provided a baseline configuration. This lasted approximately 15 060 cycles before a failure appeared on the pole immediately above the pole-mounting flange weld.

The second test was conducted on a base that was modified by making saw cuts located 45 mm ($1\frac{7}{8}$ in) up from the bottom and extending around the corners so that 76 mm (3 in) of uncut material were left on each side. All cuts were terminated with 6-mm ($\frac{1}{4}$-in) stress relief holes. This configuration failed due to propagation of cracks from the end of the saw cuts after approximately 930 cycles.

For the third test, the base was modified by cutting the sides—91 mm ($3\frac{5}{8}$ in) up from the bottom—and leaving 76 mm (3 in) of uncut material at each corner. Saw cuts were terminated with 13-mm ($\frac{1}{2}$-in) stress relief holes. Failure resulted from the initiation of cracks from the saw cuts after 1350 cycles. These cracks followed the heat-affected zone surrounding the weldment of the corner stiffener.

The base used in the fourth fatigue test was similar to the third, except that 25-mm (1-in) stress relief holes were used to terminate the saw cuts. Again, failure resulted from crack propagation from the stress relief holes after approximately 1840 cycles. These cracks followed the heat-affected zone surrounding the weldment of the corner stiffener.

Modifications to the bases used for the fifth and sixth tests were intended to move the areas of stress concentration away from the zones of metal that were affected by the welding process during assembly. The fifth base was similar to those in the third and fourth tests, but the saw cut was elevated to 111 mm ($4\frac{3}{8}$ in) above the bottom and terminated by 38-mm ($1\frac{1}{2}$-in) stress relief holes. Failure again resulted from propagation of cracks from the stress relief holes but the fatigue was increased to approximately 6900 cycles. Although the increased height of the saw cuts removed most of the influence of heat-affected metal, there is still some evidence of it. New York state engineers believe, therefore, that this modification would provide satisfactory performance in the absence of the weldment.

The last base modification tested consisted of saw cuts located 64 mm ($2\frac{1}{2}$ in) above the bottom of the base extending around each corner and of a separate cut on each side, so that two 38-mm ($1\frac{1}{2}$-in) sections were left uncut on each side outboard near the corners. Failure of this configuration occurred due to propagation of a crack immediately above the pole-mounting flange weld, the same location of the failure in the first vibration test after approximately 11 650 cycles. The failure of the pole at a lower number of cycles than in the first test was not expected since this pole had been used in previous fatigue tests. However, this base modification did not result in failure of the base, thus indicating that the in-field expected service life should approach that of the unmodified base and pole combination.

EVALUATION OF TRANSFORMER BASES

A comparative evaluation of the performance of the transformer bases tested under the reported program is contained in this section. The performance evaluation appraisal is based on three factors: (a) structural adequacy, (b) impact severity, and (c) vehicle trajectory hazard.

Structural Adequacy

Of the five impact tests performed, only the first with the unmodified transformer base proved inadequate in this category. At the nominal impact speed of 9 m/s (20 mph), this base failed to break away indicating an undesirable highway appurtenance. The remaining four tests, all employing modified bases, indicated adequate structural performance in that breakaway occurred. The final locations of the poles and mast arms for these four tests are inconclusive because the abort brake discussed in Appendix A of the complete report prevented the vehicles from clearing the pole-mounting site and drop zone at postimpact speed.

No firm conclusions can be drawn from the accelerated fatigue tests performed under this program because there are no data that relate performance under the employed test conditions to in-field service life expectancy and because testing was performed on only one sample of each modification. Implications drawn from the results are that the modification employed for the sixth fatigue test should approach the in-field service life expectancy of the unmodified configuration and that the modification used in the fifth fatigue test may approximate that of the unmodified base in the absence of weldments in or near the plane of saw cuts.

Impact Severity

The primary criterion for evaluation of breakaway supports is a maximum vehicle momentum change of 500 kg•s (1100 lb•s) with a desirable limit of 350 kg•s (750 lb•s). The momentum changes occurring in the five tests conducted are summarized below (1 kg•s = 2.2 lb•s):

	Test Number				
Item	1	2	3	4	5
Speed trap measurement	–	485	358	–	506
Integration of acceleration					
Tunnel	1145	504	351	338	457
Rear deck	1105	499	360	349	418
High-speed film reduction	1060	512	350	388	457

In test 1, there was no penetration in the speed trap measurement, and in test 4 the measurement was erroneous. Test 5 was biased due to secondary impacts.

As indicated in the above summary, the momentum change, resulting from test 2 with a modified transformer base cut so that 102 mm (4 in) of material remained on each side panel, comes close to meeting the maximum allowed momentum change at an impact speed of 9 m/s (20 mph) with a 1020-kg (2250-lb) vehicle.

The third and fourth tests employed a modified transformer base cut with 76 mm (3 in) of material remaining on each panel, and succeeded in nearly meeting the desirable momentum change limit of 350 kg•s (750 lb•s). These tests were conducted with nominal 1020-kg (2250-lb) vehicles at speeds of 9 and 18 m/s (20 and 40 mph) respectively.

The fifth impact test employed a transformer base cut so that 76 mm (3 in) of material remained at each corner. This further modification was made in an attempt to increase the fatigue life of the base and, in a 9-m/s (20-mph) impact with a 1020-kg (2250-lb) vehicle, successfully limited the momentum change to below 500 kg•s (1100 lb•s). However, as discussed in the complete report, the momentum transfer is believed to be approximately 91 kg•s (200 lb•s) too high as a result of secondary impacts with the base by both the towing attachment and the guide slipper.

The maximum 50-ms average deceleration computed for the five tests are as follows: Test 1, 16.8 *g*; test 2, 7.9 *g*; test 3, 6.2 *g*; test 4, 6.0 *g*; and test 5, 5.9 *g*.

Vehicle Trajectory Hazard

No substantial vehicle trajectory hazard exists with roadside appurtenances tested since they are not redirective devices. However, as noted previously, pole kinematics after impact could not be adequately defined because of the influence of the abort brake that did not allow the vehicle to clear the pole drop zone at exit velocity.

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Pendulum Tests of Breakaway Wood Sign Supports Using Crushable Bumpers

C. E. Kimball and J. D. Michie, Southwest Research Institute, San Antonio, Texas

Ten pendulum impact tests of breakaway wood sign supports were conducted to evaluate safety performance. Two sizes of timber supports were tested per AASHTO impact conditions, i.e., 1020 kg (2250 lb) mass and 32 km/h (20 mph). Two crushable pendulum nose designs were also used to evaluate relative performance. The findings indicate that both support sizes can be modified by drilled holes to effect structures that safely break away with a pendulum mass momentum change of less than 3.36 kN·s (750 lb·s). The findings also indicate that the crushable nose design has an important effect on the breakaway performance. Sequential photographs illustrate that the fracture mechanism is similar for the ten tests.

Two sizes of timber sign supports were impact-tested at the Southwest Research Institute's (SwRI) pendulum facility to evaluate their performance as breakaway roadside structures. A total of eight tests were conducted on 100 × 150-mm (4 × 6-in) and 150 × 200-mm (6 × 8-in) timber sign supports with and without holes near grade level with a crushable pendulum nose design (1). Two additional tests were conducted with a recently developed crushable pendulum nose design (2). Details of the program, test procedures, results, and conclusions are summarized in the following sections.