Full-Scale Crash Tests on a Luminaire Support 4-Bolt Slipbase Design

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The breakaway luminaire support concept has existed for many years and has proven to be an effective safety device. The 4-bolt breakaway slipbase design was originally used in Utah and has been used successfully in 20 years of field implementation. The state transportation departments of Idaho, Montana, Nevada, Utah, and Wyoming requested that the 4-bolt slipbase system be evaluated for possible use on Federal-aid highway projects. Two full-scale vehicle crash tests were performed by the Midwest Roadside Safety Facility to evaluate the system. Both tests had a centerline impact location. Test USBLM-1 was conducted with a 1,800-lb vehicle traveling at 15 mph, and Test USBLM-2 was conducted with a 1,800-lb vehicle traveling at 57.5 mph. The full-scale vehicle crash tests were evaluated according to the performance criteria presented in NCHRP Report 230 and the 1985 AASHTO specifications for structural supports. The Code of Federal Regulations, in which FHWA slightly modified the AASHTO requirement for maximum allowable change in velocity, was also used in the evaluation (23 CFR 625). The tests easily met all of the performance criteria mentioned above. Therefore, the safety performance of the 4-bolt breakaway slipbase design was determined to be satisfactory.

A breakaway device is a mechanism that fractures or yields when struck by a vehicle but is strong enough to withstand static and wind loads. The concept of a breakaway mechanism for highway lighting supports has existed for many years, and extensive testing has been conducted to determine the relative safety of different breakaway designs (1–7).

The 3-bolt slipbase design appears to be the most widely used system, and it has undergone extensive testing under a comprehensive program at the Federal Outdoor Impact Laboratory (unpublished data, L.A. Staron, FHWA). However, a 4-bolt slipbase design has been used in Utah for nearly 20 years. During those 20 years of field implementation, the design has proven to be so successful that, in most cases, motorists were able to drive away from the scene of the accident.

The objective of this study was to evaluate the safety performance of the 4-bolt slipbase design for possible use on Federal-aid projects. Two full-scale vehicle crash tests were conducted (8) in accordance with the guidelines presented in NCHRP Report 230 (9), AASHTO standard specifications (10), and the Code of Federal Regulations (11), in which the 1985 AASHTO specifications are updated.

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4-BOLT SLIPBASE DESIGN DETAILS

The luminaire support 4-bolt slipbase design details are shown in Figure 1, and photographs of the design are shown in Figure 2. The test article consisted of three major structural components: the luminaire support pole, the two mast arms, and the permanent lower slipbase assembly.

The maximum mounting height of the luminaire support pole was 52 ft from the ground to the top of the mast arms. The height to the top of the luminaire pole was 50 ft 4 in. from the ground. The permanent lower slipbase assembly had a stub height (the height remaining after the pole breaks away) of 4 in. The fully assembled test article is shown in Figure 2.

In actual field installations, the permanent lower slipbase assembly is held in place by four cast-in-place 1-in.-diameter galvanized ASTM A449 threaded rods. However, for testing purposes, this assembly was held in place with four 1-in.-diameter \( \times \) 12-in.-long galvanized ASTM A449 threaded rods doweled into the existing concrete apron with a high-modulus, high-strength epoxy. The embedment depth of the threaded rods was 8.25 in., leaving 3.75 in. extending above the existing concrete surface. The bottom and top surfaces of the permanent lower slipbase assembly were mounted above the existing concrete apron at heights of 1.5 in. and 4 in., respectively. The permanent lower slipbase assembly was manufactured with steel that had a minimum yield strength of 36 ksi. The steel assembly was hot-dipped galvanized in accordance with ASTM standards (ASTM A123). A concrete grout mix was placed below the lower edge of the permanent lower slipbase assembly.

The 50-ft luminaire support was mounted on the permanent lower slipbase assembly with four 1-in.-diameter ASTM A325 slip bolts. The high-strength slip bolts, nuts, and washers were electroplated cadmium in accordance with ASTM standards (ASTM A165). This was used instead of hot-dip galvanizing because it provided a smoother finish, resulting in a much more consistent torque-versus-tension relationship. This also eliminated the need for lubricating the slip bolts. The four slip bolts were torqued to 80 lbf-ft, then released and re-torqued to 70 lbf-ft. The Utah Department of Transportation conducted tests that related torque and tension on four 1-in.-diameter A325 high-strength bolts. It was determined that a torque of 70 lbf-ft would develop approximately 4,300 lb of tension per bolt. The results of these tests are shown in Figure 3.

The four 1-in.-diameter slip bolts were held in place in the slots with a keeper plate. The keeper plate conform
FIGURE 1  Design details of the 4-bolt breakaway slipbase luminaire (continued on next page).
FIGURE 1 (continued).
ASTM A446 Grade A steel with a 0.0149-in. thickness (28 gauge) before coating.

The luminaire support had a diameter of 10 in. at the base, which tapered off to 3 in. at the top. The wall thickness was 0.120 in. (11 gauge). The luminaire support was manufactured with ASTM A595 Grade A steel and hot-dipped galvanized in accordance with ASTM standards (ASTM A123).

The two steel mast arms were attached 10 in. below the top of the luminaire support. The mast arms extended 15 ft outward from the face of the luminaire pole and 1 ft 8 in. above the top of the luminaire support. They extended outward perpendicular to the direction of the impact. Weights (75 lb per mast arm) were mounted on the end of each mast arm to simulate an actual luminaire.

A reinforced handhole opening was located approximately 1 ft 10 in. above the existing concrete apron. The luminaire support was installed so that the handhole opening was located on the side of the luminaire pole opposite that impacted by the test vehicle.

The slipbase was oriented with one of the slip bolts directly

FIGURE 2 4-bolt breakaway slipbase installation.

FIGURE 3 Torque-versus-tension tests for A325 slip bolts.
in line with the test vehicle impact location, as shown in Figures 1 and 2. It was anticipated that the highest percentage of accidents would occur with this orientation.

**PERFORMANCE EVALUATION CRITERIA**

The safety performance objective of a highway appurtenance is to minimize the consequences of an off-road accident. This safety goal is met when the appurtenance allows vehicle occupants to escape major-injury-producing forces. The safety performance of the highway appurtenance was evaluated according to four criteria: (a) breakaway mechanism worthiness, (b) vehicle stability and trajectory, (c) occupant risk, and (d) test object penetration. These factors are defined and explained in NCHRP Report 230 (9). Similar criteria are presented by AASHTO (10).

The 4-bolt slipbase design was evaluated according to the performance criteria presented in NCHRP Report 230 (9), AASHTO standard specifications (10), and the Code of Federal Regulations (11).

The standards used to evaluate the crash tests were Test Designation Numbers 62 and 63 from NCHRP Report 230 (9). These criteria require a 20-mph test in which the vehicle contacts the luminaire support at the center point of the bumper and a 60-mph test in which the impact occurs at the quarter point of the bumper. The location of impact for the 60-mph test was changed from the quarter point to the center point of the bumper under the AASHTO (10) recommendation that the quarter point impact may be more stringent than can easily be met under the current state of the art. According to the AASHTO guidelines, acceptable performance under the high-speed, off-center impact may be considered a goal, and acceptance may be based on a centerline, high-speed test.

The safety evaluation criteria are presented in Table 1 (9–11). NCHRP Report 230 (9) requires that the test article activate in a predictable manner by breaking away or yielding. In addition, detached fragments from the test article should not penetrate or show potential for penetrating the passenger compartment, nor should they present undue hazard to other traffic. The vehicle must remain upright during and after the collision, and the integrity of the passenger compartment must be maintained with essentially no deformation or intrusion. A design value of 15 g is recommended for the maximum longitudinal occupant ridedown deceleration (9). After the collision, the vehicle should intrude a minimum distance, if at all, into adjacent traffic lanes.

AASHTO specifications (10) include the same criteria as NCHRP Report 230 (9) except that they also recommend that the change in velocity of the vehicle be less than or equal to 15 ft/sec. FHWA updated that criterion to 16 ft/sec or less (11).

After each test, vehicle damage was assessed by the traffic accident data (TAD) scale (12) and the vehicle damage index (VDI) (13).

### TABLE 1 Performance Evaluation Results

<table>
<thead>
<tr>
<th>Evaluation Factors</th>
<th>Evaluation Criteria</th>
<th>Test USBLM-1</th>
<th></th>
<th>Test USBLM-2</th>
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</thead>
<tbody>
<tr>
<td></td>
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<td>NCHRP 230</td>
<td>AASHTO</td>
<td>FHWA</td>
<td>NCHRP 230</td>
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<td></td>
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<td>(9)</td>
<td>(10)</td>
<td>(11)</td>
<td>(9)</td>
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<tr>
<td>Structural Adequacy</td>
<td>1. The test article shall readily activate in a predictable manner by breaking away or yielding.</td>
<td>S</td>
<td>S</td>
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<td></td>
<td>2. Detached elements, fragments or other debris from the test article shall not penetrate or show potential for penetrating the passenger compartment or present undue hazard to other traffic.</td>
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<tr>
<td>Occupant Risk</td>
<td>3. The vehicle shall remain upright during and after collision although moderate roll, pitching and yawing are acceptable. Integrity of the passenger compartment must be maintained with essentially no deformation or intrusion.</td>
<td>S</td>
<td>S</td>
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<td></td>
<td>4. Longitudinal Occupant Impact Velocity (fps).</td>
<td>7.6&lt;15</td>
<td>7.6&lt;15</td>
<td>7.6&lt;15</td>
<td>14.2&lt;15</td>
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<tr>
<td></td>
<td>5. Long. Occupant Ridedown Decelerations (g).</td>
<td>3.5&lt;15</td>
<td>3.5&lt;15</td>
<td>3.5&lt;15</td>
<td>1.0&lt;15</td>
</tr>
<tr>
<td>Vehicle Trajectory</td>
<td>7. After collision, the vehicle trajectory and final stopping position shall intrude a minimum distance, if at all, into adjacent traffic lanes.</td>
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<td></td>
<td>8. Vehicle trajectory behind the test article is acceptable.</td>
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<td>S</td>
<td>S</td>
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</tr>
</tbody>
</table>

S Satisfactory        M Marginal          U Unsatisfactory     NA Not Applicable
- Test Number: USBLM-1
- Date: 1/24/91
- Installation: 4-Bolt Breakaway
- Luminaire Height: 52 ft-0 in.
- Mast Arm Span Width: 30 ft-10 in.
- Luminaire System Weight: 902 lbs
- Permanent Lower Slipbase Assembly
  - Bolt Type: four 1-in. diameter ASTM A325 bolts
  - Bolt Circle Diameter: 1 ft-4 in.
  - Stub Height: 4 in.
- Luminaire Support Pole
  - Base Diameter: 10 in.
  - Top Diameter: 3 in.
  - Length: 50 ft
  - Slipbolt Type: four 1-in. diameter ASTM A325 slipbolts
  - Bolt Circle Diameter: 1 ft-1 in.
  - Slip Bolt Gasket Thickness: 0.0149 in. (28 gauge)
  - Initial Bolt Torque: 80 ft-lbs.
  - Final Bolt Torque: 70 ft-lbs.
  - Clamping Bolt Force: 4 @ 4,300 lbs each

- Vehicle Model: 1984 Dodge Colt
- Vehicle Weight:
  - Curb: 1,990 lbs
  - Test Inertial: 1,750 lbs
  - Gross Static: 1,750 lbs
- Vehicle Impact Speed: 15.0 mph
- Vehicle Impact Angle: 0 deg
- Vehicle Impact Location: Center of bumper
- Vehicle Snagging: None
- Vehicle Stability: Satisfactory
- Occupant Impact Velocity: 7.6 fps
- Occupant Ridedown Deceleration: 3.5 g's
- Vehicle Change-in-Speed: 6.1 fps
- Vehicle Damage: Minimal
- TAD: 12-FC-2
- VDI: 12FCEN1, 12TZ6W2
- Vehicle Front-End Deflection: 9 in.
- Vehicle Stopping Distance: 40 ft
- Luminaire Support Damage: Small permanent set deflection near luminaire pole top
- Final Luminaire Support Location: 35 ft to Base

FIGURE 4 Summary and sequential photographs, Test USBLM-1.
TEST PARAMETERS

A 1984 Dodge Colt weighing 1,750 lb was used to evaluate the 4-bolt slipbase design. After Test USBLM-1, the bumper was replaced and the hood repaired so that the vehicle could be used for Test USBLM-2. Both tests were conducted with a centerline head-on impact. Test USBLM-1 was conducted with the vehicle traveling at 15 mph; Test USBLM-2 was conducted with the vehicle traveling at 57.5 mph.

TEST RESULTS

Test USBLM-1

A summary of Test USBLM-1 is shown in Figure 4; sequential photographs are shown in Figure 5. The safety evaluation results are presented in Table 1. The test vehicle struck the luminaire support at the center of the front bumper at a speed of 15 mph. This impact speed was less than the target speed of 20 mph because of technical difficulties. Because the speed in this test was only 15 mph, it was more severe than in the 20 mph test because less kinetic energy was available to initiate breakaway.

On impact with the luminaire support, the front bumper of the vehicle crushed inward until approximately 0.08 sec after impact. At that time the luminaire support began to slip from the base. The luminaire support remained approximately vertical until 0.39 sec after impact when the top of the pole started to rotate toward the vehicle. The luminaire support continued to fall toward the vehicle until it hit the roof approximately 2.33 sec after impact. The top of the luminaire support hit

FIGURE 5 Sequential photographs, Test USBLM-1.

FIGURE 6 Vehicle and installation damage, Test USBLM-1.
Impact

0.188 sec

0.500 sec

0.625 sec

0.906 sec

Test Number

USBLM-2

Date

2/1/91

Installation

4-Bolt Breakaway Slipbase Luminaire

Luminaire Height

52 ft-0 in.

Mast Arm Span Width

30 ft-10 in.

Luminaire Weight

902 lbs

Permanent Lower Slipbase Assembly

Bolt Type

four 1-in. diameter ASTM A325 Bolts

Bolt Circle Diameter

1 ft-4 in.

Stub Height

4 in.

Luminaire Support Pole

Base Diameter

10 in.

Top Diameter

3 in.

Length

50 ft

Slipbolt Type

four 1-in. diameter ASTM A325 slipbolts

Bolt Circle Diameter

1 ft-1 in.

Slip Bolt Gasket Thickness

0.0149 in. (28 gauge)

Initial Bolt Torque

80 ft-lbs.

Final Bolt Torque

70 ft-lbs.

Clamping Bolt Force

4 @ 4,300 lbs each

Vehicle Model

1984 Dodge Colt

Vehicle Weight

Curb

1,990 lbs

Test Inertial

1,750 lbs

Gross Static

1,750 lbs

Vehicle Impact Speed

57.5 mph

Vehicle Impact Angle

0 deg

Vehicle Impact Location

Center of bumper

Vehicle Snagging

None

Vehicle Stability

Satisfactory

Occupant Impact Velocity

14.2 fps

Occupant Ridedown Deceleration

1.0 g's

Vehicle Change-In-Speed

13.5 fps

Vehicle Damage

Moderate

TAD

12-FC-3

VDI

12FCEN2

Vehicle Front-End Deflection

12 in.

Vehicle Stopping Distance

310 ft

Luminaire Support Damage

Large permanent set deflection near top

Final Luminaire Support Location

70 ft to Base

FIGURE 7 Summary and sequential photographs, Test USBLM-2.
the ground 2.73 sec after impact. The vehicle stopped 40 ft from the point of impact with the base of the luminaire pole resting on its roof.

The vehicle damage was minimal, with a maximum crushing distance of 9 in. in the bumper and slight damage to the roof. There was no intrusion of the passenger compartment, and the vehicle was repaired for use in Test USBLM-2.

The surface of the steel pole at the point of impact was not dented or deformed. There was only a slight deformation near the top of the support pole caused by the impact with the concrete. The permanent lower slipbase assembly was undamaged.

The damage to the vehicle and the installation is shown in Figure 6. The TAD (12) and VDI (13) vehicle damage classifications are shown in Figure 4. The occupant impact velocity was determined to be 7.6 ft/sec, which is much less than the 15 ft/sec suggested in NCHRP Report 230 (9). The maximum occupant ridedown deceleration was 3.5 g, which is less than the 15 g recommended in NCHRP Report 230 (9). The vehicle change in speed, calculated from impact to first loss of contact, was 6.1 ft/sec, which is lower than the 15 ft/sec required by AASHTO (10) and the 16 ft/sec required by FHWA (11).

Test USBLM-2

A summary of Test USBLM-2 is shown in Figure 7, and sequential photographs are shown in Figure 8. The safety evaluation results are presented in Table 1. The permanent lower slipbase used for Test USBLM-1 was also used in Test USBLM-2. However, new mast arms, a new pole, and new clamping bolts were used in the second test.

The test vehicle struck the luminaire support at the center of the front bumper at a speed of 57.5 mph. On impact, the front bumper of the vehicle was crushed inward for 0.02 sec. At that time the luminaire support began to slip from the base. At 0.17 sec, the front of the car began to lift up, and it continued on its rear wheels until 1 sec after impact. At 0.87 sec, the luminaire support was approximately 16 ft above and parallel to the ground. The luminaire support impacted the ground at 1.11 sec. The vehicle continued in a straight path until it slid sideways and stopped 310 ft downstream from the base.

The only damage sustained by the vehicle was to the bumper, which had a maximum crushing distance of 12 in. There was no intrusion of the occupant compartment.

The surface of the steel pole at the impact point was not dented or deformed. The support pole was deformed slightly more than in the first test. This deformation occurred at the top of the support pole and was caused by the impact of the pole on the concrete apron. The permanent lower slipbase assembly was not damaged.

The damage sustained by the vehicle and the installation is shown in Figure 9. The TAD (13) and VDI (14) damage classifications are shown in Figure 7.

The occupant impact velocity was determined to be 14.2 ft/sec, which is less than the 15 ft/sec suggested in NCHRP Report 230 (9). The maximum occupant ridedown deceleration was 1 g, which is much less than the 15 g recommended in NCHRP Report 230 (9). The vehicle change in velocity, calculated from impact to first loss of contact, was 13.5 ft/sec, which is lower than the 15 ft/sec required by AASHTO (10) and the 16 ft/sec required by FHWA (11).

CONCLUSIONS

Two full-scale crash tests were conducted to evaluate the safety performance of the 4-bolt breakaway slipbase design. The analysis of the crash tests revealed the following:

• The test article activated in a predictable manner by breaking away.
FIGURE 9 Vehicle and installation damage, Test USBLM-2.

- Detached elements, fragments, and other debris from the test article did not penetrate or show potential for penetrating the passenger compartment or present undue hazard to other traffic.
- The vehicle remained upright during and after the collision, and the integrity of the passenger compartment was maintained.
- The longitudinal occupant impact velocities for Tests USBLM-1 (7.6 ft/sec) and USBLM-2 (14.2 ft/sec) were less than the 15 ft/sec recommended in NCHRP Report 230 (9).
- The longitudinal occupant ride-down decelerations for Test USBLM-1 (3.5 g) and Test USBLM-2 (1 g) were less than the 15 g recommended in NCHRP Report 230 (9).
- The changes in vehicle speed for Test USBLM-1 (6.1 ft/sec) and Test USBLM-2 (13.5 ft/sec) were less than the 15 ft/sec required by AASHTO (10) and the 16 ft/sec required by FHWA (11).

On the basis of this analysis, the results of Tests USBLM-1 and USBLM-2 are acceptable according to the guidelines established in NCHRP Report 230 (9), AASHTO standard specifications (10), and the Code of Federal Regulations (11). Therefore, the use of the 4-bolt slipbase design is recommended for use in Federal-aid projects.

ACKNOWLEDGMENTS

This study was conducted under a cooperative program between the Midwest Roadside Safety Facility, the University of Nebraska Center for Infrastructure Research, the Midwest Transportation Center, and the state transportation departments of Idaho, Montana, Nevada, Utah, and Wyoming. The crash tests were conducted by personnel at the Midwest Roadside Safety Facility. The 4-bolt slipbase system was provided by Valmont Industries of Valley, Nebraska.

REFERENCES


The contents of this report reflect the views of the authors, who are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Utah Department of Transportation or FHWA. This report does not constitute a standard, specification, or regulation.