Road closure gates are used to close certain highways when the driving conditions become too hazardous under severe winter weather conditions. The Wyoming Department of Transportation (WYDOT) developed a new road closure gate design that had not been crash tested to determine if it would meet nationally recognized safety standards. The WYDOT sponsored a study at the Texas Transportation Institute to crash test and evaluate the new road closure gate design and, as appropriate, to improve the design from the standpoints of safety performance, cost and practicality. The original road closure gate design was crash tested and failed to meet guidelines set forth in NCHRP Report 350 and the 1985 AASHTO Standard Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals. The design was then modified and crash tested with successful results. The modified road closure gate design consists of: a standard 8.84 m (29 ft) high luminaire support pole structure with a mast arm and light standard; a 4-bolt slip base breakaway base; a telescoping fiberglass/aluminum gate arm with an electric in-line linear actuator lift mechanism; and a gate arm bracket to restrict the lateral movement of the gate arm in the up position. The road closure gate design has been adopted by the Wyoming Department of Transportation and accepted by the Federal Highway Administration for use on the National Highway System.
# SI* (Modern Metric) Conversion Factors

## Approximate Conversions to SI Units

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| **AREA** | | | |
| in² | square inches | 645.2 | square millimeters | mm² |
| ft² | square feet | 0.093 | square meters | m² |
| yd² | square yards | 0.836 | square meters | m² |
| ac | acres | 0.405 | hectares | ha |
| mi² | square miles | 2.59 | square kilometers | km² |

| **VOLUME** | | | |
| fl oz | fluid ounces | 29.57 | milliliters | mL |
| gal | gallons | 3.785 | liters | L |
| ft³ | cubic feet | 0.028 | cubic meters | m³ |
| yd³ | cubic yards | 0.765 | cubic meters | m³ |

**Note:** Volumes greater than 1000 l shall be shown in m³.

## Approximate Conversions from SI Units

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<tr>
<td>km</td>
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| **AREA** | | | |
| mm² | square millimeters | 0.0016 | square inches | in² |
| m² | square meters | 10.764 | square feet | ft² |
| m² | square meters | 1.195 | square yards | yd² |
| ha | hectares | 2.47 | acres | ac |
| km² | square kilometers | 0.386 | square miles | mi² |

| **VOLUME** | | | |
| mL | milliliters | 0.034 | fluid ounces | fl oz |
| L | liters | 0.264 | gallons | gal |
| m³ | cubic meters | 35.71 | cubic feet | ft³ |
| m³ | cubic meters | 1.307 | cubic yards | yd³ |

## Mass

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**Note:** The "metric ton" is also known as the "tonne" or "ton".

## Temperature (exact)

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<td>°C</td>
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<td>fl</td>
<td>foot-Lamberts</td>
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<td>candela/m²</td>
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## Force and Pressure or Stress

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**Note:** Rounding should be made to comply with Section 4 of ASTM E380.

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* SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised September 1993)
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**Figure 37** Vehicle angular displacements for test 472280-3

**Figure 38** Vehicle longitudinal accelerometer trace for test 472280-3

**Figure 39** Vehicle lateral accelerometer trace for test 472280-3

**Figure 40** Vehicle vertical accelerometer trace for test 472280-3

**Figure 41** Predicted Angular Velocity for Different Support Combinations

**Figure 42** Predicted Change in Vehicular Velocity for Different Support Combinations

**Figure 43** Estimated Weight of Different Support Combinations
I. INTRODUCTION

The Wyoming Department of Transportation (herein referred to as the Department) uses road closure gates to close off certain highways when the driving conditions become too hazardous under severe winter weather conditions. The existing road closure gate design has been not crash tested to determine if it would meet nationally recognized safety standards, i.e., the performance criteria outlined in National Cooperative Highway Research Program (NCHRP) Report 350(1) and the 1985 American Association of State Highway and Transportation Officials (AASHTO) Standard Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals(2).

The objectives of this study were to crash test and evaluate the existing Wyoming road closure gate design to determine if the design would meet with the appropriate impact performance guidelines and specifications and to improve the design from the standpoints of safety performance, cost and practicality. The scope of the study included engineering analysis of the existing road closure gate design, followed by full-scale crash testing and evaluation of the design.

This report summarizes the results of the study. Chapter II of the report outlines the study approach, including detailed descriptions of the final designs of the road closure gate, the crash test matrix, and full-scale crash test procedures. Results of the crash tests are documented in Chapter III of the report. Chapter IV presents the study findings, conclusions and recommendations.
II. STUDY APPROACH

An existing road closure gate installation was provided by the Department for analysis, crash testing, and evaluation. The existing design was analyzed and modified as deemed appropriate in two areas: (1) attachment and lift mechanisms for the gate arm, and (2) breakaway mechanism. The gate arm attachment and lift mechanisms were redesigned, including replacing the manual camper jack with an electric in-line linear actuator or jack. A variety of breakaway mechanisms were also evaluated, including frangible transformer bases and slip bases. After some consideration, a four-bolt slip base design was selected for use with the road closure gate support structure. The existing road closure gate design with the modified gate arm attachment and lift mechanisms was then crash tested and failed to meet the evaluation criteria set forth in NCHRP Report 350. The support pole structure, after separating from the base, rotated onto the roof of the test vehicle resulting in significant intrusion into the passenger compartment. Analysis of the test results indicated that the excessive rotation of the separated support pole structure contributed to the unsatisfactory performance of the existing road closure gate design. The road closure gate design was then modified by incorporating a taller support pole structure with a light standard attached. The increased mass moment of inertia was intended to reduce the rotation of the support pole structure. The modified road closure gate design was then crash tested with successful results.

Detailed descriptions of the final road closure gate design are presented in the next section, followed by discussions on the crash test matrix and the crash test procedures.

2.1 Test Installation

A schematic of the final road closure gate design is shown in Figure 1 and photographs of the test installation are shown in Figure 2. The major components of the design are as follows:

1. Support pole structure,
2. Breakaway mechanism,
3. Gate arm, and
4. Gate arm attachment and lift mechanisms.
Figure 1. Schematic of road closure gate (arm down) as tested.
Figure 2. Photographs of test installation.
Brief descriptions on these components are presented as follows.

2.1.1 Support Pole Structure

A standard 8.84 m (29 ft) high luminaire support pole structure with a 2.44 m (8 ft) long mast arm and a light standard is used with the road closure gate, a schematic of which is shown in Figure 1. The pole shaft is made from 11-gauge hot rolled ASTM A595 Grade A carbon steel and hot-dipped galvanized in accordance with ASTM standard A123. The pole shaft has an outside diameter of 203 mm (8 in) at the base and 102 mm (4 in) at the top with a linear taper rate of 1.2 mm/m (0.14 in/ft). The height to the top of the support pole structure is 8.94 m (29 ft-4 in) and the stub height of the permanent lower slip base assembly is 102 mm (4 in). The mast arm shaft is also made from 11-gauge hot rolled ASTM A595 Grade A carbon steel and hot-dipped galvanized. The approximate weights of the components are: 109 kg (240 lb) for the pole shaft including the top slip base plate, 20 kg (44 lb) for the mast arm, and 18 kg (40 lb) for the light standard assembly.

2.1.2 Breakaway Mechanism

A 4-bolt slip base breakaway design was selected for use with the road closure gate, details of which are shown in Figure 3. This 4-bolt slip base design was successfully crash tested with a 15.2-m (50-ft) luminaire support weighing approximately 408 kg (900 lb). The slip base breakaway design consists of a top plate welded to the base of the luminaire support pole and a permanent lower slip base assembly. The top plate is 343 mm (13-11/16 in) square and 25.4-mm (1-in) thick with a circular opening in the center equal to the outside diameter (203 mm or 8 in) of the pole shaft base. The permanent lower slip base assembly consists of a 381 mm (15 in) square, 25.4-mm (1-in) thick bottom base plate with a 292 mm (11-1/2 in) square, 38.1 mm (1-1/2 in) thick spacer plate welded on top of the bottom base plate. The top and bottom base plates and the spacer plate are fabricated from ASTM A36 steel and hot-dipped galvanized.

In actual field installations, the permanent lower slip base assembly is bolted to a concrete foundation with four 25.4-mm (1-in) diameter AASHTO M314 Grade 55 anchor bolts on a 406-mm (16-in) diameter bolt circle. However, for the test installation, the
Figure 3. Schematic of 4-bolt slip base breakaway design.
Figure 3. Schematic of 4-bolt slip base breakaway design (continued).
Figure 3. Schematic of 4-bolt slip base breakaway design (continued).
permanent lower slip base assembly was bolted to an existing universal steel mounting plate anchored in a concrete footing with four 25.4-mm (1-in) diameter ASTM A325 high strength bolts. The permanent lower slip base assembly has a stub height of 102 mm (4 in). The top and bottom base plates are fastened together with four 25.4-mm (1-in) diameter ASTM A325 high strength slip bolts on a 330-mm (13-in) diameter bolt circle and 76.2-mm x 50.8-mm x 12.7-mm (3-in x 2-in x 1/2-in) plate washers. The slip bolts are held in place with a 28-gauge keeper plate fabricated from ASTM A526 material. The slip bolts are first tightened to a torque of 5.5 N·m (80 ft-lb), then released and retightened to a torque of 4.8 N·m (70 ft-lb), which is estimated to develop approximately 19.2 kN (4,300 lb) of tension per bolt.

2.1.3 Gate Arm

The gate arm used in the test installation was a Safetran™ fiberglass/aluminum gate arm consisting of a 3.7 m (12 ft) long base section of rectangular shaped extruded aluminum and a second telescoping section made of pultruded fiberglass. The maximum recommended length of the gate arm is 9.8 m (32 ft). The length of the gate arm used with the test installation was 7.3 m (24 ft). The gate arm is attached to the support pole structure with a cast aluminum breakaway mounting adapter that uses three 7.9-mm (5/16-in) diameter brass shear bolts. These shear bolts are designed to break off when the gate arm is impacted by a vehicle to allow the arm to swing free around a pivot rod, thus preventing major damage to the arm. The arm is covered with retro-reflective sheeting in red and white stripes with three red-released gate arm lamps mounted on the arm to provide better visibility.

2.1.4 Gate Arm Attachment and Lift Mechanisms

Schematics and details of the gate arm attachment and lift mechanisms are shown in Figure 4. The gate arm assembly is attached to the support pole structure through a 38.1-mm (1-1/2 in) diameter ASTM A36 steel pivot rod. Two gate arm plates are mounted onto the pivot rod using Dodge E-Z KLEEN™ 2-bolt flange-mounted sleeve bearings. These sleeve bearings have Teflon coated housings and chemical and corrosion resistant self-lubricating polymer sleeve inserts and are designed for operation in adverse environments. More detailed descriptions and specifications on the sleeve bearings are provided in Appendix A.
Figure 4. Schematics of gate arm attachment and lift mechanisms.
Figure 4. Schematics of gate arm attachment and lift mechanisms (continued).
Figure 4. Schematic of gate arm attachment and lift mechanisms (continued).
Figure 4. Schematic of gate arm attachment and lift mechanisms (continued).
Figure 4. Schematic of gate arm attachment and lift mechanisms (continued).
Figure 4. Schematic of gate arm attachment and lift mechanisms (continued).
Two channel spacers, one 381 mm (15 in) long for attachment of the gate arm and the other 127 mm (5 in) long for the upper connection of the electric in-line linear actuator (jack), are mounted between the gate arm plates. The electric jack is mounted onto the support pole structure with a bottom connection assembly. The electric jack has a 3,400 rpm, 110-volt A.C. motor with a maximum stroke of 460 mm (18-1/8 in) and a maximum load capacity of 6.7 kN (1,500 lb). More detailed specifications of the electric in-line linear actuator are shown in Appendix B. Testing with the actual installation showed that it takes approximately 2-1/2 minutes to raise the gate arm from the down to the up position.

A gate arm bracket, shown in Figure 5, is attached to the support pole structure to restrict the lateral movement of the gate arm in the up position. The bracket for the test installation was mounted at a height of 5.6 m (18 ft-4 in) above the ground. However, this mounting height of the bracket may vary depending on the length of the gate arm. Also, to avoid interference with the luminaire mast arm when the gate arm is in the up position, the mast arm is offset at an angle of 25 degrees as shown in Figure 5.

2.2 Crash Test Matrix

According to guidelines presented in NCHRP Report 350 and the 1985 AASHTO Standard Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals, two compliance crash tests are required to evaluate the performance of a breakaway support structure. These two crash tests are as follows:

1. **Test Designation 3-60.** An 820-kg (1,808-lb) passenger car impacting the support pole structure head-on at a nominal impact speed of 35 km/h (21.8 mi/h) with the quarter point of the bumper aligned with the vertical centerline of the support pole structure. The objective of this test is to evaluate the breakaway mechanism of the support pole structure.

2. **Test Designation 3-61.** An 820-kg (1,808-lb) passenger car impacting the support pole structure head-on at a nominal impact speed of 100 km/h (62.2 mi/h) with the quarter point of the bumper aligned with the vertical centerline of the support pole structure. The objective of this test is to evaluate vehicle and test article trajectory.
Figure 5. Schematics of gate arm bracket.
Figure 5. Schematic of gate arm bracket (continued).
Three full-scale crash tests were conducted under this study. The first compliance test (test designation number 3-60, test number 7228-1) with the existing road closure gate design involved an 820-kg (1,808-lb) passenger car impacting the support pole structure head-on at a nominal speed of 35 km/h (21.8 mi/h). The test failed to meet the evaluation criteria due to intrusion into the occupant compartment. After modifications to the support pole structure design, this compliance crash test was re-run (test number 7228-2) and the test results were satisfactory. The second compliance test (test designation number 3-61, test number 7228-3) with an 820-kg (1,808-lb) passenger car impacting the support pole structure head-on at a nominal speed of 100 km/h (62.2 mi/h) was also conducted with the modified road closure gate design with successful results.

These crash tests were conducted with the gate arm in the down position. This was considered a more critical test condition since the gate arm might affect the trajectory of the support pole structure after separating from the slip base assembly. The Federal Highway Administration (FHWA) was consulted and agreed with this test configuration.

2.3 Crash Test Procedures

All crash tests and data analysis were conducted in accordance with guidelines contained in NCHRP Report 350. Brief descriptions of the crash test and data analysis procedures are presented as follows.

2.3.1 Electronic Instrumentation and Data Processing

Each test vehicle was instrumented with three solid-state angular rate transducers to measure roll, pitch and yaw rates; a triaxial accelerometer at the vehicle center-of-gravity to measure longitudinal, lateral, and vertical acceleration levels, and a back-up biaxial accelerometer in the rear of the vehicle to measure longitudinal and lateral acceleration levels. The accelerometers were strain gauge type with a linear millivolt output proportional to acceleration.

The electronic signals from the accelerometers and transducers were transmitted to a base station by means of constant bandwidth FM/FM telemetry link for recording on magnetic tape and for display on a real-time strip chart. Provision was made for the transmission of
calibration signals before and after the test, and an accurate time reference signal was simultaneously recorded with the data. Pressure sensitive contact switches on the bumper were actuated just prior to impact by wooden dowels to indicate the elapsed time over a known distance to provide a measurement of impact velocity. The initial contact also produced an "event" mark on the data record to establish the exact instant of contact with the support pole structure.

The multiplex of data channels, transmitted on one radio frequency, was received at a data acquisition station, and demultiplexed into separate tracks of Intermediate Range Instrumentation Group (I.R.I.G.) tape recorders. After the test, the data was played back from the tape machines, filtered with a SAE J211 Class 180 filter, and were digitized using a microcomputer, for analysis and evaluation of impact performance. The digitized data were then processed using two computer programs: DIGITIZE and PLOTANGLE. Brief descriptions on the functions of these two computer programs are given below.

The DIGITIZE program uses digitized data from vehicle-mounted linear accelerometers to compute occupant/compartment impact velocities, time of occupant/compartment impact after vehicle impact, and the highest 10-ms average ridedown acceleration. The DIGITIZE program also calculates a vehicle impact velocity and the change in vehicle velocity at the end of a given impulse period. In addition, maximum average accelerations over 50-ms intervals in each of the three directions are computed. Acceleration versus time curves for the longitudinal, lateral, and vertical directions are then plotted from the digitized data of the vehicle-mounted linear accelerometers using a commercially available software package.

The PLOTANGLE program uses the digitized data from the yaw, pitch, and roll rate charts to compute angular displacement in degrees at 0.00067-s intervals and then instructs a plotter to draw a reproducible plot of yaw, pitch, and roll versus time. It should be noted that these angular displacements are sequence dependent with the sequence being yaw-pitch-roll for the data presented herein. These displacements are in reference to the vehicle-fixed coordinate system with the initial position and orientation of the vehicle-fixed coordinate system being that which existed at initial impact.
2.3.2 Photographic Instrumentation and Data Processing

Photographic coverage of each test included two high-speed cameras: one with a field of view perpendicular to the road closure gate and the second at a 45-degree angle. A flashbulb activated by pressure sensitive tape switches was positioned on the impacting vehicle to indicate the instant of contact with the support structure and was visible from each camera. The films from these high-speed cameras were analyzed on a computer-linked Motion Analyzer to observe phenomena occurring during the collision and to obtain time-event, displacement, and angular data. A Betacam, a 3/4-in videotape camcorder, and still cameras were used for documentary purposes and to record conditions of the test vehicle and guardrail system before and after the test.

2.3.3 Test Vehicle Propulsion and Guidance

The test vehicles were towed into the guardrail system using a steel cable guidance and reverse tow system. A steel cable for guiding the test vehicles was stretched along the impact path, anchored at each end, and threaded through an attachment to the front wheel of the test vehicle. Another steel cable was connected to the test vehicles, passed around a pulley near the impact point, through a pulley on the tow vehicle, and then anchored to the ground such that the tow vehicle moved away from the test site. A 1 to 1 speed ratio between the test and tow vehicle was used with the low-speed test and a 2 to 1 speed ratio with the high-speed test. Just prior to impact with the support structure, the test vehicle was released to be freewheeling and unrestrained. The vehicle remained freewheeling, i.e., no steering or braking inputs, until the vehicle cleared the immediate area of the test site, at which time brakes on the vehicle were activated to bring it to a safe and controlled stop.
III. RESULTS OF COMPLIANCE CRASH TESTS

As mentioned previously, the following two compliance crash tests are required to evaluate the performance of a breakaway support structure in accordance with guidelines set forth in NCHRP Report 350 and the 1985 AASHTO Standard Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals:

1. **Test Designation 3-60.** An 820-kg (1,808-lb) passenger car impacting the support pole structure head-on at a nominal impact speed of 35 km/h (21.8 mi/h) with the quarter point of the bumper aligned with the vertical centerline of the support pole structure.

2. **Test Designation 3-61.** An 820-kg (1,808-lb) passenger car impacting the support pole structure head-on at a nominal impact speed of 100 km/h (62.2 mi/h) with the quarter point of the bumper aligned with the vertical centerline of the support pole structure.

The first compliance test (test designation number 3-60, test number 7228-1) with an 820-kg (1,808-lb) passenger car impacting the support structure head-on at a nominal speed of 35 km/h (21.8 mi/h) failed to meet the evaluation criteria due to intrusion into the occupant compartment. After modifications to the support structure design, this compliance crash test was re-run (test number 7228-2) with successful results. The second compliance test (test designation number 3-61, test number 7228-3) with an 820-kg (1,808-lb) passenger car impacting the support structure head-on at a nominal speed of 100 km/h (62.2 mi/h) was also conducted with successful results. Descriptions of these three crash tests are presented as follows.

3.1 **First Compliance Crash Test (Test No. 7228-1)**

The first compliance test was conducted on the original road closure gate design with the modified gate arm attachment and lift mechanisms. The only difference between the existing road closure gate design and the final design presented previously is the size and height of the support pole structure. The original design used an 5.5 m (18 ft) high pole support structure that had an outside diameter of 229 mm (9 in) at the base and 6.5 in
(165 mm) at the top and a linear taper rate of 1.2 mm/m (0.14 in/ft). The weight of the support pole structure, including the top slip base plate, was approximately 91 kg (200 lb). Photographs of the test installation of the original road closure gate design are shown in Figure 6.

The first compliance crash test (test designation 3-60) involved an 820-kg (1,808-lb) passenger car impacting the road closure gate head-on at a nominal impact speed of 35 km/h (21.8 mi/h). The left quarter point of the vehicle front bumper was aligned with the vertical centerline of the road closure gate support pole structure. The gate arm was in the down position, which was considered the more critical impact condition than with the gate arm in the up position. The objective of this test is to evaluate the breakaway mechanism of the support structure.

A 1986 Chevrolet Sprint (Figures 7 and 8) was used for the crash test. Test inertia mass or empty weight of the vehicle was 820 kg (1,808 lb). The gross static mass or test weight of the vehicle was 896 kg (1,975 lb), including a restrained 50th percentile anthropometric dummy placed in the driver position. The height to the lower edge of the vehicle bumper was 340 mm (13.2 in) and the height to the top of the bumper was 480 mm (18.7 in). Additional dimensions and information on the test vehicle are given in Figure 9. The vehicle was directed into the road closure gate using the cable reverse tow and guidance system, and was released to be freewheeling and unrestrained just prior to impact.

The vehicle impacted the road closure gate support structure head-on at a speed of 34.7 km/h (21.6 mi/h) with the left front quarter point of the vehicle aligned with the centerline of the support pole structure. Upon impact, the bumper of the vehicle began to deform around the support pole structure. At 0.017 s, the slip base began to activate and the support pole structure began to move off the slip-base. By 0.044 s, the support pole structure was detached and rotating free of the slip-base. At approximately 0.057 s, the gate arm began to rotate with the support pole structure. The support pole structure rotated clear of the vehicle front bumper by 0.091 s. The vehicle continued traveling forward as the support pole structure continued to rotate over the vehicle. The support pole structure rotated past the horizontal position above the vehicle and impacted the rear of the roof of the vehicle at 0.521 s and broke the glass in the rear hatchback at 0.538 s. The impact of the support pole
Figure 6. Wyoming road closure gate (test 472280-1).
Figure 7. Vehicle before test 472280-1.
Figure 8. Road closure gate/vehicle geometrics for test 472280-1.
Figure 9. Vehicle properties for test 472280-1.
structure significantly compressed the rear suspension of the vehicle. As the vehicle rebounded, the support pole structure lost contact with the vehicle at 0.896 s. After the vehicle exited, the brakes were applied and the vehicle came to rest 25.3 m (83.0 ft) downstream from the point of impact. Sequential photographs of the test are shown in Figure 10.

As shown in Figures 11 and 12, the road closure gate installation received minimal damage. The cast aluminum housing of the electric motor was fractured during the test and would require repair or replacement prior to reinstalling the road closure gate.

As shown in Figure 13, the front of the vehicle sustained only minor damage, but the roof of the vehicle was severely damaged. Maximum crush at the left quarter point of the bumper was 130 mm (5.1 in). The roof was deformed downward 160 mm (6.3 in) across the passenger compartment area. As is shown in Figure 13, the roof was deformed down around the head of the anthropomorphic dummy that was positioned in the driver’s seat. In addition, the B and C-pillars were bent and the rear hatchback glass shattered.

Impact speed was 34.7 km/h (21.6 mi/h) and the angle of impact was 0 degrees. The vehicle lost initial contact with the road closure gate traveling at 28.2 km/h (17.5 mi/h). Data from the accelerometer located at the center-of-gravity were digitized for evaluation of the occupant risk factor and were computed as follows. In the longitudinal direction, occupant impact velocity was 1.7 m/s (5.5 ft/s) at 0.393 s, the highest 0.010-s average ridedown acceleration was 0.8 g between 0.526 and 0.536 s, and the maximum 0.050-s average acceleration was -3.6 g between 0.005 and 0.054 s. No occupant contact was recorded in the lateral direction. The maximum 0.050-s average lateral acceleration was -0.55 g between 0.627 and 0.677 s. These data and other pertinent information from the test are summarized in Figure 14. Vehicular angular displacements are displayed in Figure 15. Vehicle accelerations versus time filtered at SAE J211 (Class 180) are presented in Figures 16 through 18.

This test was considered a failure due to intrusion into the occupant compartment as the separated support pole structure impacted the roof of the test vehicle. Analysis of the high-speed film indicated that the separated support pole structure had an angular velocity of approximately 180 deg/s and had rotated more than 90 degrees from vertical upon impact with the roof of the vehicle. In comparison, review of high-speed films for other crash tests
Figure 10. Sequential photographs for test 472280-1. (perpendicular and oblique views)
Figure 10. Sequential photographs for test 472280-1 (continued).
(perpendicular and oblique views)
Figure 11. Wyoming road closure gate after test 472280-1.
Figure 12. Details of damage sustained to road closure gate (test 472280-1).
Figure 13. Damage sustained to vehicle in test 472280-1.
Figure 13. Damage sustained to vehicle in test 472280-1 (continued).
Figure 14. Summary of results for test 472280-1.
Sequence for determining orientation is:
1. Yaw
2. Pitch
3. Roll

Axes are vehicle fixed.

Figure 15. Vehicle angular displacements for test 472280-1.
CRASH TEST 472280-1
Accelerometer at center-of-gravity

Test Article: Wyoming Road Closure Gate
Test Vehicle: 1986 Chevrolet Sprint
Test Inertia Weight: 820 kg (1808 lb)
Gross Static Weight: 896 kg (1975 lb)
Test Speed: 34.7 km/h (21.6 mi/h)
Test Angle: 0 deg - left front quarter point

Figure 16. Vehicle longitudinal accelerometer trace for test 472280-1.
CRASH TEST 472280-1
Accelerometer at center-of-gravity

Test Article: Wyoming Road Closure Gate
Test Vehicle: 1986 Chevrolet Sprint
Test Inertia Weight: 820 kg (1808 lb)
Gross Static Weight: 896 kg (1975 lb)
Test Speed: 34.7 km/h (21.6 mi/h)
Test Angle: 0 deg - left front quarter point

Figure 17. Vehicle lateral accelerometer trace for test 472280-1.
Figure 18. Vehicle vertical accelerometer trace for test 472280-1.
with luminaire supports indicated a much smaller angular velocity and rotation for the separated support pole structure. A theoretical analysis based on conservation of linear and angular momentum principles indicated that the high angular velocity and rotation were attributed to the relatively small mass moment of inertia of the separated support pole structure. This problem could be remedied by increasing the length of the support pole structure and/or adding mass, such as a mast arm and luminaire, to the top of the support pole structure. Details of the theoretical analysis are presented in Appendix C of the report.

Based on the results of the analysis and consultation with the Wyoming Department of Transportation, it was decided to replace the 5.5 m (18 ft) high, 229-mm (9-in) base diameter pole structure with a standard 8.84 m (29 ft) high, 203-mm (8-in) base diameter luminaire support pole structure with an 2.44 m (8 ft) long mast arm and a light standard. The taller support pole structure adds approximately 45 kg (100 lb) to the weight of the support pole structure, but increases the mass moment of inertia by a factor of more than four. For the impact speed at which the first compliance test was conducted, the predicted angular velocity of the separated pole structure is reduced from 180 to 95 deg/s and the rotation would be less than 90 degrees (i.e., the separated pole structure would not reach a horizontal position above the vehicle). Although the predicted velocity change from impact with the pole structure would be increased from 1.7 to 2.1 m/s (5.5 to 7 ft/s) due to the increased weight, this value is still well below the recommended limit of 4.6 m/s (15 ft/s).

3.2 Repeat of First Compliance Crash Test (Test No. 7228-2)

The first compliance test was repeated with the taller support structure. A 1987 Chevrolet Sprint (Figures 19 and 20) was used for the crash test. Test inertia mass or empty weight of the vehicle was 820 kg (1,808 lb). The gross static mass or test weight of the vehicle was 896 kg (1,975 lb), including a restrained 50th percentile anthropometric dummy placed in the driver position. The height to the lower edge of the vehicle bumper was 400 mm (15.7 in) and the height to the top of the bumper was 510 mm (20.1 in). Additional dimensions and information on the test vehicle are given in Figure 21. The vehicle was directed into the road closure gate using the cable reverse tow and guidance system, and was released to be freewheeling and unrestrained just prior to impact.
Figure 19. Vehicle before test 472280-2.
Figure 20. Road closure gate/vehicle geometrics for test 472280-2.
Figure 21. Vehicle properties for test 472280-2.
The vehicle impacted the road closure gate head-on at a speed of 31.8 km/h (19.7 mi/h) with the left front quarter point of the vehicle aligned with the centerline of the support pole structure. Upon impact, the bumper of the vehicle began to deform around the road closure gate support pole. At 0.029 s, the support pole structure began to move off the slip-base. By 0.056 s, the support pole structure was detached and rotating free of the slip-base at an angular velocity of approximately 73 deg/s. The support pole structure separated from the vehicle front bumper by 0.235 s. At approximately 0.353 s and again at 0.589 s, the pole base contacted the ground. The vehicle continued traveling forward as the support pole structure rotated over the vehicle. At 1.045 s, the support pole structure briefly contacted the left rear corner of the roof of the vehicle. The luminaire came into contact with the ground at 1.266 s. After the vehicle exited, the brakes were applied and the vehicle came to rest 22.3 m (73.0 ft) downstream from the point of initial impact. Sequential photographs of the test are shown in Figure 22.

As shown in Figure 23, the road closure gate installation received minimal damage. The electric motor housing was again fractured during the test and would require repair or replacement prior to reinstalling the road closure gate. Additionally, the luminaire was broken and would require replacement.

The vehicle sustained light damage to the front of the vehicle, the left front fender, and the left rear of the roof. Vehicle damage is shown in Figure 24. Maximum crush at the left quarter point of the bumper was 100 mm (3.9 in). The roof was deformed downward 10 mm (0.4 in) at the left rear corner, but there was no apparent intrusion into the passenger compartment area.

Impact speed was 31.8 km/h (19.7 mi/h) and the angle of impact was 0 degrees. The vehicle lost initial contact with the road closure gate traveling at 20.8 km/h (12.9 mi/h). Data from the accelerometer located at the center-of-gravity were digitized for evaluation of the occupant risk factor and were computed as follows. In the longitudinal direction, occupant impact velocity was 2.3 m/s (7.6 ft/s) at 0.301 s, the highest 0.010-s average ridedown acceleration was 0.3 g between 0.462 and 0.472 s, and the maximum 0.050-s average acceleration was -4.0 g between 0.005 and 0.054 s. Contact in the lateral direction occurred at 1.156 s at 0.3 m/s (1.1 ft/s) with the highest 0.010-s average ridedown acceleration being
Figure 22. Sequential photographs for test 472280-2. (perpendicular and oblique views)
Figure 22. Sequential photographs for test 472280-2 continued. (perpendicular and oblique views)
Figure 23. Wyoming road closure gate after test 472280-2.
Figure 24. Vehicle after test 472280-2.
1.6 g between 1.884 and 1.894 second. The maximum 0.050-second average lateral acceleration was -0.52 g between 0.060 and 0.110 second. These data and other pertinent information from the test are summarized in Figure 25. Vehicular angular displacements are displayed in Figure 26. Vehicle accelerations versus time filtered at SAE J211 (Class 180) are presented in Figures 27 through 29.

The impact speed of 31.8 km/h (19.7 mi/h) was below the target impact speed of 35 km/h (21.7 mi/h). However, since a lower impact speed is typically more critical from the standpoint of activating the breakaway mechanism, the lower than targeted impact speed is not considered a problem.

3.3 Second Compliance Crash Test (Test No. 7228-3)

The second compliance crash test (test designation 3-61) involved an 820-kg (1,808-lb) passenger car impacting the support pole structure head-on at a nominal impact speed of 100 km/h (62.2 mi/h). The right quarter point of the bumper aligned with the vertical centerline of the support pole structure. As with the first compliance crash test, the gate arm was in the down position which was considered the more critical impact condition than with the gate arm in the up position. The objective of this test was to evaluate vehicle and test article trajectories.

The 1987 Chevrolet Sprint used in the low-speed crash test (test no. 7228-2) was reused for this crash test. Pretest photographs of the vehicle are shown in Figures 30 and 31. Test inertia mass of the vehicle was 820 kg (1,808 lb) and gross static was 896 kg (1,975 lb). The height to the lower edge of the vehicle bumper was 400 mm (15.7 in) and the height to the top of the bumper was 510 mm (20.1 in). Additional dimensions and information on the test vehicle are given in Figure 32. The vehicle was directed into the road closure gate using the cable reverse tow and guidance system, and was released to be freewheeling and unrestrained just prior to impact.

The vehicle impacted the road closure gate at an impact speed of 104.0 km/h (64.6 mi/h) with the right front quarter point of the vehicle aligned with the centerline of the support pole structure. Upon impact, the bumper of the vehicle began to deform around the
### General Information
- **Test Agency**: Texas Transportation Institute
- **Test No.**: 472280-2
- **Date**: 01/14/94

### Test Article
- **Type**: Road Closure Gate
- **Name or Manufacturer**: N/A
- **Installation Length (m)**: 8.8 m (29.0 ft) Pole Height
- **Size and/or dimension and material of key elements**: N/A
- **Soil Type and Condition**: Passenger
- **Vehicle**: 1987 Chevrolet Sprint
- **Mass (kg) Curb**: 896 kg (1,975 lb)
- **Test Inertial Dummy**: 820 kg (1,808 lb)
- **Gross Static**: 76 kg (167 lb)

### Impact Conditions
- **Speed (km/h)**: 31.8 (19.7 mi/h)
- **Angle (deg)**: 0 (1/4 pt)
- **Exit Conditions**
  - **Speed (km/h)**: 20.7 (12.9 mi/h)
  - **Angle (deg)**: 0
- **Occupant Risk Values**
  - **Impact Velocity (m/s)**
    - x-direction: 2.3 (7.6 ft/s)
    - y-direction: 0.3 (1.1 ft/s)
  - **THIV (optional)**
  - **Ridedown Accelerations (g's)**
    - x-direction: 0.3
    - y-direction: 1.6
  - **PHD (optional)**
  - **ASI (optional)**
  - **Max. 0.050-sec Averages (g's)**
    - x-direction: -4.0
    - y-direction: -0.5

### Test Article Deflections (m)
- **Dynamic**: N.A.
- **Permanent**: N.A.

### Vehicle Damage
- **Exterior**
  - VDS: 12FL-1
  - CDC: 12FLAN1
- **Interior**
  - OCDI: AS0000000
  - Maximum Exterior
    - *Vehicle Crush (mm)**: 100 (3.9 in)
  - Max. Occ. Compartment
    - Deflection (mm): 0

### Post-Impact Behavior
- **Max. Roll Angle (deg)**: 2.1 @ 0.367 s
- **Max. Pitch Angle (deg)**: -0.6 @ 0.154 s
- **Max. Yaw Angle (deg)**: -3.3 @ 0.939 s

**Figure 25** Summary of results for test 472280-2.
Axes are vehicle fixed.
Sequence for determining orientation is:
1. Yaw
2. Pitch
3. Roll

Figure 26. Vehicle angular displacements for test 472280-2.
CRASH TEST 472280-2
Accelerometer at center-of-gravity

Test Article: Wyoming Road Closure Gate
Test Vehicle: 1987 Chevrolet Sprint
Test Inertia Weight: 820 kg (1808 lb)
Gross Static Weight: 896 kg (1975 lb)
Test Speed: 31.8 km/h (19.8 mi/h)
Test Angle: 0 deg - left front quarter point

Figure 27: Vehicle longitudinal accelerometer trace for test 472280-2.
Figure 28. Vehicle lateral accelerometer trace for test 472280-2.
CRASH TEST 472280-2
Accelerometer at center-of-gravity

Test Article: Wyoming Road Closure Gate
Test Vehicle: 1987 Chevrolet Sprint
Test Inertia Weight: 820 kg (1808 lb)
Gross Static Weight: 896 kg (1975 lb)
Test Speed: 31.8 km/h (19.8 mi/h)
Test Angle: 0 deg - left front quarter point

Figure 29. Vehicle vertical accelerometer trace for test 472280-2.
Figure 30. Vehicle before test 472280-3.
Figure 31. Road closure gate/vehicle geometrics for test 472280-3.
DATE: 1/14/94  TEST NO.: 472280-2 and 3  VIN NO.: JG1MR615XHK746145

YEAR: 1987  MAKE: Chevrolet  MODEL: Sprint (4 door)

TIRE INFLATION PRESSURE: ODOMETER: 13311  TIRE SIZE: 155R12

MASS DISTRIBUTION (kg)  LF 247  RF 241  LR 170  RR 162

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:

Dent right rear door (marked)

GEOMETRY - (mm)

A 1470  E 660  J 730  N 1330.5  R 370
F 730  G 510  K 1300  O 470  S 700
C 2340  H 947  L 120  P 540  T 93
D 1330  M 400  Q 330  U 280

MASS - (kg)  CURB  TEST INERTIAL  GROSS STATIC

M1  450  488  526
M2  277  332  367
M3  722  820  893

ENGINE TYPE: 4 cyl
ENGINE CID: 1.0 L
TRANSMISSION TYPE: X MANUAL
OPTIONAL EQUIPMENT:

DUMMY DATA:
TYPE: 50th Male
MASS: 7.3kg
SEAT POSITION: Driver side front

Figure 32. Vehicle properties for test 472280-3.
support pole structure. At 0.010 s, the support pole structure began to move off the slip base. By 0.020 s, the support pole structure was detached and rotating free of the slip-base. The support pole structure separated from the vehicle front bumper by 0.123 s. At approximately 0.127 s, the luminaire separated from the mast arm. The vehicle continued traveling forward as the support pole structure rotated over the vehicle. At 0.607 s, the top of the support pole structure contacted the ground and the base of the support pole structure contacted the ground at 1.290 s. After the vehicle exited, the brakes were applied and the vehicle came to rest 50.3 m (165.0 ft) downstream from the point of initial impact. Sequential photographs of the test are shown in Figure 33.

As shown in Figure 34, the road closure gate installation received extensive damage. The support pole structure was broken at the location of the pivot rod for the gate arm attachment. The cap at the top of the support pole structure was broken and separated from the support pole structure. The gate arm bracket was bent from impact with the ground. The luminaire was separated from the mast arm and shattered when it impacted the ground. The electric actuator was broken and would require replacement. The fiberglass section of the gate arm was also damaged. In summary, the entire road closure gate installation was damaged to such an extent that the entire installation would need to be replaced.

The vehicle sustained moderate damage to the right front, as shown in Figure 35. Maximum crush at the right quarter point of the bumper was 180 mm (7.1 in). A small hole, 10 mm (0.4 in) × 20 mm (0.8 in), was punched in the passenger side floor pan and the oil pan was punctured. It appeared that one slip bolt was first caught between the permanent lower slip base assembly and the undercarriage of the vehicle and then between the concrete pavement and the undercarriage of the vehicle, causing the damage. This was shown by gouge marks that were present on the top surface of the spacer plate of the permanent lower slip base assembly bolt and on the concrete pavement.

Impact speed was 104.0 km/h (64.6 mi/h) and the angle of impact was 0 degrees. The vehicle lost initial contact with the road closure gate traveling at 88.0 km/h (54.7 mi/h). Data from the accelerometer located at the center-of-gravity were digitized for evaluation of the occupant risk factor and were computed as follows. In the longitudinal direction, occupant impact velocity was 3.2 m/s (10.5 ft/s) at 0.215 s, the highest 0.010-s average ridedown
Figure 33. Sequential photographs for test 472280-3. (perpendicular and oblique views)
Figure 33. Sequential photographs for test 472280-3 continued. (perpendicular and oblique views)
Figure 34. Wyoming road closure gate after impact, test 472280-3.
Figure 35. Vehicle after test 472280-3.
acceleration was -0.9 g between 0.215 and 0.225 s, and the maximum 0.050-s average acceleration was -6.5 g between 0.005 and 0.054 s. Contact in the lateral direction occurred at 0.435 s at 1.7 m/s (5.7 ft/s) with the highest 0.010-s average ridedown acceleration being 1.1 g between 0.511 and 0.521 s. The maximum 0.050-s average lateral acceleration was 0.8 g between 0.025 and 0.075 s. These data and other pertinent information from the test are summarized in Figure 36. Vehicular angular displacements are displayed in Figure 37. Vehicle accelerations versus time filtered at SAE J211 (Class 180) are presented in Figures 38 through 40.
Figure 36. Summary of results for test 472280-3.
Axes are vehicle fixed.
Sequence for determining orientation is:
1. Yaw
2. Pitch
3. Roll

Figure 37. Vehicle angular displacements for test 472280-3.
Figure 38. Vehicle longitudinal accelerometer trace for test 472280-3.

Test Article: Wyoming Road Closure Gate
Test Vehicle: 1987 Chevrolet Sprint
Test Inertia Weight: 820 kg (1808 lb)
Gross Static Weight: 896 kg (1975 lb)
Test Speed: 104.0 km/h (64.6 mi/h)
Test Angle: 0 deg - right front quarter point
CRASH TEST 472280-3
Accelerometer at center-of-gravity

Test Article: Wyoming Road Closure Gate
Test Vehicle: 1987 Chevrolet Sprint
Test Inertia Weight: 820 kg (1808 lb)
Gross Static Weight: 896 kg (1975 lb)
Test Speed: 104.0 km/h (64.6 mi/h)
Test Angle: 0 deg - right front quarter point

Figure 39. Vehicle lateral accelerometer trace for test 472280-3.
CRASH TEST 472280-3
Accelerometer at center-of-gravity

Test Article: Wyoming Road Closure Gate
Test Vehicle: 1987 Chevrolet Sprint
Test Inertia Weight: 820 kg (1808 lb)
Gross Static Weight: 896 kg (1975 lb)
Test Speed: 104.0 km/h (64.6 mi/h)
Test Angle: 0 deg - right front quarter point

Figure 40. Vehicle vertical accelerometer trace for test 472280-3.
IV. SUMMARY OF FINDINGS AND RECOMMENDATIONS

4.1 Summary of Findings

An existing road closure gate design used by the Wyoming Department of Transportation was analyzed and redesigned in this study. Modifications to the design included: replacing the existing 5.5 m (18 ft) high support pole structure with a standard 8.8 m (29 ft) high luminaire support pole structure with an 2.4-m (8-ft) mast arm and a light standard, use of a 4-bolt slip base breakaway design, redesign of the gate arm attachment and lift mechanism, and replacing the manual camper jack with an electric in-line linear actuator. The final road closure gate design was successfully crash tested in accordance with guidelines set forth in NCHRP Report 350 and the 1985 AASHTO Standard Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals.

In both compliance crash tests with the final road closure gate design, the 4-bolt slip base breakaway mechanism was properly activated. There were no detached elements, fragments, or other debris from the test article that penetrated or showed any potential for penetrating the passenger compartment of the vehicle or presented any undue hazard to other traffic. The vehicle sustained only minor damage and the integrity of the passenger compartment was maintained. The vehicle remained upright and stable during and after the collision sequence. The changes in vehicle velocities and occupant risk factors, i.e., occupant impact velocities and highest 10-ms ridedown accelerations, were well below the recommended limits.

In summary, the final road closure gate design has successfully met all evaluation criteria set forth in NCHRP Report 350 and the 1985 AASHTO Standard Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals and is recommended for field implementation. The road closure gate design has been adopted by the Wyoming Department of Transportation, a copy of the standard drawings is shown in Appendix D, and approved by the Federal Highway Administration for use on the National Highway System.
4.2 Recommendations and Discussions

- Some components used with the road closure gate design, such as the gate arm, sleeve bearings and electric actuator, are proprietary products that are available commercially. The Texas Transportation Institute (TTI) does not endorse any of these products and the names of the manufacturers or trademarks are included for information purposes only. The Department may choose to use these products or products from other manufacturers with equivalent specifications and performance.

- A standard 8.8 m (29 ft) high luminaire support pole structure with an outside base diameter of 203 mm (8 in) and equipped with an 2.4-m (8-ft) mast arm and light standard was selected for use with the road closure gate design. Analysis results indicate that a taller support pole structure, e.g., a standard 11.4 m (37 ft-6 in) high luminaire support pole structure with an outside base diameter of 238 mm (9-3/8 in) would also function properly with or without a mast arm and light standard attached. While the taller support pole structure was not crash tested, there is no reason to believe that it would not function properly and could be considered as an alternative at locations where a taller support pole structure is required.

- The height of the gate arm bracket was set at 5.5 m (18 ft) above the base of the support pole structure for the test installation. It should be noted that the mounting height of the gate arm bracket should be adjusted to accommodate the actual length of the gate arm in use. However, a minimum mounting height of 5.5 m (18 ft) is recommended.

The purpose of the gate arm bracket is to facilitate retraction of the gate arm into its vertical position. For locations where high wind poses a problem to proper retraction of the gate arm into the bracket, the length and/or the angle of the bracket can be increased to better accommodate the retraction of the gate arm. The increase in length and/or the angle of the bracket should not adversely affect the impact performance of the road closure gate.

- Concerns were expressed by the Department regarding the brass shear bolts used for mounting of the gate arm due to an incident in which the shear bolts failed on a 7.0 m (23-ft) gate arm under a 71 km/h (44 mi/h) wind load condition. Results of an analysis
indicate that the three brass shear bolts, with an ultimate tensile strength of 296 MPa (43,000 psi) could resist a maximum wind speed of 95.3 km/h (59.2 mi/h) for a gate arm length of 7.0 m (23 ft). This represents a wind gust of 34.5 percent above the 71 km/h (44 mi/h) wind gust recorded. However, it should also be noted that the strength of the bolts could have been affected by other factors, such as fatigue, corrosion, etc. If the brass shear bolts are replaced with ASTM A449 bolts with a minimum ultimate tensile strength of 827 MPa (120,000 psi), the bolts could withstand a maximum wind speed of up to 114 km/h (71 mi/h) for the maximum gate arm length of 9.8 m (32 ft). Of course, for shorter gate arms, the maximum allowable wind speed will be even higher. For example, for a 7.0-m (23-ft) gate arm, the maximum allowable wind speed would be 159 km/h (98.9 mi/h), which is higher than the 50-year wind speed of 144.9 km/h (90 mi/h).

The use of higher strength bolts for the gate arm should not adversely affect the impact performance of the gate arm if struck by an errant vehicle in the down position. First, the force applied at the gate arm required to shear off the bolts is relatively low. For example, for a 9.8-m (32-ft) gate arm, a force of only 781 N (350 lb) applied at the center of gravity of the gate arm (i.e., at 4.9 m or 16 ft) is needed to shear off the bolts. This level of force would not pose any hazard to the impacting vehicle. Second, the force required to break the fiberglass gate arm itself should also be relatively low. Thus, the use of higher strength bolts for attachment of the gate arm assembly should not pose any safety hazard.

- The road closure gate design as tested uses a four-bolt slip base for the breakaway mechanism. However, there is no reason to believe that the road closure gate design would not perform satisfactorily when used with other crash tested and approved breakaway bases, such as a three-bolt slip base, a frangible transformer base, or frangible couplings.

- The road closure gate design as tested uses an electric in-line linear actuator as the gate arm lift mechanism. Some Department personnel have expressed the preference for a manual winch and pulley lift mechanism for the gate arm. The lift mechanism has no direct bearing on the impact performance of the road closure gate design.
provided it does not significantly add to the weight or size of the design. Thus, the use of an alternate lift mechanism such as a manual winch and pulley system should not adversely effect the impact performance.
APPENDIX A.

SLEEVE BEARINGS
**Dimensions:**

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<tr>
<th>Shaft Size</th>
<th>Ring Size</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>Pillow Blocks</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>4-Bolt Flange</th>
<th>2-Bolt Flange</th>
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</tr>
</tbody>
</table>

**Features**

- **Housing Coated with Teflon**
  - Protects housing in washdown and chemical environments.
- **Impregnated Polymer Sleeve Insert**
  - Self lubricating.
- **Corrosion Resistant Anti-Rotation Device**
  - Locks the Polymer Sleeve Insert to the housing.
- **Polymer Sleeve Insert**
  - Supports and positions the rotating shaft.

**Benefits**

- The coated housing resists oxidation, provides a "non-stick" surface for the food industry and is FDA/USDA approved.
- No lubrication required and operates in wet or dry environments. Corrosive and chemical resistant and is FDA/USDA approved.
- The stainless steel and polymer device prevents the insert from rotating in the housing due to unbalanced or eccentric loads.
- No thrust washer required.

**Radial Load Ratings (Lbs.) at Various Revolutions per Minute**

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<th>75</th>
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**Operating Temperature Range:** -40°F to 100°F.

For loads and speed combinations not shown on this chart or thrust load capabilities contact DODGE Engineering, Columbus, IN.

Due to unknown loads on take-up. F-Z KLEEN sleeve bearings are not recommended for use as a take-up bearing.

Commercial shafting tolerances are acceptable; however, a finish of 16-20/6 will reduce bearing wear.

Dodge collars are available and should be purchased separately for shaft location.

Radial load ratings were established for normal operating conditions, the service life may be reduced due to harsh environmental conditions with excessive temperature, dust and abrasive materials. Therefore, field testing is recommended to verify bearing operating performance under harsh environmental conditions.

**For More Information:**

For more information about DODGE E-Z KLEEN Bearings with housings coated with Teflon, consult your DODGE Sales Representative.

DODGE/P.O. Box 499/2 Ponder's Court/Greenville, S.C. 29602-0499/803-207-1800/FAX: 803-281-2318

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APPENDIX B.

ELECTRIC IN-LINE LINEAR ACTUATOR
SPECIFICATIONS:

1. STROKE: 18 1/8" ± 1/8" 
2. LOAD: 1500 LBS. MAX. (COMPRESSION) 2500 LBS. MAX. (TENSION) 
3. GEAR REDUCTION: 110:1 
4. MOTOR: 3400 R.P.M., 110 VOLT AC 
5. TUBE SPECIFICATIONS: 
   - OUTER TUBE: 2 1/4" DIA. x 24 3/4" LONG 
   - INNER TUBE: 2" DIA. x 21 1/8" LONG 
6. LUBRICATION: AMSOIL (MOLY FORTIFIED) SYNTHETIC GREASE (P/N 638-0005) 
7. 5/8-5 DOUBLE BRAKE BALL SCREW (MASTER P/N 18557) (DIM. "X" = 19.93) 
8. OPERATION NOTES: 
   a) SPEED: 6.10 IN./MIN. APPROX. 
   b) TORQUE LIMITER SETTING: 290/310 IN. LBS. 
9. SHIP LOOSE: 
   - P/N 19071 CRANK ASS'Y
APPENDIX C.
THEORETICAL ANALYSIS

As discussed in Section 3.1, the first compliance test conducted on the original road closure gate design was considered a failure due to intrusion into the occupant compartment resulting from the secondary impact of the separated support pole structure with the roof of the test vehicle. Analysis of the high-speed film indicated that the separated support pole structure had an angular velocity of approximately 180 deg/s and was rotating about a point approximately 610 mm (2 ft) above the roof of the test vehicle. In comparison, a review of high-speed film from successful crash tests with slip-base luminaire supports indicated a much smaller angular velocity and higher point of rotation for the separated support pole structure.

An engineering analysis based on conservation of linear and angular momentum principles was used to study the impact performance and post-impact trajectory of the road closure gate support structure. Details of the analytical methodology are given below.

Derivation of Analytical Model

The analysis procedure is broken into three phases of impact. During the first phase, energy is dissipated as the impacting vehicle crushes into the luminaire support until the force on the pole reaches a level sufficient to activate the breakaway mechanism. Using the principle of conservation of energy, the vehicular velocity at the end of phase I was calculated from the vehicle’s stiffness and slip-base activation force as shown in Equation 1.

\[ V_a = \sqrt{V_i^2 - F_s^2 / (k_v m_v)} \] (1)

where \( V_i \) = initial impact velocity; \( V_a \) = velocity at activation of slip-base mechanism; \( F_s \) = slip-base activation force; \( k_v \) = ratio of crush force to crush distance; and \( m_v \) = mass of impacting vehicle. For purposes of this analysis, it was assumed that the crush force was proportional to the crush distance, that is, \( k_v = 1 \).

The base activation force, \( F_s \), is defined as the force required to activate the slip-base mechanism. This activation force, or slip force, is dependent on a wide variety of factors including bolt diameter, bolt torque, surface treatment and finish, friction coefficient between
the sliding surfaces, and notch geometry. Because of the complexities of these interactions, defining the activation force through analytical means is difficult.

In a previous study, an empirical relationship was developed between bolt torque $T$ and bolt tension $N$ in which the tension in a single bolt was given by

$$N = (K_r)(T)$$

(2)

where $K_r$ depends on the bolt diameter. The total tensile force is thus the tensile force in a single bolt $N$ multiplied by the number of bolts in the slip-base mechanism. The slip force, $F_s$, is then calculated by the following equation:

$$F_s = (\mu_e)N_T$$

(3)

where $\mu_e$ = "effective" friction coefficient for the slip base, and $N_T$ = total bolt tension.

In addition to the normal friction between the sliding surfaces, the effective friction coefficient accounts for the mechanical interlocking forces that arise from contact of the bolts within the notches. In a previous research study, it was found that an effective friction coefficient of 0.5 gave the best correlation with experimental data. This value was therefore used for the analytical efforts performed under this project.

The second phase of impact involves momentum transfer from the vehicle to the support as the base of the support is accelerated. The laws of conservation of linear and angular momentum were used to determine the resulting velocity change of the impacting vehicle due to this momentum transfer phase. The results of this formulation are shown in Equation 4.

$$V_b = V_a \frac{d^2 + r^2 - er^2m_s/m_v}{d^2 + r^2 + r^2m_s/m_v}$$

(4)

where: $V_a$ = vehicle velocity at beginning of phase two; $V_b$ = vehicle velocity after momentum transfer to support; $d$ = distance from vehicle bumper (or contact point) to center of gravity of luminaire support; $r$ = radius of gyration of support; $m_s$ = mass of support; $m_v$ = mass of vehicle; and $e$ = coefficient of restitution for vehicle.
The third phase of the impact involves energy dissipation as the slip-base mechanism releases. The law of conservation of energy was used to determine the velocity change of the vehicle during this phase of impact. To simplify the analysis, the force-deflection relationship associated with the breakaway mechanism was assumed to vary linearly. The energy associated with activation and release of the breakaway mechanism can then be calculated if the travel distance during release can be estimated. Equation 5 gives the vehicular velocity at the end of the impact event.

\[
V_c = \sqrt{V_b^2 - F_s \delta_s / m_v}
\]  

(5)

where: \(V_c\) = vehicle’s velocity at end of impact, \(\delta_s\) = distance traveled by base of support during slippage of the breakaway mechanism. Based on previously performed static tests of slip-base mechanisms, slip distances in the range of 25.4–76.20 mm (1–3 in.) were common. Furthermore, the associated force-deflection curves obtained from these tests were approximately linear, supporting the assumption made in the derivation of Equation 5. A slip distance of 25.4 mm (1 in.) was used in this study.

In addition to predicting the change in vehicular velocity resulting from an impact with the road closure gate, pole trajectory was also investigated. The pole trajectory was of particular interest due to concerns regarding the potential for occupant compartment intrusion resulting from secondary impacts with the roof of the vehicle as observed in the first crash test. The angular velocity imparted to the pole during the impact sequence was determined using the principle of conservation of angular momentum as shown in Equation 6.

\[
\omega_s = \frac{m_v d (V_a - V_b)}{I_T}
\]  

(6)

where: \(\omega_s\) = angular velocity of support after momentum transfer; \(m_v\) = mass of vehicle; \(d\) = distance from vehicle bumper (or contact point) to center of gravity of luminaire support; \(V_a\) = vehicle velocity at beginning of phase two; \(V_b\) = vehicle velocity after momentum transfer to support; and \(I_T\) = total mass moment of inertia of support structure.

Similarly, the translational velocity of the support structure was derived using the principle of conservation of linear momentum. The results of this formulation are shown in Equation 7.
\[ V_s = \frac{m_v(V_a - V_b)}{m_s} \] (7)

where: \( V_s \) = translational velocity of support after momentum transfer; \( m_v \) = mass of vehicle; \( m_s \) = mass of support; \( V_a \) = vehicle velocity at beginning of phase two; and \( V_b \) = vehicle velocity after momentum transfer to support.

These equations were incorporated into a spreadsheet for the purpose of analyzing design alternatives for the road closure gate. The performance evaluation was based on such factors as change in vehicular velocity, degree of rotation of the support, height of the support above ground, and translation of the support for a prescribed impact condition. Some of the properties required to perform these computations, such as the mass, center of gravity (c.g.), and mass moment of inertia of the support pole, were calculated within the spreadsheet using readily available input parameters such as pole diameter, length, thickness, and taper rate. These values were combined with the properties (mass, c.g. height referenced to support structure) of specific components of the system (e.g., arm, arm support, arm plates, channel spacers, bearings, actuator, luminaire arm, and luminaire) to compute the combined properties of the road closure gate structure including total mass, c.g. height, mass moment of inertia, and radius of gyration.

The foregoing analytical methodology and spreadsheet program were validated by comparing predicted vehicular velocity change and pole trajectory with results measured during the first crash test of the original road closure gate. As reported in section 3.1 of this report, the velocity of the vehicle after impact was measured to be 28.18 km/h (17.5 mph) and the angular velocity of the support structure was measured to be 180 deg/s. When the appropriate impact speed and pole properties were input into the analytical model, the exit velocity of the vehicle was predicted to be 28.66 km/h (17.8 mph) and angular velocity of support was estimated to be 179.5 deg/s. The correlation of these parameters was considered satisfactory to proceed with the analytical investigation of various design alternatives as described in the next section.
Results

In order to resolve the deficiencies identified in the first crash test of the original road closure gate system, several options were explored with the Wyoming Department of Transportation (WYDOT), including lengthening or shortening of the pole structure. Although shortening the pole structure to reduce its height and mass seemed intuitively appealing, this option was rejected over concern that: (a) the shorter pole structure may have the propensity to rotate into the windshield area of the impacting vehicle which could result in intrusion of the occupant compartment; and (b) the shorter pole structure would not provide any support for the long gate arm, which could result in damage to the gate arm under high wind conditions.

The option of lengthening the pole structure was therefore selected for further investigation. The basic concept behind this option was to reduce the angular velocity and raise the point of rotation of the separated support pole structure by increasing the mass moment of inertia and center-of-gravity height, respectively. To accomplish this, several alternatives were evaluated, including the length of the pole structure and/or adding a mast arm and luminaire to the top of the pole.

Since the standard luminaire poles used by the Wyoming DOT have lengths of 8.85 m (29 ft) and 11.44 m (37.5 ft), these poles were used in the theoretical analysis. The impact performances of these poles were investigated with and without a mast arm and luminaire attached. The addition of a mast arm and light standard further increased the mass moment of inertia and c.g. height of the support structure, and would provide better visibility at the installation site.

The analysis was based on a frontal impact with an 817.20-kg (1,800-lb) passenger car at a speed of 34.78 km/h (21.6 mph). These impact conditions correspond to those of the first crash test with the original road closure gate. Figure 41 shows the predicted angular velocity for the different support combinations including the original design (i.e., 5.49 m (18 ft) test pole). The estimated change in vehicular velocity for the same support combinations is shown in Figure 42. The total weight of the different road closure gate alternatives is given in Figure 43.

As illustrated in Figure 41, the angular velocity of the support is significantly reduced as the height of the pole increases. The addition of a mast arm and luminaire have a similar
effect. In fact, an 11.44 m (37.5 ft) pole has a similar angular velocity to a 8.85 m (29 ft) pole with an 2.44 m (8 ft) mast arm and luminaire. For the options that included a mast arm and luminaire, the analysis showed no significant difference in the results for a 2.44 (8 ft) or 3.05 (10 ft) mast arm. As expected, the change in vehicular velocity increases as the weight of the support increases (see Figures 42 and 43). However, the relative increase among the support combinations analyzed is small and the values are well within acceptable limits.

After careful consideration of these results and consultation with the Wyoming DOT, it was decided to replace the original 5.5 m (18 ft) high pole structure with a standard 8.85 m (29 ft) high luminaire support. In addition, a 2.44 m (8 ft) long mast arm and an 18.16 kg (40 lb) light standard were incorporated into the design. The taller support pole structure, with mast arm and luminaire, increased the weight of the road closure gate system by 54 kg (118 lb) from 198 kg (437 lb) to 252 kg (555 lb). The mass moment of inertia was increased by a factor of more than five, from $1.648 \times 10^9 \text{ mm}^4$ (3960 in$^4$) to $8.460 \times 10^9 \text{ mm}^4$ (20326 in$^4$), and the height of the center of gravity was raised from 2096 mm (82.5 in.) to 3653 mm (143.8 in.).

For the impact speed at which the first low-speed test was conducted, the predicted angular velocity of the separated pole structure was reduced from 180 to 95 deg/s and the estimated rotation would be less than 90 degrees prior to re-contacting the vehicle or the ground (i.e., the separated pole structure would not reach a horizontal position above the vehicle). Although the predicted velocity change from impact with the modified road closure gate increased from 1.7 to 2.1 m/s (5.5 to 7 ft/s) due to the additional mass, this value is still well below the acceptable limit of 5 m/s (16.4 ft/s).

As reported in Section 3.2, the low-speed crash test of the modified road closure gate was successful. The angular velocity of the pole after separation from the vehicle was measured to be 73 deg/s. Although the predicted angular velocity was 95 deg/s, the analysis was based on an impact speed of 33.81 km/h (21.6 mph.). When the actual impact velocity 31.72 km/h (19.7 mph) was input into the analytical model, the predicted angular velocity was 77 deg/s. This was considered a good validation of the theoretical procedure.
Figure 41. Predicted Angular Velocity for Different Support Combinations.
* Note: Either an 8 ft or 10 ft Luminaire Arm may be used with 40 lb Luminaire

Figure 42. Predicted Change in Vehicular Velocity for Different Support Combinations.
* Note: Either an 8 ft or 10 ft Luminaire Arm may be used with a 40 lb Luminaire.

Figure 43. Estimated Weight of Different Support Combinations.
APPENDIX D.
STANDARD DRAWINGS
GENERAL NOTES

SPECIFICATIONS:


STEEL LUMINAIREpoles: Steel luminaire poles shall have a 205 mm outside diameter at the base with a 4.5 mm minimum wall thickness and a uniform taper throughout. Poles shall be round or twelve or more sides and fabricated in accordance with Subsection 624.24 - Traffic Signal and Roadway Lighting Poles, of the Standard Specifications.

Certified test reports required to be submitted in accordance with Subsection 624.24 - Traffic Signal and Roadway Lighting Poles, of the Standard Specifications, shall be submitted prior to or after fabrication of the poles and arms. Physical tests, including tensile properties for the poles and arms, may be taken after fabrication and need not include similar tests taken prior to fabrication.

REFERENCES:

GALVANIZING: The steel luminaire poles, mast arms, gate arm photos, supports, and guides, and all associated hardware shall be galvanized in accordance with Subsection 703.18 - Galvanizing, of the Standard Specifications. All rough edges and burrs shall be ground smooth prior to galvanizing.

BOLTED CONNECTIONS: All bolts shall conform to ASTM F 568, Class 4.6, unless designated as HS (High Strength), which shall conform to ASTM A 325W.

FIELD ASSEMBLY: In some installations, the connection plates for the luminaire arms may require modification to draw the pier above to slip over. Any damage to the galvanizing shall be repaired with two coats of zinc rich point conforming with the requirements of ASTM A 790.

NOTES:

1) The location of road closure gates and mounting height of gate arm pivot shall be verified by the Engineer.

2) Height of gate arm guides may be varied as required for working light clearance.

Steven E. Syms

Designated

DATE: 27-NOV-96

Drawing by: SMS/MAD

WYOMING DEPARTMENT OF TRANSPORTATION

STANDARD ROAD CLOSURE GATE DETAILS

(General Plan and Elevation)
WYOMING DEPARTMENT OF TRANSPORTATION

STANDARD ROAD CLOSURE

GATE DETAILS

(Gate Arm Pivot And Gate Details)

DRAWN BY: NES
DATE: 17-NOV-96

CHKO BY: SMS / MAD

SHEET 2 OF 3

1. Fiberglass/Aluminum gate arm and cast adapter shall be as supplied by Safetron, or equivalent.
2. Worm gear winch and cable shall be as supplied by Dunton - Lainson (Stock number 421831), or equivalent.
3. When the gate is fully raised, the nut and washer shall be placed snugly against the outside of the rear channel and paledlocked in place. The Fabricator shall supply one heavy, waterproof padlock with 2 keys for each gate arm pivot. Paired pivots with like keys shall be keyed alike.

Lighting Post
4-Bar Trip Light

GATE ARM SUPPORT DETAIL
Gate arm and bolts not shown

VIEW A-A

GATE ARM GUIDE DETAIL

Note:

1. Fiberglass/Aluminum gate arm and cast adapter shall be as supplied by Safetron, or equivalent.
2. Worm gear winch and cable shall be as supplied by Dunton - Lainson (Stock number 421831), or equivalent.
3. When the gate is fully raised, the nut and washer shall be placed snugly against the outside of the rear channel and paledlocked in place. The Fabricator shall supply one heavy, waterproof padlock with 2 keys for each gate arm pivot. Paired pivots with like keys shall be keyed alike.
REFERENCES


4. Letter from Mr. Leonard G. Swanson, Wyoming Division, Federal Highway Administration to Mr. D.G. Diller, Director, Wyoming Department of Transportation, dated April 12, 1995.