Midwest States' Regional Pooled Fund Research Program
Fiscal Year 1999-2000 (Year 10)
Research Project Number SPR-3(017)
NDOR Sponsoring Agency Code RPFP-00-05

ANALYSIS OF SIGN ATTACHMENTS TO BREAKAWAY LUMINAIRE SUPPORTS

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MIDWEST STATES' REGIONAL POOLED FUND PROGRAM
Nebraska Department of Roads
1500 Nebraska Highway 2
Lincoln, Nebraska 68502

MwRSF Research Report No. TRP-03-122-02

October 23, 2002

Technical Report Documentation Page

1. Report No.	2.	3. Recipient's Accession No.
SPR-3 (017)		

4. Title and Subtitle	5. Report Date
Analysis of Sign Attachments to Breakaway Luminaire Supports	October 23, 2002
	6.
7. Author(s) Nelson, R.M., Sicking, D.L., and Polivka, K.A.	8. Performing Organization Report No. TRP-03-122-02
9. Performing Organization Name and Address Midwest Roadside Safety Facility (MwRSF) University of Nebraska-Lincoln 1901 Y St., Bldg. C Lincoln, NE 68588-0601	10. Project/Task/Work Unit No. 11. Contract © or Grant (G) No. SPR-3(017)
12. Sponsoring Organization Name and Address Midwest States' Regional Pooled Fund Program Nebraska Department of Roads 1500 Nebraska Highway 2 Lincoln, Nebraska 68502	13. Type of Report and Period Covered Final Report 1999-2002 14. Sponsoring Agency Code RPFP-00-05

15. Supplementary Notes

Prepared in cooperation with U.S. Department of Transportation, Federal Highway Administration

16. Abstract (Limit: 200 words)

Removal of fixed objects is one of the most basic methods for improving roadside safety. Although breakaway signs and luminaire supports are generally considered to be relatively minor hazards, combining these systems has been proven to be a cost effective approach to improving roadside safety. In order to reduce the number of roadside obstacles, small roadside signs can be attached to luminaire supports. The large mass associated with luminaire supports and the high forces required to activate large breakaway devices are the primary considerations associated with the system's safety performance. Consequently, luminaire supports are subjected to high decelerations when struck by errant vehicles. The rapid acceleration of the luminaire support could cause the sign panel to become detached and pose a potential hazard to vehicle occupants. A study was undertaken to determine the connection strength required to assure that sign panels remain attached to luminaire supports subjected to high-speed impacts.

Most small signs are fabricated from aluminum sheeting and are limited to a maximum size of approximately 1.5 m^2 (16 ft^2) due to the bending strength of the panel. Since sign panel mass increases with sign area, the larger signs will generate high connection loads. Furthermore, luminaire support accelerations are inversely related to size of the support. Several combinations of vehicle and support geometries and properties were investigated to assess a critical design case. Maximum connection loads were found to be associated with 1.2 m x 1.2 m (4 ft x 4 ft) sign panels mounted on short, 5.2-m (17-ft) tall, luminaire supports. Finally, recommendations were made pertaining to the connection devices used to keep the sign panels attached along with recommendations on attaching sign panels to very tall luminaire supports.

17. Document Analysis/Descriptors	18. Availability Statement
Highway Safety, Breakaway Luminaire Supports, Sign Attachments, Roadside Appurtenances, Compliance Test	No restrictions. Document available from: National Technical Information Services, Springfield, Virginia 22161

19. Security Class (this report)	20. Security Class (this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	12	

DISCLAIMER STATEMENT

The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the state Highway Departments participating in the Midwest States' Regional Pooled Fund Research Program nor the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

TABLE OF CONTENTS

List of Tables

Page

1 BACKGROUND

Removal of fixed objects is one of the most basic methods for improving roadside safety. Although breakaway signs and luminaire supports are generally considered to be relatively minor hazards, combining these systems has been proven to be a cost effective approach to improving roadside safety. In order to reduce the number of roadside obstacles, small roadside signs can be attached to luminaire supports. By eliminating one small sign support, the risk of impacts with roadside hazards is diminished, and the cost of installing the sign is also reduced.

The large mass associated with luminaire supports and the high forces required to activate large breakaway devices are the primary considerations associated with the system's safety performance. Even large, 1.2 m x 1.2 m (4 ft x 4 ft), aluminum sign panels weigh only 13 kg (29 lbs). When compared to the mass of more than 340 kg (750 lbs) for a large luminaire support, it is readily apparent that adding even large sign panels to a luminaire support does not materially affect the mass of the system. Similarly, adding the sign panel to a luminaire support will not influence the primary function of the breakaway mechanism.

However, luminaire supports are subjected to high decelerations when struck by errant vehicles. The rapid acceleration of the luminaire support could cause the sign panel to become detached and pose a potential hazard to vehicle occupants. The study described herein was undertaken to determine the connection strength required to assure that sign panels remain attached to luminaire supports subjected to high-speed impacts. Most small signs are fabricated from aluminum sheeting and are limited to a maximum size of approximately 1.5 m^2 (16 ft^2) due to the bending strength of the panel. Since sign panel mass increases with sign area, the larger signs will generate high connection loads. Furthermore, luminaire support accelerations are inversely related to size of the support. Hence, the analysis described within was limited to large, 1.2 m x 1.2 m (4 ft x 4 ft), sign panels mounted on short, 5.2-m (17-ft), slip-base luminaire supports. For this analysis, aluminum poles were selected over galvanized steel poles as the shorter and lighter poles would produce the maximum pole accelerations and velocities. Slip-base designs were also selected over frangible transformer base designs for this study. Vehicular impacts into transformer bases typically result in a greater change in vehicle speed from that observed for slip-base configurations, thus resulting in lower peak pole accelerations and velocities. Thus, the most conservative design approach (i.e., greatest design loading to sign panel) would consist of modeling a short, light weight pole configured with a slip-base device.

2 BREAKAWAY LUMINAIRE SUPPORT ANALYSIS

Analysis of breakaway luminaire supports has centered on the procedures outlined by the National Cooperative Highway Research Program (NCHRP) Report No. 318, *Roadside Safety Design for Small Vehicles* (1). These procedures were codified to produce a computer program that accurately predicted the safety performance of luminaire designs in which activation characteristics for the breakaway mechanism could be determined. This same analysis tool is used to estimate the maximum g-loading and maximum velocity of a luminaire support during an impact. These impulse loadings and the associated mast velocities are then converted into sign panel accelerations and wind loadings. The maximum practical sign panel loadings are then converted into the maximum connection loadings for design purposes.

The luminaire analysis program outlined by NCHRP Report No. 318 derives the vehicle's velocity for three different phases of the impact event using the support system's geometric and material properties, the vehicle properties, and the slip-base characteristics. The first phase of the impact event involves crushing of the impact vehicle until the breakaway activation force is achieved. Since energy is dissipated only through the vehicle crushing, conservation of energy is used to calculate the vehicle velocity at the end of this phase. Phase II involves the acceleration of the luminaire base after the breakaway mechanism is activated. This process primarily involves a transfer of momentum from the impact vehicle to the support. The laws of conservation of linear and angular momentum are used to determine the velocity change of the impact vehicle due to the momentum transfer and to predict the vehicular velocity at the end of Phase II. It should be noted that the maximum loading on the luminaire pole is achieved at the end of Phase II when the base of the luminaire support and the front of the vehicle achieve the same velocity. Thus, the maximum g-loading on the sign panel will occur when the vehicle and support base reach the same velocity. The maximum connection loading includes this acceleration force and the sign panel wind load generated by the velocity of the luminaire support. The computer program presented in NCHRP Report No. 318 is used to estimate maximum g-loading on the luminaire support and the velocity of the sign panel.

Several combinations of vehicle and support geometries and properties were investigated to assess a critical design case. These variable conditions are defined in Tables 1 and 2. As expected, critical connection loadings were associated with large passenger vehicles, large sign panels, and small luminaire supports. The critical impact condition consisted of a 1,996-kg (4,400-lb) pickup truck striking the luminaire pole at a speed of 96.6 km/hr (60 mph).

For this impact condition, the analysis program predicted that when the peak accelerations were applied, the pole's base would be subjected to a maximum acceleration of 463 g's and the velocity of the pole's base would be approximately 107.5 km/hr (66.8 mph). The corresponding peak vehicle acceleration and velocity were determined to be 7.9 g's and 94.6 km/hr (58.8 mph), respectively. It should be noted that the bottom of a small sign is normally mounted at least 2.1 m (7 ft) from the ground. Therefore, the pole acceleration and velocity at the bottom of the sign panel would be lower due to the angular acceleration and velocity of the pole. Furthermore, a sign panel would normally be attached to a luminaire support at two locations, the lower of which would have a higher acceleration than the upper connection. In order to estimate maximum connection loads, it was assumed that the lower connection would need to withstand both the impulse loading and the wind loading applied to the bottom half of the sign. The impact analysis predicted that when the peak deceleration occurred, the center of the bottom half of a 1.2 m x 1.2 m (4 ft x 4 ft) sign, mounted 2.1 m (7 ft) from the ground, would be subjected to a peak acceleration of 245 g's and would achieve a sign panel velocity of 57.0 km/hr (35.4 mph).

Since a 1.2 m x 1.2 m (4 ft x 4 ft) aluminum sign panel weighs approximately 13 kg (29 lbs), an acceleration of 245 g's would generate a maximum loading of 15,804 N (3,553 lbs) at the bottom connection. The wind loading associated with a 0.7 m^2 (8 ft^2) sign panel traveling 64.4 km/hr (40 mph) would be approximately 329 N (74 lbs). Therefore, the peak connection load required to secure a 1.2 m x 1.2 m (4 ft x 4 ft) sign panel to a luminaire support was estimated to be 16,133 N (3,627 lbs). It should be noted that this peak loading is applied such that it would pull the sign panel away from the luminaire support. Furthermore, the analysis indicated that shear and bending loads on the connection would be very low and could be neglected. Finally, this combined design loading (i.e., pole acceleration and 40 mph wind loading at panel location) is much greater than the loading induced to the panel during typical high wind events, say of more than 112.7 km/hr (70 mph).

The nominal design capacity of an ASTM A325 7.9-mm (5/16-in.) diameter bolt is 20.9 kN (4.7 kips) per bolt as dictated by the specifications set forth in the American Institute of Steel Construction's (AISC's) *Load and Resistance Factor Design (LRFD) Manual of Steel Construction* (2). Thus, two ASTM A325 7.9-mm (5/16-in.) diameter bolts would provide adequate strength to secure a 1.2-m x 1.2-m (4-ft x 4-ft) sign panel to a luminaire support. A simple punching shear analysis indicated that a 7.9-mm (5/16-in.) diameter bolt would not pull through a 3.2-mm (1/8-in.) thick aluminum sign blank at a load of approximately 20.0 kN (4.5 kips). However, it is recommended that a 22.2-mm (7/8-in.) O.D. x 3.2-mm (1/8-in.) thick washer be placed on the outside of the sign blank in order to assure an adequate connection.

At the request of the State Highway Agencies, an alternative bolt configuration which utilized the ASTM A307 specification was also provided. The nominal design capacity of an ASTM A307 11.1-mm (7/16-in.) diameter bolt is 21.4 kN (4.8 kips) per bolt as dictated by the AISC's *LRFD Manual* (2). Therefore, two A307 11.1-mm (7/16-in.) diameter bolts would also provide adequate strength to secure a 1.2-m x 1.2-m (4-ft x 4-ft) sign panel to a luminaire support. Washer diameter and thickness should be equal to or greater than that specified previously for the A325 bolt.

It is noted that it was not the objective of this study to develop the attachment hardware for the physically mounting the sign panels to the various types and sizes of poles. For this study, it was assumed that the sign panels could be adequately attached to the pole using available structural brackets. If this is not true, it is recommended that the design engineer use pole brackets with structural capacities that are equal to or greater in strength than the bolts specified previously.

Finally, the additional mass and wind drag associated with adding a small sign to a 12.8-m (42-ft) high luminaire support was analyzed using the computer program in NCHRP Report No. 318. This analysis indicated that the small additional mass and the wind drag associated with a 1.2 m x 1.2 m (4 ft x 4 ft) aluminum sign panel would have a negligible effect on the vehicular velocity changes associated with such an impact.

Table 1. Steel Support Geometries

Support Type	Pole Height (ft)	Pole Weight (lbs)	Base O.D. (in.)	Top O.D. (in.)	Arm Weight (lbs)	Mounting Height (ft)	Luminaire Weight (lbs)	Base Plate Weight (lbs)
A	17	127	6.5	4.1	36	20	50	17
B	22	168	7.0	3.9	36	25	50	16
C	27	206	7.5	3.7	36	30	50	18
D	32	255	8.0	3.5	36	35	50	19
E	37	326	9.0	3.8	36	40	50	23
F	42	375	9.5	3.6	36	45	50	29

* Conversion factors: 1 ft = 0.3048 m, 1 in. = 25.4 mm, and 1 lb = 0.45359 kg.

Table 2. Vehicle Properties

Vehicle Type [1]	Description	Vehicle Weight (lbs)	Effective Bumper Height (in.)
A	Compact Car	1800	14.5
B	Pickup/SUV	4400	17.5

[1] Initial vehicle velocities ranged from 64.4 - 96.6 km/hr (40 - 60 mph).
* Conversion factors: 1 lb = 0.45359 kg and 1 in. = 25.4 mm.

3 CONCLUSIONS

As summarized in this report, the attachment of sign panels to small and large luminaire supports was evaluated. Maximum connection loads were found to be associated with 1.2 m x 1.2 m (4 ft x 4 ft) sign panels mounted on short, 5.2-m (17-ft) tall, luminaire supports. Two 7.9-mm (5/16-in.) diameter ASTM A325 bolts or two 11.1-mm (7/16-in.) ASTM A307 bolts were found to be sufficient to keep the sign panel attached to such a support during high-speed impacts. Furthermore, although a punching shear analysis indicated that a washer may not be necessary, it is recommended that a 22.2-mm (7/8-in.) O.D. x 3.2-mm (1/8-in.) thick washer be placed on the outside of the sign blank in order to assure an adequate connection. Finally, the analysis indicated that even a 1.2 m x 1.2 m (4 ft x 4 ft) aluminum sign panel would have a negligible affect on the safety performance of very tall breakaway luminaire supports.

4 REFERENCES

1. Ross, H.E., Perera, H.S., Sicking, D.L., and Bligh, R.P., *Roadside Safety Design for Small Vehicles*, National Cooperative Highway Research Program (NCHRP) Report No. 318, Transportation Research Board, Washington, D.C., 1989.

2. *Load & Resistance Factor Design Manual of Steel Construction*, Vol. I & II, Second Edition, American Institute of Steel Construction Inc., 1995.

5 APPENDICES

APPENDIX A

Critical Case Example

IMPACT VEHICLE:	***Truck / SUV***				
Initial Velocity:	60	*mph*			
Vehicle Weight:	4400	*lbs*			
Effective Bumper Height:	24.5	*in*			
Vehicle Stiffness:	4400	*lb/in*			
Slip Force:	12000	*lbs*			
Slip Base Slip Distance:	1	*in*			
Pole Weight:	127	*lbs*			
Pole Height:	204	*in*			
Radius at Top of Pole:	2.05	*in*			
Radius at Bottom of Pole:	3.25	*in*			
Arm Weight:	36	*lbs*			
Luminaire Weight:	50	*lbs*			
Luminaire Height:	240	*in*			
Base Plate Weight:	17	*lbs*			
Mass of Vehicle:	136.646	*slugs*	=	11.387	*lb-sec^2/in*
Total Weight of Luminaire Support:	230	*lbs*			
Total Mass of Luminaire Support:	7.143	*slugs*	=	0.595	*lb-sec^2/in*
Vertical Distance from Slip Plane to CG of System:	137.64	*in*			
Mass Moment of Inertia of System:	4478.371	*in-lb-sec^2*			
Radius of Gyration:	86.739	*in*			
Initial Velocity	88.00	*ft/sec*	=	1056.00	*in/sec*
Phase I Velocity:	87.887	*ft/sec*	=	1054.64	*in/sec*
Phase II Velocity:	86.218	*ft/sec*	=	1034.62	*in/sec*
Distance from Eff. Bumper Height to CG of System:	113.14	*in*			
Point of Interest (Measured from Base of System):	96.00	*in*			
Rotational Velocity of Support:	5.76	*rad/sec*			
Transverse Velocity of Support:	383.14	*in/sec*			
Energy of Vehicle:	136512	*lb-in*			
Deflection:	7.88	*in*			
Applied Force:	34660	*lbs*			
Transverse Acceleration of Support	58227	*in/sec^2*			
Rotational Acceleration of Support:	875.63	*rad/sec^2*			
Total Acceleration of Support @ Point of Interest:	**94689**	***in/sec^2***	=	**7891**	***ft/sec^2***
Total Acceleration of Support @ Base:	**178750**	***in/sec^2***	=	**14896**	***ft/sec^2***
Total Velocity of Support @ Point of Interest:	**623**	***in/sec***	=	**52**	***ft/sec***
Total Velocity of Support @ Base:	**1176**	***in/sec***	=	**98**	***ft/sec***