Crash Test of Type 1 and Type 15 FBS Standards for Ramp Meter Use

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Executive Summary

Background

Type 1 Standards include Type 1A and Type 1B standards. Type 1A is a tapered steel post with a 5-inch inside diameter at the base while the Type 1B is a 4-inch NPS pipe the entire length. These 10 feet long steel poles are typically installed 3 feet off the shoulder on the right hand side of a single lane on-ramp, and on both sides of a multilane on-ramp. A Type 1 Standard carries three signal heads. The upper and lower three section signal heads face upstream and are used to control the approaching and stopped motorists, respectively. The single-section head faces downstream (installed back to back with the upper head) and is used for enforcement purposes. In addition to these three signal heads, these poles carry traffic signs, such as R10-6 and R89 (CA) series.

The Type 15 Standards include several variations. For the purposes of this Preliminary Investigation, the Type 15 in question is the Type 15 FBS (Flashing Beacon with Slip Base Installation). A typical Type 15 FBS pole is 18 feet long and is tapered with an 8-inch outside diameter at the base and has an outside diameter of 5-3/8 inches at the top.

The cross-section diameter of both the Type 1 and the Type 15 FBS is sufficient enough for these Standards to be considered as a roadside fixed object. The Caltrans Highway Design Manual states that all fixed roadside objects should be placed outside of the 30-foot clear recovery zone (CRZ) for freeway facilities. However, such a placement will render the metering signal heads functionally useless because the signal heads will be outside of the cone of vision of both the approaching and stopped motorists on the ramp. Currently, a design exception must be prepared and approved when a Type 1 Standard for ramp metering is installed in a metered on-ramp. According to the Ramp Metering Development Plan 2011, more than 1700 ramp metering locations were planned in California. The Ramp Metering Development Plan is biennially updated and the latest version in 2017 indicates 1840 proposed ramp meter locations in addition to the 3,014 existing locations. The planned ramp meter locations require the installation of hundreds more Type 1 Standards or Type 15 FBS poles. It is recommended that the Type 1 and Type 15 FBS Standards be crash-tested or redesigned and crash-tested to confirm compliance with crashworthiness of roadside safety hardware under the current MASH ’16 Guidelines.

Summary of Findings

Through a literature search, we identified past and current research and publications that address light pole standards. Not all of the found research is directly applicable to the Type 1A or 1B standard or the Type 15 FBS, but is useful in documenting the various areas of past and current research on the crashworthiness of poles, base plates and hardware.

International Research and Guidance

1. February of 1984, *The Legal Implications of Frangible Poles*, Project Sponsor was the Office of Road Safety, Commonwealth Department of Transportation-Australia. In 1978, the Office of Road Safety of the Australian Department of Transport, commissioned this study into the legal implications surrounding the use of frangible or breakaway poles for street lighting and the support of overhead conductors. Frangible or breakaway poles

are safety devices in that they yield or collapse on impact, thus decreasing the possibility of injury to the occupants and the amount of damage to the vehicle. Conventional rigid poles, on the other hand, whether made of timber, steel or concrete, result in a rapid deceleration of the impacting vehicle and thus their potential for severe injury to the occupants and damage to the vehicle is high. The Office of Road Safety considered that the use of frangible poles was an important way of creating a safer roadside environment, as they significantly reduce the severity of vehicle-pole collisions. As the title of the project indicates, the aim was to clarify legal implications of the use of frangible or breakaway poles. This involved an investigation into the legal liability of the various State instrumentalities and authorities who decided on the type of pole to be utilized or who control the installation or maintenance of the pole or signal.

2. May-June of 1991, *Side Impact Crash Test and Evaluation Criteria for Roadside Safety Hardware*, a report by M.H. Ray, et.al. Reducing the severity of side impact collisions has been an emerging area of research during the past decade by a variety of organizations and research communities. The international research community has developed test procedures for performing impacts into poles, one of the most severe types of side impact collisions. One in three vehicle occupants involved in side impacts with roadside objects are injured and one in one hundred is fatally injured. Developing roadside hardware with better side impact performance is an emerging factor in improving roadside safety in the next decade but before roadside hardware can be designed for side impacts, the roadside safety community must develop a consensus on how side impact crash tests should be performed and what constitutes successful performance. The recommendations for roadside hardware side impact crash tests summarized in Tables 1 and 2 have been based on about 25 full-scale crash tests at the FHWA's FOIL test facility over the past decade. With the exception of four tests of guardrail terminals, these tests have been performed to explore the impact performance in side impacts of a variety of luminaire supports. This body of test work and other developments in the broader automobile and highway safety communities have demonstrated several issues that require additional research. The side impact test and evaluation criteria presented in Table 1 and 2 represent a good combination of field relevancy, harmonization with other agencies and experimental practicality. Side impact crash testing is expected to become a more important part of the test and evaluation of roadside hardware in the future, especially guardrail terminals and luminaire supports. While there are important issues and areas for further research as discussed above, the recommendations described in this paper are a first step toward developing better roadside hardware for side impact collisions.

3. June 14, 2000, Results of a *Full-scale Crash Test into an Energy Absorbing Lighting Pole on a Sloped Roadside*, an Australian research study. This paper presents the results of a full-scale crash test into an energy absorbing lighting pole situated on an uneven or sloped roadside. With poles representing approximately one third of single vehicle accidents involving roadside objects it is important to ascertain the performance of luminaire supports in the Australian road environment. The performance of lighting poles in crash events are not well documented for installations on sloped surfaces, such as in most road shoulder or median locations with cut or fill slopes. Single vehicle run-off-road incidents with lighting poles constitutes a large proportion of road fatalities and therefore light poles are the focus of this research. Due to the poor in-service performance of slip base poles in uneven/sloped road environments it is necessary to test in a manner that simulates an impact under these conditions. Energy absorbing

poles have considerable performance advantages and thus were selected as the test article for this research using the NCHRP Report 350 criteria.

National Research and Guidance

1. There are two Research Needs Statements (RNS) in the Transportation Research Boards' database that address issues related to fixed objects in the clear recovery zone. These RNS documents, dated September, 2015, are entitled, *Development Methods to Evaluate Side Impacts with Roadside Safety Features*, and *A Practical Approach to Fixed Objects within the Clear Zone*. The research results and final reports are not yet available for these studies. Also, there is proposed research (August 2013) on the *Assessment of Luminaires and Manual on Assessing Safety Hardware (MASH) testing*. The research results are not yet available.

2. In addition to the RNS information, there is an active National Cooperative Research Program (NCHRP) Panel, 03-119, tasked with the research on the *Application of MASH Criteria to Breakaway Supports*. As of 12-6-2018 the work continues however, there is not currently a report issued on the research findings. The previous work on this topic is from an NCHRP Report 411, *Structural Supports for Highway Signs, Luminaires, and Traffic Signals* dated 1998. This report is based on NCHRP 350 testing of products.

3. A search of the Federal Highway Administration (FHWA) website for Accepted Products yielded no MASH tested luminaire products. The latest version of the Accepted Products indicates a single product acceptance letter for Luminaire Support, LS-78 issued by FHWA for a fiberglass breakaway pole approved in November of 2012 under the NCHRP Report 350 crash test criteria.

4. The Transportation Research Record, Number 1233, of 1989, sites two studies in the report titled *Design and Testing of Roadside Safety Devices; Vehicle Impact Testing of Lightweight Lighting Standards* and *Case Study: Poles in Urban Clear Zone*, both are based on the previous testing guidance of the NCHRP 230 criteria (the predecessor to NCHRP 350).

5. The Transportation Research Record, Number 1647, *General Design and Roadside Safety Features*, dated 1998, includes a study, *Side Impact Crash Test and Evaluation Criteria for Roadside Safety Hardware,* which considered the development of improved roadside safety hardware based on safer side-impact crash data under NCHRP 350 guidelines.

State Research Efforts and Guidance

There are several research efforts underway through Pooled Fund studies with regards to luminaire poles.

Pooled Fund Studies:

1. As a result of the work by the Transportation Pooled Fund (TPF) research group TPF-5(002), the 1980 *Guide to Standardized Highway Lighting Pole Hardware* was updated. The TPF-5(002) report, dated March 13, 2013, describes the development, use and maintenance of an updated *On-line Guide to Luminaire Supports*. The *Guide* is a web-based content management system for luminaire support systems that allows full

viewing, submission, management, and reporting services to its users. The *On-line Guide to Luminaire Supports* is one of six on-line guides maintained by the AASHTO and the Associated General Contractors (AGC) along with the American Road Transportation Builders Association (ARTBA) as AASHTO-AGC-ARTBA Joint committee on New Highway Materials Task Force 13 (TF13). The luminaire support systems included in the *On-line Guide* have been successfully crash tested according to *NCHRP Report 350* or *MASH* and comply with the AASHTO Standard Specification for Structural Supports for Highway Signs, Luminaires and Traffic Signals. Thus, the more than 8,000 luminaire configurations listed in the *On-line Guide* all meet the AASHTO criteria and FHWA eligible requirements for use on federally funded projects.

2. TPF-5(114) investigated the problem of steel sign support and light standards requiring a concrete foundation and which are installed on a sloped terrain. For this project, a new foundation was designed and detailed along with a structural support with a slip base attachment for smaller signs that incorporated the use of a multi-directional slip base. In addition, a new foundation was designed and detailed along with a structural support attachment to be used for larger signs. This design incorporated the use of an Omni-directional slip base. For both designs, the structural supports with slip base attachments extend approximately 4 inches maximum from the down slope grading edge. The slope design is for 2H:1V or flatter slope conditions.

3. TPF-5(116) investigated the fatigue life of steel base plates to pole connections for commonly used traffic structures and recommended connections with enhanced fatigue performance that can be economically produced by a variety of fabricators. The connection geometries included in the test program were based on consensus reached in project meetings.

4. TPF-5(193) *Performance Evaluation of Brass Breakaway Couplings* study was completed on December 22, 2010, by the Midwest States Regional Pooled Fund Research Program (MwRSF). Breakaway couplings are commonly used to mitigate the severity of impacts between errant vehicles and luminaire or support poles placed at the edge of the roadway. However, existing breakaway couplings have several disadvantages, including being proprietary in nature, prohibitively expensive, inherently they have inconsistent energy absorption due to temperature effects, and variable fatigue strength due to corrosion. Thus, the Illinois Department of Transportation (ILDOT) developed a free-cutting, brass breakaway coupling for use on luminaire or support poles. The free-cutting, brass breakaway couplings in combination with luminaire poles were evaluated according to the Test Level-3 (TL-3) safety performance criteria found in NCHRP Report No. 350. A total of 7 tests were conducted at the Valmont/UNL-MwRSF pendulum testing facility in compliance with the impact criteria corresponding to test designation No. 3-60. The results of these tests were then used to predict the high-speed test results, test designation No. 3-61, using the FHWA-approved extrapolation equation. Luminaire poles used were selected to provide one of two worst-case impact scenarios: (1) a tall massive pole that requires the most energy to rotate the pole, or (2) the lightest and weakest pole that may bend, fracture, or crush before the couplings break away. Successful tests of these two scenarios then provided a range of pole sizes that could be used in combination with the brass couplings. Upon completion of the physical testing and extrapolation analysis, aluminum luminaire poles with nominal heights between 30 ft (9.1 m) and 55 ft (16.8 m) and weighs less than 755 lbs. (343 kg) were found to satisfy the TL-3 safety performance criteria when evaluated with the brass couplings. However, the selected and tested heavy steel poles failed to satisfy the

change in velocity limit for the high-speed test. The study identified the need for further research.

State DOT Research:

In chronological order of research:

1. October 1967, Report Number 75-8, *Supplementary Studies in Highway Illumination*, Research Project Number 2-8-64-75 sponsored by the Texas Highway Department, and research conducted at Texas Transportation Institute, Texas A&M University. For several years, engineers of the Texas Highway Department have recognized the potential hazard of collisions with lighting poles. Accordingly, they have taken steps to minimize this hazard as rapidly as possible, by experience alone they found collisions with lighting poles on cast aluminum transformer bases were far less severe than collisions with poles on steel transformer bases. As a result, design engineers are encouraged to use the aluminum transformer bases for lighting standards, especially where the standards are not protected by guard rails. As a remedial measure, engineers of the Texas Highway Department have developed a cast aluminum insert to be placed under the steel transformer bases of existing lighting systems. Since 1964 Texas Transportation Institute (TTI) has been engaged in research on highway illumination with the Texas Highway Department in cooperation with the Bureau of Public Roads. Initially, this research was concerned only with the illumination aspects, but the severity of collisions with lighting poles on Texas highways prompted the inclusion of a phase dealing with the impact behavior of lighting poles. Part of this research has been referred to as a "state of the art" study, a study to determine the impact characteristics of the various pole and base mounting designs in use on Texas highways. In addition, part of the research effort has been devoted to the development and evaluation of a slip base design similar to that used in the break-away sign support. The lighting pole designs included in the "state of the art" study were representative of the new standards for roadway illumination adopted by the Texas Highway Department. These standards call for 40-foot mounting heights for 400-watt luminaires and 50-foot mounting heights for 1000-watt luminaires [by comparison the Type 1A standard is 10-foot mounting height (base to signal head)]. In order to have a single design representative of both the 40- and 50-foot mounting heights, a 45-foot mounting height was selected. This was accomplished by using a 1'-8" base, a 38'-4" shaft and a 10-foot mast arm with an upsweep of 5 feet. In addition, one design of a 30-foot mounting height was used to evaluate the cast aluminum inserts designed to be placed under steel transformer bases of poles that were already in existence. A description of the various designs tested is presented in Table A of the report and the designs are illustrated in Figure 1of the report.

2. 1981 Nevada DOT research study “Captive Column” Crash Test-Light Standard Luminaire Pole, FHWA-RD-81-501. The research was a precursor to actual site studies and dealt with “captive column” light standard appurtenances under ideal conditions and controlled crash guidance. The “captive column” design reacted exceptionally well giving a favorable indication to test further. Test will continue in actual service areas to determine proper function.

3. August of 2004, Final Report: *Analysis of Light Pole Failures in Illinois*. The Illinois Department of Transportation has experienced failures of light pole structures in both

serviceability and collapse. The root cause of each was uncertain, though it is clear that dynamic considerations were important. Aluminum tenon top poles have been used extensively on major highway interchanges in Illinois. Advantages are related to lower mass (about three times lighter than steel) but also higher flexibility (E_{al}=70 GPa [10,100 ksi] vs. E_{steel}=205 GPa [29,500 ksi]). These are also usually very low-damping systems. Combination of lower mass with low damping increases susceptibility to wind-induced vibration. The recommendations are:

- Avoid using curved-arm poles on the I-80 Le Claire Bridge, which are particularly susceptible to excitation induced by traffic and enhanced by dynamic interaction with the bridge;
- Increase of damping is difficult due to in-plane second mode shape geometry of the pole;
- Mitigation of curved-arm poles: stiffening by introducing braces (although further analyses are required for optimal design);
- Use of tapered aluminum straight poles (40-foot) with high-G rated fixtures (3G); the introduction of impact dampers may be desirable to reduce acceleration levels.

4. December 2006, Final Report: Crash Testing of Various Roadside Hardware. Caltrans conducted 820C Report 350 tests of a Type 15 Flashing Beacon System. The tests were at 35 and 100 kph and are reported to have passed Report 350 criteria.

5. March of 2007, *Field Tests and Analytical Studies of the Dynamic Behavior and the Onset of Galloping in Traffic Signal Structures*, a study by the Center for Transportation Research at the University of Texas at Austin. Unpredictable fatigue failures of cantilevered traffic signal structures in Texas and throughout the United States in recent years have created the need to study their fatigue behavior. Based on recent research, AASHTO has adopted a design equation for galloping loads that is overly conservative in many cases. The Texas Department of Transportation (TxDOT) is interested in establishing design criteria for galloping that more accurately represents galloping potential and provides a more efficient design. In this study, three signal structures in Texas were monitored for a total of 9 months to detect the magnitude of galloping forces experienced in the field. Although large-amplitude displacements were measured in the field, sustained galloping did not occur. In addition to the field tests, an analytical model was developed and used to perform a parametric study for predicting the galloping potential of traffic signal structures with various properties. The analytical model suggests that modifying the aerodynamic properties of the sign and signal attachments may be the most effective way to handle galloping. On the basis of the analytical studies conducted as part of the present study, it was shown that the forces induced by galloping depend on the location of the attachments (signals, panels, etc.) on the arm. Greater forces are expected at locations closer to the tip of the arm. The expectation is that Eq. 11-1 in the Specifications should probably recognize that a panel of the same area at different locations along the arm will likely not experience the same vertical shear range. Additional work in this area is suggested so that the design equation may be appropriately modified in the future.

6. December of 2007, *Breakaway Utility Poles*, *Feasibility of Energy Absorbing Utility Pole Installations in New Jersey*, a study from Virginia Tech for the New Jersey Department of Transportation. Vehicle impacts with utility poles are one of the most unforgiving types of crashes to which motorists are exposed. In New Jersey, nearly 200 vehicle

occupants died on state highways after crashes into utility poles between the years 2000 to 2003. This report describes the findings of a research program to reduce the fatalities and injuries that result from traffic crashes with utility poles in New Jersey. The specific objective of the research was to investigate and recommend methods to mitigate the fatalities and injuries that result from vehicular collisions with utility poles.

7. January 1–June 30, 2009 research by the Washington State Transportation Research Center (TRAC) on *The Life Span of Luminaire and Traffic Signals*. This research is aimed at developing a preliminary methodology for determining replacement priorities for in-service WSDOT luminaire and traffic signal poles. Furthermore, the research will identify critical WSDOT details for which experimental data are not available in the literature, and will begin development of a reliability-based methodology for estimating the remaining life of such structures. Recommendations for additional research, including field and laboratory testing as well as analytical modeling and methodology development, will be made on the basis of the findings of this preliminary study. Additionally, recommendations will be made regarding the types of damage to look for when inspecting poles to determine whether they need replacement. The specific research products will be as follows:
    - A preliminary ranking of poles likely to be susceptible to fatigue failure based on existing experimental data and a parametric study of typical WSDOT pole configurations using the AASHTO fatigue design loads;
    - A database of tested and classified fatigue critical pole details based on existing experimental data;
    - A preliminary framework for a reliability-based assessment of the remaining fatigue life of traffic signal and luminaire pole structures in Washington State;
    - Recommendations regarding in-service pole inspection;
    - Recommendations regarding additional research.

8. November 2009, *Remaining Life Assessment of In-Service Luminaire Support Structures*, prepared for the Washington Department of Transportation by the University of Washington. The Report focused on the fatigue failures of in-service luminaire support structures. The research had four primary components: a literature review, experimental fatigue testing of two in-service luminaire poles, a finite element analysis of the pole base, and development of a framework for estimating remaining life. The extensive literature review found previous experimental studies, which were used to identify details in older WSDOT luminaire support structures that may be critical and to help inform the selection of test specimens. Quasi-static and high cycle fatigue testing were performed on two previously in-service luminaire poles to determine the stress concentration factors in critical details and determine fatigue resistance. The results were then compared to the finite element analysis and the fatigue classifications used in the design. The finite element model was also used to determine the impact of parameters including base plate thickness, hand-hole stiffener thickness, and location of anchor bolts.

9. August of 2013, *Parametric Study of Fatigue in Light Pole Structures*, a thesis presented to the Graduate Faculty of the University of Akron. Failures caused by fatigue cracking often occur around welded structural details, some welded details include the light pole support base and hand-hole. Many of these failures are caused by wind-induced

vibration, resulting in various applied stress cycles at the weld toe. This report analyzed the application of wind forces and specifically wind-gusts at the weld toes of light pole structures. Predicting fatigue life, damage, stress and strain were the goals of this study.

10. November of 2013, Caltrans Division of Research, Innovation and System Information Research Results, *Updating the Guide for Highway Lighting Pole Hardware*. Caltrans, as well as other state departments of transportation, rely on federally approved standards for all types of roadside materials and technology, such as guardrails, crash cushions, and small sign supports, luminaire supports, and bridge railings, when purchasing for highway and bridge construction projects. These standards are developed and published by the national Task Force 13 (TF13), a joint committee of representatives experienced in transportation. These guides, which essentially serve as catalogs, have helped standardize technical specifications and criteria for the roadside hardware industry.

11. January of 2016, *Florida Department of Transportation (FDOT) Modifications To Standard Specifications For Structural Supports For Highway Signs, Luminaries And Traffic Signals (LTS-6)*, FDOT Structures Manual, Volume 3. Updates information in the standards for structural supports for traffic signals, including wind loading, connections, and anchor bolts, etc.

Gaps in Findings

There does not appear to be any current relevant research available on the issue of vehicle impacts with the Type 1 or the Type 15 FBS Standard for MASH compliance. There are research results available from the 1980's and 1990's, specifically NCHRP Report 411 *Structural Supports for Highway Signs, Luminaires, and Traffic Signals* in 1998, but no research results are available for crash tested standards under the new MASH criteria. There are several research reports that detail the impact of a vehicle with a utility pole, but these results are not transferable to a smaller diameter pole like the Type 1 or Type 15 FBS Standard. Therefore, future research is recommended for:

- Front impact of a vehicle into a Type 1 and a Type 15 FBS standard and crash tests under the new MASH criteria for Type 1A, Type 1B, and Type 15 FBS standards used as ramp meter poles. Caltrans initiated testing of a modified Type 15 FBS to the MASH 2016 guidelines in 2018. Based on the first test, additional system modeling is being performed. Additional information regarding testing will be available as it is published.
- Side impact research and crash tests under the new MASH criteria for Type 1A, Type 1B and Type 15 FBS standards used as ramp meter poles. MASH 2016 Section 2.4 suggests that side impact tests be conducted "whenever practical in order to build a better understanding of the efficacy of the proposed procedures and the performance of modern safety features during side impacts." Caltrans does not currently have plans to conduct side impact testing on the Type 15 FBS.

Next Steps

Research by the Pooled Fund partners will continue to evaluate breakaway light poles in conjunction with Nebraska DOT Midwest States Pooled Fund Program TPF-5(193) and Washington State DOT "Roadside Safety Research for MASH Implementation" pooled fund study TPF-5(343).

Other planned research will be that of the NCHRP Project 03-119 "*Application of MASH Criteria to Breakaway Supports…"* mentioned above. Caltrans has a panel member monitoring the progress of this project. In addition, the following may yield additional information:

- Testing of poles by manufacturers and/or vendors may come as a result of the new timeline to implement the MASH 2016 guidelines. Manufacturers and vendors may initiate testing of their products in anticipation of the need for updated hardware.
- A survey of other State DOTs for the type of pole used at ramp metering locations may result in information that will be useful to California.
- A survey of other testing facilities like Texas Transportation Institute and the FHWA Federal Outdoor Impact Laboratory (FOIL) may reveal tests that have been requested and/or initiated that would provide useful information regarding the acceptability of the Type 1 and Type 15 standard under the MASH requirements.

Detailed Findings

National Research and Guidance

The following table contains the information gleaned from a search of the TRB website and the FHWA website for the topic of Type 1 Standard, or a luminaire pole, in addition to the Type 15 FBS standard. The table contains a link to the text of the research along with pertinent information about the source of the research information.

Table of Found Records:
Research Needs Statement (RNS)

Title	Date	Text	Org
RNS: Development of Methods to Evaluate side Impacts with Roadside Safety Features	9/7/2015	http://sp.design.transportation.org/Documents/TC%20Roadside%20Safety/TCRS%20Strategic%20Plan%202015%20-%20Chapter%204%20attachment%20-%20MASH.pdf	TRB-AFB20
RNS: A Practical Approach to Fixed Objects within the Clear Zone	9/7/2015	https://rns.trb.org/details/dproject.aspx?n=40334	TRB-AFB20
NCHRP 03-119: Application of MASH Test Criteria to Breakaway Sign and Luminaire Supports and Crashworthy Work-Zone Traffic Control Devices	September 2015	https://www.mytrb.org/CommitteeDetails.aspx?CMTID=4339	TRB-NCHRP
NCHRP Report 796: New Specifications for Luminaires	2014	http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_796.pdf	TRB
RNS: Assessment of Luminaires to MASH	8/6/2013	https://rns.trb.org/details/dproject.aspx?n=34921	TRB
AASHTO Roadside Design Guide 4th Edition	6/26/2012	http://www.roadsystems.com/pdf/faq/FHWA-FAQ-Memo-June2012.pdf	FHWA
Sapa crash test	5/17/2012	http://www.sapagroup.com/en/sapa-pole-products/newswall/2012/sapa-crash-test-a-smashing-success/sapa-crash-test-a-smashing-success	Sapa
Passively Safe Traffic Signal Installations	March 2012	Passively Safe Traffic Signal Installations	TRB
Base Connections for Signal/Sign Structures	February 2012	Base Connections for Signal/Sign Structures	TRB
Signs and Light Standard Foundation Design when Installed on 2:1 or Flatter Slopes	February 2012	http://www.roadsidepooledfund.org/files/2012/02/TM-405160-22-rev3-web.pdf	TTI & Roadside Safety Pooled Fund

Title	Date	Text	Org
FHWA Acceptance letters (no MASH tested items in the listing)	6/30/2011	http://safety.fhwa.dot.gov/roadway_dept/policy_guide/road_hardware/listing.cfm?code=lumin	FHWA
Frangible post system available in range of sizes	June 2010	http://trid.trb.org/view/2010/C/1151019	TRB
NCHRP Web-Only Document 157; Vol. 1: Evaluation of Existing Roadside Safety Hardware Using Updated Criteria	March 2010	http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_w157.pdf	TRB
The Use of Passively Safe Signposts and Lighting Columns	2008	css-s14-passive-safety.pdf	TRL
Vehicle Crash Test against a Lighting Pole: Experimental Analysis and Numerical Simulation	2007	http://trid.trb.org/view/2007/C/814514	TRB
Analysis of Sign Attachments to Breakaway Luminaire Supports	October 2002	http://mwrsf.unl.edu/researchhub/files/Report256/TRP-03-122-02.pdf	MwRSF
Lighting Columns-European		http://jerol.se/en/produkter-cat/lighting-columns/	
ROSA-Passive Safety		http://rosa.pl/en/Knowledge_base/Bezpieczenstwo_bierne	
FHWA FAQ		FHWA FAQs.docx	FHWA
TRID research summary		TRIDDOC_1-11-2016.docx	TRB
FHWA Dynamic Evaluation of the New FOIL Instrumented Rigid Pole	1999	http://www.fhwa.dot.gov/publications/research/safety/99026/	FHWA
TRR 1647 Side-Impact Crash Test and Evaluation Criteria for Roadside Safety Hardware	1998	http://trrjournalonline.trb.org/doi/pdf/10.3141/1647-12	TRB
FHWA Instrumented Rigid Pole tests	Spring 1996	https://www.fhwa.dot.gov/publications/research/safety/99026/index.cfm	FHWA
Results of a full-scale crash test into an energy absorbing lighting pole on a sloped roadside		https://www.researchgate.net/publication/27469627_Results_of_a_full-scale_crash_test_into_an_energy_absorbing_lighting_pole_on_a_sloped_roadside	Queensland Dept. of Main Roads
Vehicle Impact Testing of Lightweight Lighting Standards	1989	http://trid.trb.org/view.aspx?id=308824	TRB
Laboratory Procedures to Determine the Breakaway Behavior of Luminaire supports in Mini-Sized Vehicle Collisions	December 1981	Surrogate Luminaire Support Validation Test Results Report Test Number 1469-1A81 http://trid.trb.org/view.aspx?id=280971	FHWA
Full-scale crash tests of luminaire supports	1972	http://trid.trb.org/view.aspx?id=103170	TRB
On-Line Guide to Luminaire Support		http://guides.roadsafellc.com/luminaireGuide/index.php?action=browse-general	

State DOT Research and Guidance

Table of Found Records:

Title	Date	Text	Org
Crashworthiness and Protection of ITS Field Devices	March 2014	http://enterprise.prog.org/Projects/2010_Present/crashworthy/Crashworthiness_Protection_ITS_Devices_Final_Rpt_March2014.pdf	TPF-5(231)
Update to a Guide to Standardized Highway Lighting Pole Hardware	March 2013	http://www.dot.state.wy.us/files/live/sites/wydot/files/shared/Planning/Research/TPF5002_1302F.pdf	WyDOT & TPF, FHWA
Evaluation of Valmont Industries' Decorative Clamshell Basses on Luminaire Poles	August 2010	http://mwrsf.unl.edu/reportresult.php?reportId=51&search-textbox=luminaire	MwRSF
Performance Evaluation of Brass Breakaway Couplings-A Midwest States Regional Pooled Fund Program study	2009-2010	http://ne-ltap.unl.edu/Documents/NDOR/eval_of_breakway_couplings.pdf	MwRSF
Dynamic Evaluation of New York State's Aluminum Pedestrian Signal Pole System	December 2009	https://www.dot.ny.gov/divisions/engineering/technical-services/trans-r-and-d-repository/TRP-03-223-09.pdf	NYDOT & MwRSF
Crash Testing of Various Roadside Hardware	December 2006	http://www.dot.ca.gov/newtech/researchreports/reports/2006/crash_testing_various_roadside_hardware.pdf	Caltrans
Investigation of Breakaway Light Standards	April 2006	https://www.michigan.gov/documents/mdot/MDOT_Research_Report_R1474_200946_7.pdf	MDOT
Safety Evaluation of Traffic Control Devices and Breakaway Supports	2003	http://d2dtl5nnlpfr0r.cloudfront.net/tti.tamu.edu/documents/1792-S.pdf	TTI
Testing and Evaluation of a Pedestal Base Sign Support	2001	http://d2dtl5nnlpfr0r.cloudfront.net/tti.tamu.edu/documents/1792-3.pdf	TTI
Testing and Evaluation of the Solar Panel Sign Support System	2001	http://d2dtl5nnlpfr0r.cloudfront.net/tti.tamu.edu/documents/1792-4.pdf	TTI
Test and Evaluation of Arizona Slip-Away Base Luminaire Supports	November 1994	http://d2dtl5nnlpfr0r.cloudfront.net/tti.tamu.edu/documents/472360-1F.pdf	TTI
Nevada DOT "Captive Column" Crash Test-Light Standard Luminaire Pole	1981	http://trid.trb.org/view.aspx?id=169345	TRID
Supplementary Studies in Highway Illumination	1969	http://d2dtl5nnlpfr0r.cloudfront.net/tti.tamu.edu/documents/75-13F.pdf	TTI
Fatigue Analysis of the Cast Aluminum Base	1968	http://d2dtl5nnlpfr0r.cloudfront.net/tti.tamu.edu/documents/75-11.pdf	TTI
Multi-Directional Slip Base for Breakaway Luminaire Supports	1967	http://d2dtl5nnlpfr0r.cloudfront.net/tti.tamu.edu/documents/75-10.pdf	TTI
Impact Behavior of Luminaire Supports	1967	http://d2dtl5nnlpfr0r.cloudfront.net/tti.tamu.edu/documents/75-8.pdf	TTI