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16. Abstract

On November 23, 2004, a breakaway light standard located in the clear zone of southbound US-131, near eastbound I-96, north of Grand Rapids, fell onto southbound US-131 traffic lanes under high winds, striking a vehicle. The incident prompted an investigation into breakaway light standards on MDOT trunklines.

Statewide, 2,649 breakaway light standards were inspected. From the inspection reports, it was determined that overall, 61 percent of breakaway light standards statewide were in good condition, requiring no corrective action. Those breakaway light standards needing corrective action numbered 36 percent. Only 3 percent statewide required immediate action for removal, including 15 steel screw-in foundations. With proper maintenance, a typical breakaway light standard correctly installed on a concrete foundation can remain in service for at least 50 years, based on the design wind speed recurrence interval (MDOT Subsection 918.08). Continued inspection will provide the margin of safety desired by the department, and assure the public that incidents of the type that occurred on November 23, 2004, will not be repeated.

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Investigation of Breakaway Light Standards

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Testing and Research Section
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TABLE OF CONTENTS

LIST OF FIGURES

EXECUTIVE SUMMARY

At approximately 1 pm on November 23, 2004, a breakaway light standard located in the clear zone of southbound US-131, near eastbound I-96, north of Grand Rapids, fell onto southbound US-131 traffic lanes under high winds, striking a vehicle. State police responded to the scene and contacted the Michigan Department of Transportation (MDOT). The state police reported the accident, and indicated that the two individuals in the vehicle were injured. The breakaway light standard was removed from the traffic lanes and transported to the Kent County maintenance facility.

On December 9, 2004, a meeting was held at the MDOT Construction and Technology support area to discuss immediate actions and follow up inspections. Design division estimated the total MDOT inventory of about 8,000 light standards statewide, including breakaway light standards. Of those, approximately 4,600 were prioritized for inspection, representing the best engineering opinion for investigation. Due to the number of light standards and the necessity for immediate action, the breakaway light standards were prioritized for the first inspection wave.

As a result of the December 9, 2004 meeting, a moratorium on steel screw-in foundations was issued as an instructional memorandum (IM). A qualified products list (QPL), along with a qualification procedure and special provision, were developed for the breakaway transformer base.

Statewide, 2,649 breakaway light standards were inspected. The North region did not have any breakaway light standards. From the inspection reports, it was determined that overall, 61 percent of breakaway light standards statewide were in good condition, requiring no corrective action. Those breakaway light standards needing corrective action numbered 36 percent. Only 3 percent statewide required immediate action for removal, including 15 steel screw-in foundations.

Investigation into the breakaway light standard collapse on southbound US-131 revealed the following probable cause of failure. The slots to accommodate variable bolt circle sizes on the steel screw-in foundation allowed movement of the anchor bolts. The improper installation of a non-approved Union Metal A2852 breakaway transformer base, by not using the required anchor clips, resulted in minimal washer contact to the breakaway transformer base tabs. The sloped tab surface promoted freedom of movement from wind force and loosening of the foundation to breakaway transformer base connections on all but one bolt. Wind force was then sufficient to overcome the resistive force of one bolt connection and break the tab. As the wind that day was gusting from the west-southwest, blowing into oncoming traffic on southbound US-131, and the arm (weighing 100 lbs) was cantilevered out towards the roadway, the breakaway light standard collapsed in the general direction of the wind and roadway.

With proper maintenance, a typical breakaway light standard correctly installed on a concrete foundation can remain in service for at least 50 years, based on the design wind speed recurrence interval (MDOT Subsection 918.08). Continued inspection will provide the margin of safety desired by the department, and assure the public that incidents of the type that occurred on November 23, 2004, will not be repeated.

BACKGROUND

At approximately 1 pm on November 23, 2004, a breakaway light standard located in the clear zone of southbound US-131, near eastbound I-96, north of Grand Rapids, fell onto southbound US-131 traffic lanes under high winds, striking a vehicle. State police responded to the scene and contacted the Michigan Department of Transportation (MDOT). The state police reported the accident, and indicated that the two individuals in the vehicle were injured. The breakaway light standard was removed from the traffic lanes and transported to the Kent County maintenance facility.

Breakaway light standard inspections

Between the period of November 24, 2004 and December 9, 2004, MDOT staff began investigating the cause of the failure and inspected other breakaway light standards along the US-131 highway corridor in the immediate 5-mile vicinity of the toppled breakaway light standard. Breakaway light standards are composed of a pole, arm, breakaway transformer base, and foundation. A breakaway transformer base is made of cast aluminum, and has tabs on the bottom for mounting to the foundation, and on the top for installation of the pole. The breakaway light standard that fell was bolted to a steel screw-in foundation (a steel auger-type casing with a base plate attached to the top). It was noted that the breakaway transformer base was relatively intact except for a broken tab on the lower right corner and a scratch on one face. See Figure 1. This photograph was taken after the breakaway light standard was moved to the shoulder area.

Figure 1. Toppled breakaway light standard that struck traffic

Another steel screw-in foundation was located along the same corridor. It appeared intact, with large wedge shaped anchor clips used to secure the breakaway transformer base to the foundation. See Figure 2. Note the presence of a lock washer under the nut, on top of the wedge anchor clip.

Figure 2. Steel screw-in foundation in the vicinity along US-131

The foundations on other breakaway light standards in the immediate vicinity on US-131 were of the concrete cast-in-place type. Other breakaway light standards in the area were noted to be in varied condition, and one appeared to have been struck by a vehicle recently. The anchor bolts for the fallen breakaway light standard were still attached to the steel base plate, and were able to slide along the slotted opening, except for the one corner bolt that retained the broken breakaway transformer piece (wedged under the washer). See Figure 3.

Figure 3. Steel screw-in foundation is shown on left and a close up of the broken breakaway transformer base tab on the right. Note the slot openings in the base plate of the steel screw-in foundation.

The cast aluminum breakaway transformer base is designed to break away when struck by a vehicle, for safety considerations. This type of breakaway transformer base is used on breakaway light standards that are within the clear zone, otherwise guardrail or crash cushions are used to shield the light standards from errant vehicles. MDOT standard plan for the breakaway light standard is shown in Figure 4.

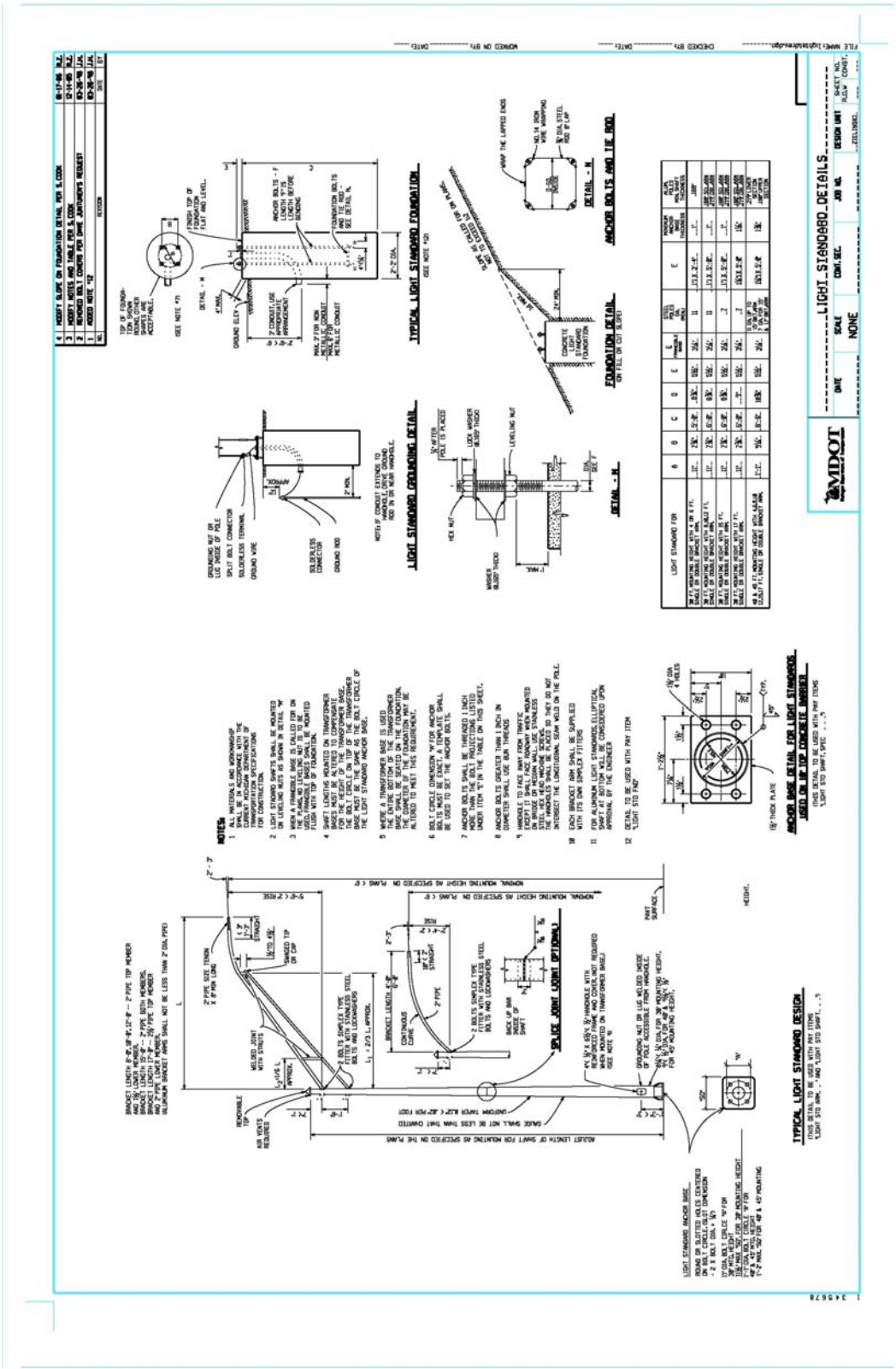

Figure 4. Typical design details for light standards, including breakaway transformer base.

The contract agency responsible for maintenance and repair of the US-131 corridor in that area is the Grand Rapids Public Works department (GRPW). Review of previous accident reports showed that a vehicle struck the breakaway light standard on April 30, 2002. On May 17, 2002, GRPW installed a new foundation using a 7-ft long, 10-in diameter, single helix, steel screw-in foundation because the existing concrete foundation was damaged. The steel screw-in foundation used was manufactured by Aluma-Form of Memphis, TN. GRPW used the salvaged pole and arm, but replaced the lamp and breakaway transformer base. Patrick Bush, the director of GRPW, stated that "all of the proper materials were used and it was correctly installed" (WZZM TV-13 news article, 12/7/04).

Contract documents for the original installation along US-131 in 1975 (CS 41131, JN 05498A) indicate that the breakaway light standard is intended to be mounted onto a concrete foundation. Currently, the MDOT 2003 standard specifications for construction, subsection 819.03.E, Light Standard Foundation, do not contain language prohibiting the use of steel screw-in foundations. Further, in subsection 819.03.F, it states that light standards "…may be installed on new foundations, bridges …frangible transformer bases, or other structures". The MDOT Maintenance guide (Activity # 13500) for freeway lighting states "Replace aluminum or concrete bases by either mixing and pouring bases or exchanging aluminum base with new one". At the time of the retrofit installation, mounting a breakaway light standard onto other than concrete foundation was not explicitly prohibited.

On December 9, 2004, a meeting was held at the MDOT Construction and Technology support area to discuss immediate actions and follow up inspections. Design division estimated the total MDOT inventory of about 8,000 light standards statewide, including breakaway light standards. Of those, approximately 4,600 were prioritized for inspection, representing the best engineering opinion for investigation. Due to the number of light standards and the necessity for immediate action, the breakaway light standards were prioritized for the first inspection wave. The Deputy Metro Region engineer was present via phone conference, and had indicated that Metro Region would complete their review of breakaway light standards utilizing existing maintenance forces by the end of January 2005.

As a result of the December 9, 2004 meeting, a moratorium on steel screw-in foundations was issued as an instructional memorandum (IM). A qualified products list (QPL), along with a qualification procedure and special provision, were developed for the breakaway transformer base. The IM, with qualification procedure and special provision, is included in Appendix A.

A contract authorization was activated for inspection and minor repair of the statewide (all except Metro Region) inventory of breakaway light standards, which was to be completed by the end of December 2004. It was decided that any major deficiencies noted in the inspections would be handled under separate contract.

Statewide inspection results

The consultant, Non-Destructive Testing Group, Inc (NDT), was provided with an inspection procedure for breakaway light standards, along with standard report forms. The procedure and forms are included in Appendix B. The inspections began on December 15, 2004, and were completed for all Regions except Metro by December 29, 2004. The inspection teams

documented the type and condition of the breakaway light standard pole and arm, the foundation, the breakaway transformer base, connection details, and the anchor bolts. During the inspection, each breakaway light standard location was noted and global positioning system (GPS) coordinates were established to create a statewide inventory of breakaway light standards.

The inspection reports and photographs were individually reviewed, collated, and summary results entered into a spreadsheet by MDOT staff. Within the spreadsheet, separated by Region, each inspection report was further classified into action items, using a color code to identify areas of concern. See Table 1 for an excerpt from the Bay Region spreadsheet.

Table 1. Excerpt from inspection spreadsheet, Bay Region. Bolt circle diameter measurements not shown.

Group #	**Report #**	**Foundation Type**	**Lock Washers**		**Breakaway Transformer Base Condition**	**Light standard Condition**	**Leveling Nuts**	**Comments**
			Light standard/ Base	**Base/ Found.**				
1	60	Concrete	Yes	No	Cracked	Good	No	Replace top bolt assemblies
1	61	Concrete	Yes	No	Good	Good	Yes	None
1	62	Concrete	No	No	Good	Good	Yes	None
1	63	Concrete	No	No	Good	Good	Yes	None
1	64	Concrete	No	No	Good	Good	Yes	None
1	68	Concrete	Yes	No	Good	Dented	Yes	Tighten arm connection
1	117	Concrete	No	No	Good	Good	Yes	Two inch shims screwed onto anchor bolts
Color Key:		Immediate action			Corrective action			No action
		Damaged breakaway transformer base			Damaged breakaway light standard			

Statewide, 804 breakaway light standards were inspected in the initial contract authorization. Metro Region breakaway light standards were added to the consultant contract in mid-December 2004, as the Deputy Region engineer, after further evaluation, indicated that they could not perform the required inspections in the necessary timeframe. This brought the total contracted inspections of breakaway light standards statewide to 2,649. The North region did not have any breakaway light standards. From the inspection reports, it was determined that overall, 61 percent of breakaway light standards statewide were in good condition, requiring no corrective action. Those breakaway light standards needing corrective action numbered 36 percent. Only 3 percent statewide required immediate action for removal, including 15 steel screw-in foundations. See Table 2 for a summary.

Table 2. Summary of statewide inspections of breakaway light standards.

Statewide totals by Region	Bay	Grand	Metro	North	South-west	Superior	University	**Totals**
Number of breakaway light standards inspected	367	285	1832	0	12	4	149	**2649**
Number of Steel Foundations	9	5	0	0	0	0	1	**15**
Number of breakaway transformer bases with minor defects not requiring corrective action[1]	20	14	23	0	0	0	2	**59**
Number of breakaway light standards with minor defects not requiring corrective action[2]	21	13	29	0	0	0	0	**63**
Number of Foundation Type Undetermined[3]	0	0	27	0	0	4	0	**31**
Number of structures scheduled for removal (includes steel foundations)	62	8	0	0	0	0	1	**71**
Number of structures with corrective action to be taken by Regions[4]	105	81	748	0	11	4	5	**954**

[1,2]Defects in breakaway transformer bases and light standards not requiring corrective action include small dents and holes, and missing lock washers. [3]Inspectors were unable to determine the type of foundation due to the foundation being buried in frozen soil. [4]Structures with corrective action to be taken by Regions include defects such as dents and holes, and missing or improperly installed nuts and washers that necessitate repair or installation.

Once the inspections were completed, the next step was to determine the breakaway light standards that required corrective action or removal by MDOT maintenance forces. Due to the need for timely action, removal was first priority, with replacement of the breakaway light standards taken down and corrective action scheduled for a future date. Each effected Region's maintenance forces removed the breakaway light standards specified in the inspection reports (summarized in Table 2 as structures scheduled for removal). For systematic replacement of breakaway light standards, a new template "Replacement of existing freeway lighting" was created. Replacement will be included in new projects as selected annually by the Regions. A timetable will be established and funding sources identified for Region maintenance forces to perform corrective action as noted in the report.

The apparent discrepancy between the estimated number of breakaway light standards (4,600 estimated at the December 9, 2004 meeting) and the actual number (2,649 inspected) is due to the lack of information on existing inventory at the time.

The most common types of defects found are summarized in Table 3. These items will be scheduled for corrective action by the Regions or by contract repair authorization. The criteria for repairing the defects are summarized in Table 4.

Table 3. Summary of defect type by region.

Defect type	Frequency							Percentage of breakaway light standards inspected
	Bay	Grand	Metro	North	SW	Superior	University	
Access panel door broken or missing	23	39	513	0	2	0	1	21.7%
Dig out and regrade foreslope	0	0	11	0	0	4	0	0.6%
Light standard knocked down by vehicle	0	0	17	0	0	0	0	0.6%
Loose, improper or missing connections (arm, washer, nut, etc)	13	0	21	0	0	0	0	1.3%
Place on new foundation	16	3	142	0	0	0	0	6.1%
Remove leveling nuts and lower structure	16	3	0	0	0	0	1	0.8%
Replace breakaway base	15	14	33	0	0	0	2	2.4%
Replace top bolt assemblies	22	22	11	0	11	0	1	2.5%
Total of corrective action items*	105	81	748	0	13	4	5	36.1%

*This represents the total number of defects; as some structures may have more than one defect, the column totals may not match those listed in Table 2.

Table 4. Summary of defect action criteria

Defect Type	Cause for corrective action
Access panel door broken or missing	Replacement of access panel is required to prevent access to electrical lines and to minimize environmental exposure.
Dig out and regrade foreslope	Removing soil around foundation minimizes exposure to harsh soil conditions, and allows proper inspection.
Light standard knocked down by vehicle	Replacement of the breakaway light standard is required to maintain effective lighting.
Loose, improper or missing connections (arm, washer, nut, etc)	Proper connections are required for the breakaway light standard to achieve full design capacity.
Place on new foundation	The original foundation is damaged, improperly sized, or irregular.
Remove leveling nuts and lower structure	Breakaway performance of the transformer base is dependant on mounting the transformer base flush to the concrete foundation.
Replace breakaway base	The breakaway transformer base is damaged from impact and remains in service, but for safety reasons must be replaced.
Replace top bolt assemblies	The bolt assemblies connecting the breakaway transformer base to the pole are damaged or incomplete. Proper connections are required for the breakaway light standard to achieve full design capacity.

Some examples of common defects found during the inspections are shown in Figure 5 through Figure 12.

Figure 5. Missing access door.

Figure 6. Dig out and regrade slope.

Figure 7. Breakaway light standard struck by vehicle.

Figure 8. Incomplete nut engagement to the anchor bolt.

Figure 9. Stacked washers and incomplete nut engagement to the anchor bolt.

Figure 10. Replacement of top bolt assembly required due to missing washers.

Figure 11. Damaged breakaway transformer base.

Figure 12. Place on new foundation.

FALLEN LIGHT STANDARD INVESTIGATION

While breakaway light standards needing removal were identified as the inspection reports came in weekly, and the remaining action items sorted by priority, a concurrent task in the investigation of the breakaway light standard collapse on US-131 involved examination of the steel screw-in foundation and the breakaway transformer base. The purpose was to determine whether the breakaway light standard retrofit in 2002 was with hardware approved by the Federal Highway Administration (FHWA). The Union Metal A2852 breakaway transformer base was identified by the logo and die stamp APA 2852 on the base. See Figures 13 and 14.

Figure 15. Die stamp APA 2852. The 52 is not legible due to die stamp imperfection.

A subsequent search in the FHWA database for approved breakaway transformer bases was conducted, both for the base on US-131, and others installed throughout the state (http://safety.fhwa.dot.gov/roadway_dept/road_hardware/lumsupports.htm). The FHWA approval letter for the Union Metal A2852 breakaway transformer base was located by requesting hard copies of letters between 1976 and 1987. The letter, included as Appendix C, stated that the A2852 breakaway transformer base met the breakaway requirements of the 1975 American Association of State Highway and Transportation Officials (AASHTO) *"Standard Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals,"* provided that the light standard assembly weight was less than 1,000 lbs, luminaire mounting height was less than 50 ft, and the base was installed with cast iron, hot dipped galvanized anchor clips as specified in the shop drawings. Acceptance letters pertaining to other manufacturers' hardware were also reviewed from the above website.

On January 21, 2005, the steel screw-in foundation (7-ft long, 10-in diameter, single helix) at the fallen breakaway light standard location on southbound US-131 was removed and salvaged by MDOT personnel. The soil subsidence around the foundation was measured, as well as soil samples taken at 1 ft depth intervals at foundation location and at 3 ft distance away from the steel screw-in foundation. The purpose was to verify the installation method of the steel screw-in foundation, whether torque and thrust or preboring was used. Torque and thrust method uses the steel screw-in foundation as an auger to drill into the ground, and the steel screw-in foundation is left in place. Preboring involves simply drilling an oversized hole, placing the foundation, and backfilling. The torque and thrust installation is required by the manufacturer to

develop full structural capacity through interaction between the soil and the steel screw-in foundation. Local soil conditions, however, determine the ultimate capacity.

The ground immediately around the steel screw-in foundation measured 12 in below the top of the steel plate, and 1.5 ft away the ground measured 5 in below the top of plate. The difference in elevation of 7 in indicated some subsidence or possibly soil erosion around the foundation, as it was located on the fore slope. The interior of the steel shaft was observed to have soil present at an average depth of 43 in as measured from the top, indicating torque and thrust installation. Water was present inside the shaft at the auger. The ground was frozen 5 to 6 in up from the shaft end. No voids in the soil around the steel shaft were observed during removal operations, and helical marks were present in the soil (arrow) indicating rotation of the auger. These factors indicate torque and thrust was used for installation of the steel screw-in foundation. See Figure 16.

Figure 16. Steel screw-in foundation removal. The picture on the right is a close-up of the inset rectangle in the left photo.

SAFETY AND PERFORMANCE CRITERIA

The AASHTO *"Standard Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals,"* is the design code reference used by MDOT for roadside hardware. The 1975 AASHTO code specified a 2,230 lb passenger car as the design vehicle, and the evaluation criteria was defined as a maximum 1,100 pound-seconds of momentum change for the passenger. The 1985 AASHTO specifications reference the National Cooperative Highway Research Program (NCHRP) Report 230 for crash test parameters (vehicle size, weight, speed, angle of impact), and acceptance criteria. Safety performance was measured using three categories: structural adequacy (as related to vehicle collisions), occupant risk, and vehicle trajectory after collision. Adequate performance for the occupant risk category, for example, requires that the support may not cause a vehicle velocity change in excess of 15 ft/s after impact (Report 230, Table 8).

From 1981 to 1993 the FHWA utilized Report 230 for crash testing criteria and acceptance. However, Report 230 was never formally recognized by the agency. The NCHRP Report 350, published in May 1993, was formally adopted by the FHWA on July 16, 1993. In Report 350, the primary difference from the older Report 230 is that the key criterion, maximum change in velocity, was set to a less stringent 16.4 ft/s (5.0 m/s), and the use of 'standard' soil (equivalent to Report 230 'strong' soil). Further, the acceptance of hardware is more reliant on crash testing for specific circumstances and 'standard' soil conditions. For a given safety feature, there are multiple test levels, each of which has its own set of impact conditions. For example, there are six test levels defined for longitudinal barriers. The impact conditions for these different test levels vary in impact speed from 22 mph to 62 mph (35 km/h to 100 km/h) and in vehicle type from an 1,800 lb (820 kg) passenger car to an 80,000 lb (36,000 kg) tractor trailer unit. Report 350 was published in S.I. (metric) units.

For breakaway structural supports, the basic test level (TL-3) impact conditions use a 1,800 lb (820 kg) passenger car impacting at 22 mph (35 km/h) and an angle of 0 to 20 degrees. The 4,400 lb (2,000 kg) pickup truck test vehicle is optional, depending on structural support geometry. The 1,800 lb (820 kg) passenger car test is used to evaluate the occupant risk. For some types of breakaway supports, the FHWA will accept pendulum testing and the use of the test results to calculate an estimate of high speed breakaway performance. In any case, after October 1, 1998, FHWA required all new hardware installed to be crashworthy to Report 350. When FHWA adopted this standard, it allowed the maximum velocity change to be 16 ft/s (FHWA Policy Memorandum HNG-14, included as Appendix D). However, breakaway hardware meeting earlier criteria (AASHTO 1985 or NCHRP Report 230) does not have to be requalified. The breakaway transformer base used on the US-131 retrofit in May 2002, although certified as meeting AASHTO 1975 criteria, was not requalified to the AASHTO 1985 or NCHRP Report 230, or the current NCHRP Report 350 requirements, and therefore should not have been used.

DISCUSSION

The Union Metal A2852 breakaway transformer base from the fallen breakaway light standard on southbound US-131 was examined visually for signs of premature wear or other defects. No unusual wear or damage was found, other than that resulting from the disengagement from the foundation (broken tab and a scratch on the exterior face). The scratch was bright in appearance, indicating recent placement, presumably from the collapse. It was noted that three of the four breakaway transformer base tabs were intact, indicating that the breakaway transformer base had disengaged from the anchor bolts at those locations. The reason for the disengagement of the breakaway transformer base from the steel screw-in foundation mounting nuts may be explained by the following.

A close look at the breakaway transformer base to steel screw-in foundation connection detail reveals that available contact area is reduced by the recessed tab design (Figure 17). The FHWA acceptance letter states that "these pole assemblies must …be secured to the anchor bolts with cast iron, hot dipped galvanized anchor clips, as depicted on Union Metal drawing P02-G94 dated February 8, 1978." Instead of anchor clips, round washers were used to install the A2852 breakaway transformer base. The washer contact area available for each tab is therefore a half annulus of 0.3125 in width (1.0625-0.750 in), resulting in a total contact area of 0.22 in^2, and on a 6° slope. The section under the washer is reduced in thickness to 0.250 in, decreasing the ultimate static load resistance of the breakaway transformer base.

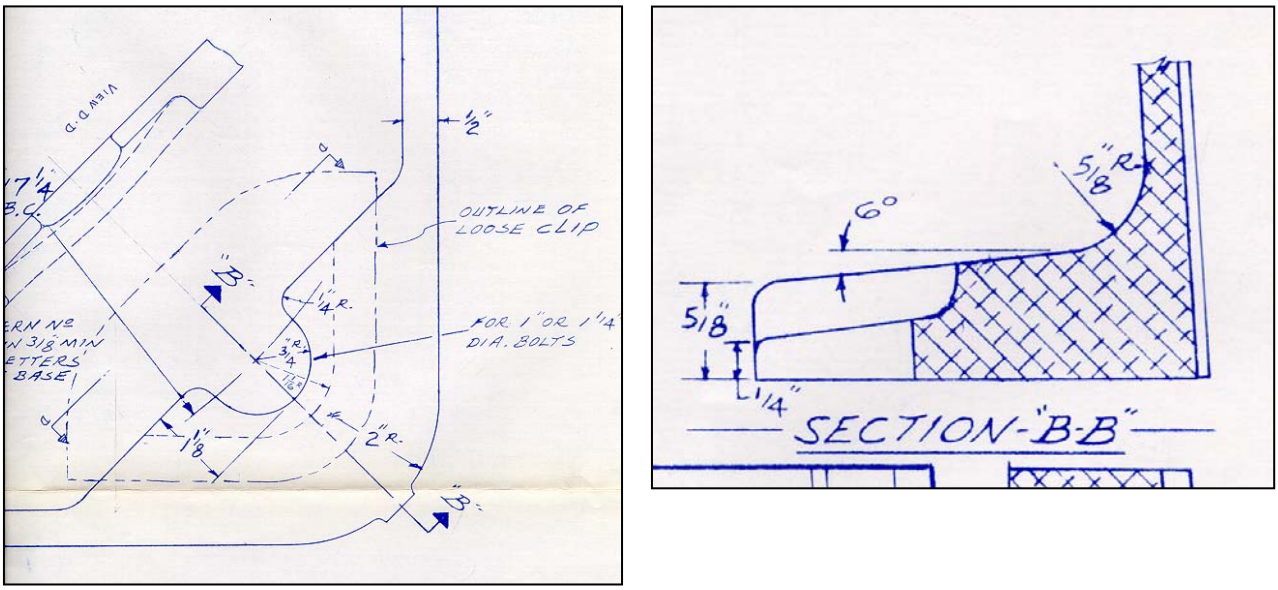

Figure 17. Shop drawing of A2852 breakaway transformer base, showing bottom tab and outline of the loose clip required for installation. The picture on the right shows cross section of the base plate tab. Note the 6 ° taper and recessed area for the nut in section B-B.

The steel screw-in foundation was examined visually. The steel screw-in foundation consists of a 7-ft long, 10-in diameter, ¼ in thick steel tube with a single helix auger tip, and the top surface is a 17½ in x 17½ in x 1½ in thick steel base plate. The predominant characteristic noted on the base plate itself was the existence of slotted holes to accommodate variation in bolt circle sizes.

The ASTM A325, 1½ in diameter, 7-in length anchor bolts are mounted from the bottom of the steel plate and secured by the mounting nut for the breakaway transformer base. See Figure 18.

Figure 18. Steel screw-in foundation. Note the open slots used to accommodate variable bolt circle sizes.

When the breakaway transformer base is mounted to the steel screw-in foundation, and prior to tightening the mounting nuts, the anchor bolt assembly is free to move along the gap in the slot from the breakaway transformer base tab to the outside edge of the steel screw-in foundation tube. When assembled, the washer contacts only a portion of the breakaway transformer base tab, a ½ in gap is present along the steel screw-in foundation slot, and the washer is sloped greater than 6 ° (presence of gap between washer and lock washer). See Figure 19.

Figure 19. Reassembled Union Metal A2852 breakaway transformer base and Aluma-Form steel screw-in foundation assembly.

When the breakaway light standard is subject to wind loading and vortex shedding (resonant oscillations of the breakaway light standard in a plane normal to the direction of wind flow), movement could occur over time to work the anchor bolt washers loose, given the 6° angle, minimal engagement of the breakaway transformer base tabs, and existence of open slots on the steel screw-in foundation plate (for the variable bolt circle sizes). The remaining three intact tabs

on the breakaway transformer base indicate disengagement from the anchor bolts occurred at some point prior to the collapse.

TESTING AND QUALIFICATION

A 4 ft x 4 ft x 1 ft non-reinforced concrete block was used for installing galvanized threaded anchor rods (1 in and 1¼ in diameter), for the standard MDOT bolt circle sizes of 11 in and 13 in. See Figure 20. The blocks were previously used for adhesive anchor system testing, as evident in the background. After certification that the product is approved for use on the NHS, and meeting specific MDOT criteria, the breakaway transformer base is tested for proper fit and sufficient tab projection beyond the nut. The base is mounted on the anchor rods, fastened using washer and lock washers, and tightened to the specified torque according to the manufacturer's instructions. In addition, the base is mounted on 10° shims and fully tightened to check effects of foundation elevation variation.

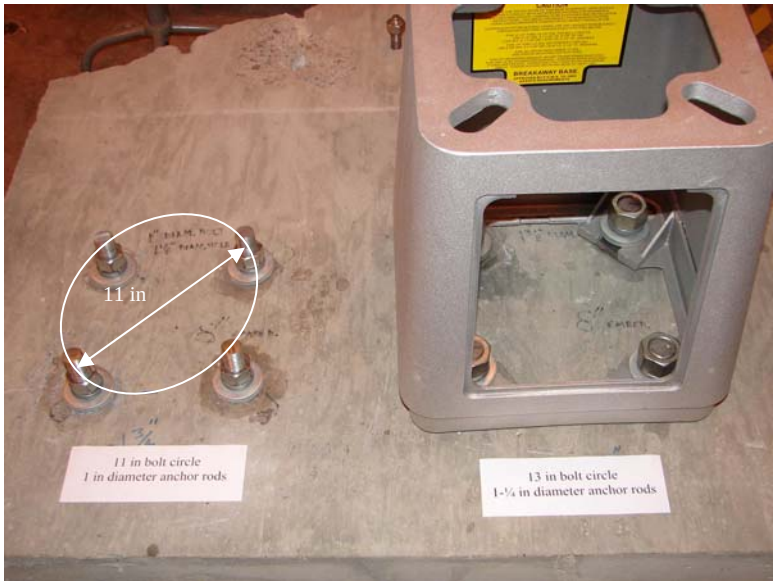

Figure 20. Test setup for evaluation of transformer base per the qualification procedure.

After the qualification procedure was established, suppliers were contacted in March 2005 to submit the required information for the newly created Qualified Products List (QPL). As of November 2005, only one supplier has submitted the required information for evaluation. The supplier, Akron Foundry Inc., of Akron, Ohio, sent four aluminum breakaway transformer bases for evaluation. One base was evaluated for use in retrofitting existing installations with larger bolt circles (15 to 17 in). All four bases were found acceptable and added to the QPL (subsection 918.08C), available online at http://www.michigan.gov/documents/MDOT-Material_Source_Guide_Qualified_Products_84764_7.pdf.

CONCLUSIONS

Investigation into the breakaway light standard collapse on southbound US-131 revealed the following probable cause of failure. The slots to accommodate variable bolt circle sizes on the steel screw-in foundation allowed movement of the anchor bolts. The improper installation of a non-approved Union Metal A2852 breakaway transformer base, by not using the required anchor clips, resulted in minimal washer contact to the breakaway transformer base tabs. The sloped tab surface promoted freedom of movement from wind force and loosening of the foundation to breakaway transformer base connections on all but one bolt. Wind force was then sufficient to overcome the resistive force of one bolt connection and break the tab. As the wind that day was gusting from the west-southwest, blowing into oncoming traffic on southbound US-131, and the arm (weighing 100 lbs) was cantilevered out towards the roadway, the breakaway light standard collapsed in the general direction of the wind and roadway.

Inspection reports compiled on all breakaway light standards indicate only 15 steel screw-in foundations were used statewide, or 0.6 percent. All of these breakaway light standards were removed, as well as 56 others, representing 3 percent of the statewide total. The new inspection procedure and QPL for the breakaway transformer base will ensure that proper installation is completed for new construction and retrofit installations. Approved breakaway transformer bases have connection details to maximize the foundation contact area. Further, a statewide database complete with GPS coordinates to track each single breakaway light standard ensures a known inventory and log of corrective actions taken. Statewide inspection of breakaway light standards will occur every four years. As a result, the likelihood of another breakaway light standard collapse due to improper installation is effectively minimized.

The following action items developed as a result of the investigation into breakaway light standards:

1. Statewide inspection of breakaway light standards every four years;
2. A new template “Replacement of existing freeway lighting” was created for systematic replacement of light standards, including breakaway light standards. Replacement will be included in new projects as selected annually by the Regions;
3. Establish timetable and identify funding sources for Region maintenance forces to perform corrective action as noted in the report;
4. Creation and maintenance of a qualified products list for breakaway transformer bases;
5. Inspection of new and retrofit installations of breakaway light standards for compliance with the special provision;
6. Prohibition of steel screw-in foundations.

With proper maintenance, a typical breakaway light standard correctly installed on a concrete foundation can remain in service for at least 50 years, based on the design wind speed recurrence interval (MDOT Subsection 918.08). Continued inspection will provide the margin of safety desired by the department, and assure the public that incidents of the type that occurred on November 23, 2004, will not be repeated.

REFERENCES

1. Dawson, P. (2004). *City Says Light Pole Installed Correctly*. Available: http://www.wzzm13.com/news/grmetro_article.aspx?storyid=34003 . Last accessed April 2006.

2. Michie, J. D., NCHRP Report 230 - *Recommended Procedures for the Safety Performance Evaluation of Highway Safety Appurtenances,* 1981, Transportation Research Board, 2101 Constitution Ave, N.W., Washington, D.C., 20418.

3. Ross, H. E., et al., NCHRP Report 350 - *Recommended Procedures for the Safety Performance Evaluation of Highway Features,* 1993, Transportation Research Board, 2101 Constitution Ave, N.W., Washington, D.C., 20418.

4. American Association of State Highway and Transportation Officials (AASHTO), *"Standard Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals,"* 2001, 4th edition, Washington, D.C., 20418.

5. Steinke, D. (1997). FHWA Office of Engineering Policy Memorandum HNG-14. Available: http://safety.fhwa.dot.gov/roadway_dept/docs/accept.pdf . Last accessed April 2006.

Appendix A - MDOT Bureau of Highways Instructional Memorandum 2005-05

MDOT
Michigan Department of Transportation

OFFICE MEMORANDUM

DATE: April 22, 2005

TO: Region Engineers
Region Delivery Engineers
TSC Managers
Resident/Project Engineers
Region Construction Engineers

FROM: Larry E. Tibbits
Chief Operations Officer

John C. Friend
Engineer of Delivery

SUBJECT: Bureau of Highway Instructional Memorandum 2005-05
Frangible Light Standard Transformer Base

Recently, all frangible light standard transformer bases along state trunklines were inspected throughout the state. Based on the findings, the attached Special Provision for Frangible Light Standard Transformer Base is approved for use in projects advertised after March 1, 2005. After FHWA approval, the special provision will be added to the Frequently Used Special Provision lists with the following use statement, "Use on all projects with frangible light standard transformer bases."

In order for any frangible light standard transformer base to be used, it must be evaluated according to the attached Qualification Procedure for Frangible Light Standard Transformer Base Assembly and be listed in the Material Source Guide Qualified Product List. Suppliers of frangible light standard transformer bases must submit the required documentation immediately, as outlined in the qualification procedure.

Effective immediately, steel shaft foundations are not permitted for any light supports, including retrofitting installations.

If you have any questions, please contact the following Construction and Technology Support Area staff for assistance:

- Special Provision and Qualification Procedure — Steve Kahl 517-322-5707
- Qualified Products List and Materials Source Guide — Steve Purdy 517-322-5665

_____ _____

Chief Operations Officer Engineer of Delivery

BOHD:C/T:RDT:kab

Index: Sign and Lighting Standards

Attachments

cc: C & T Support Area Staff
M. DeLong
M. VanPortfleet
C. Roberts
J. Culp
B. O'Brien
S. El-Ahmad
C. Rademacher
P. Sebenick
G. Moore
K. Reincke
T. Fudaly, FHWA
MAPA
MCPA
MCA
MAA
MITA
CRAM
ACEC
MPA

MICHIGAN
DEPARTMENT OF TRANSPORTATION

SPECIAL PROVISION
FOR
FRANGIBLE LIGHT STANDARD TRANSFORMER BASE

a. Description. This special provision covers installation and material requirements for frangible light standard transformer bases.

b. Materials. Use only frangible transformer bases from the MDOT Qualified Products List (QPL). The frangible transformer base must meet the requirements for breakaway supports listed in Section 12 of the 2001 American Association of State Highway and Transportation Officials (AASHTO) *"Standard Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals."* Furnish each base with four bolts, hex nuts, washers, and lock washers according to subsection 918.08.C of the Standard Specifications for Construction. Use foundation anchor bolts according to subsection 918.07.C, include lock washers. Galvanize bolts, nuts, washers, and lock washers according to subsection 908.15.B.

c. Construction. Install frangible transformer bases according to subsection 819.03, and the requirements herein. Install frangible transformer base on concrete foundations with a level top surface within a 1:480 slope. Steel shaft foundations are not permitted. Mount the frangible base directly on the concrete foundation and secure to the anchor bolts according to the frangible transformer base manufacturer's installation instructions. Use lock washers. Do not use leveling nuts. Mount the frangible transformer base to the concrete foundation so that the tabs project a minimum of ½ the anchor bolt diameter beyond the nut. Complete the anchor bolt installation and tightening according to subsections 810.03.N.1, 810.03.N.2.b, and 810.03.N.2.c.

Tighten bolts connecting the pole to the frangible base to a snug tight condition according to subsection 707.03.D.7. Use lock washers. Do not use bolt or nut covers.

Use a beveled washer to compensate for slope greater than 1:40 on surfaces of bolted parts in contact with the bolt head and nut according to subsection 810.03.N.2.c.

d. Disbursement. The Engineer shall withhold in reserve an amount equal to 40 percent of the total contract value for the following pay items: *Light Std, Frangible Transformer Base* and *Light Std Fdn*.

e. Inspection. After the Contractor has complied with the requirements as stated in this special provision, the Contractor shall notify the Engineer in writing requesting final inspection. The Engineer will have 21 calendar days from receipt of Contractor's written request to schedule and complete all inspections. The Engineer shall contact the Construction and Technology Division, Structural Fabrication Engineer at (517) 322-1235, to schedule and conduct the inspection. Inspections shall be according to subsections 707.03.D.7.c, 810.03.N.1, 810.03.N.2.b, 810.03.N.2.c, 819.03 and this special provision.

f. Reporting. The Structural Fabrication Engineer shall notify the Engineer within the 21 calendar day inspection period relative to acceptance or rejection of any items. Written inspection reports will be provided to the Engineer within the 21 calendar day inspection period.

Any rejectable items found shall be corrected according to subsections 707.03.D.7.c, 810.03.N.1, 810.03.N.2.b, 810.03.N.2.c, 819.03 and this special provision at the Contractor's expense.

g. Measurement and Payment. The payment to furnish all labor, materials, tools, equipment, and incidentals for installation shall be included in the pay item(s) *Light Std, Frangible Transformer Base* and *Light Std Fdn*.

No extension of time and/or additional compensation shall be granted to the Contractor for delays resulting from the Contractor's failure to notify the Engineer in writing of the need for inspection, or any delays associated with the specified 21 calendar day inspection period. Payment of the amounts held in reserve for the pay items listed above can only be made after the Engineer has received notification of acceptance of the items inspected from the Structural Fabrication Engineer.

Other contract items (pay items) in subsection 819.04 for light standard installation shall be paid for separately.

Qualification Procedure
For
Frangible Light Standard Transformer Base Assembly

1. Scope

1.1 This document covers the qualification procedure for Frangible Light Standard Transformer Base Assembly. It includes the procedures to be followed by manufacturers or suppliers in order to have their products included on MDOT's Qualified Products List (QPL).

1.2 MDOT reserves the right to randomly sample product from lots or jobsite as required to verify conformance.

2. Submittal Procedure

2.1 Submit a cover letter and a frangible light standard transformer base along with the required information listed in Section 2.2 for each product to the MDOT address listed below. The cover letter should state the name of the designated company contact person to whom inquiries may be made. Mail to:

Structures Unit, Experimental Studies Group
Construction & Technology Division
8885 Ricks Road
P.O. Box 30049
Lansing, Mi 48909

2.2 *Product Data Sheets* - Include product literature describing the product's use and other pertinent information such as manufacturer's name and address, model & lot number, dimensional sheets, hardware, material composition, and the following information:

2.2.1 Certification that the product is crash worthy to the requirements of NCHRP Report 350 Test Level 3, and meets the additional requirements of the American Association of State Highway and Transportation Officials (AASHTO) *"Standard Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals"* Section 12, Breakaway Supports.

2.2.2 Submit a copy of the FHWA approval letter for the product use on the National Highway System. Provide certification that the product

submitted has the same chemistry, mechanical properties, and geometry as the FHWA approved product.

2.2.3 Submit a copy of the test report by an independent facility of the dynamic performance (crash) test outlined in the standards in 2.2.1 above.

2.2.4 Provide clear instructions for installation, including base bolt size, anchor bolt size, washer configuration and material, distance base tabs project beyond the nut for the specified bolt circle, and nut tightening procedures. Lock washers must be included with the base bolts and anchor bolts.

2.2.5 Provide information on the design strength of the frangible light standard transformer base, including maximum pole mounting height and weight, and ability to carry the loads as specified in AASHTO *"Standard Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals"* Section 3, Loads.

3. Evaluation

3.1 **Certified to meet NCHRP Report 350 and AASHTO dynamic performance criteria.**

3.2 Frangible light standard transformer bases must conform to the dimensional tolerances given in the FHWA approved drawing submitted in section 2.2. The base tabs must project a minimum of ½ the anchor bolt diameter beyond the nut for the specified bolt circle. Base tabs must be able to withstand snug tightening with a lock washer and a 1:20 beveled washer in place without damage.

3.3 Completed submittals will be evaluated by MDOT throughout the year. The submitted information will be reviewed for conformance to the specified requirements. If the product meets the requirements, it will be included on the QPL. The submitter will be notified in writing concerning the results of the evaluation. MDOT reserves the right to verify submitted test information or re-evaluate a product at any time by conducting its own tests.

4. Disqualification

4.1 A product may be removed immediately from the QPL if any problems develop related to installation or performance. The submitter will be notified in writing of the effective date of product removal and the reasons for disqualification.

5. Requalification

5.1 A product which has been disqualified and removed from the QPL will be considered for re-evaluation only after submittal of a written request along with acceptable evidence that the problems causing the disqualification have been corrected. The requirements for qualification, as specified in this document, also apply for requalification of the product at the qualification period.

Appendix B - Inspection procedure and form for breakaway transformer base light standards

MICHIGAN DEPARTMENT OF TRANSPORTATION
CONSTRUCTION AND TECHNOLOGY SUPPORT AREA
PROCEDURE FOR THE INSPECTION OF
BREAKAWAY LIGHT STANDARDS

I. General Inspection Procedure

a. Description: This procedure describes the requirements for inspecting the structural elements of breakaway light standards.

b. Establish Structure Location: Location information should include Region name, county name, route number, control section, and description of the light standard location using global position system (GPS) coordinates, visible reference (intersections, buildings) to facilitate future inspections. Also, reference quadrant when facing north (at intersections) and stationing or mile markers if available.

c. General Light Standard Inspection: If the structure information is not on the inspection form, the following should be noted: record upright material (aluminum or steel), coating material (galvanized or painted), and upright diameter at the base. Measure and record as much additional data as possible (arm diameter, arm length, upright diameter taper, etc.). A 25 foot collapsible survey rod aids in obtaining many of the dimensions. A set of light standard detail sheets can be used to determine the dimensions that cannot be measured for the clamp type arm to upright connection. Use photographs as needed to supplement inspection data.

Visually inspect the condition of the structure's components. This may require the use of binoculars or other visual aids. The inspection shall include the arm to upright connection as well as the base to foundation connection. Note any unusual gaps between the connection flanges, loose or missing bolts, washers, lock washers, missing hardware, cracked welds, cracks in the clamps and clamp ends, miss alignment or sagging of the arm. Luminaries should be inspected to ensure they are secure to the arm. Note unsecured or missing access panel covers. Also, note any signs mounted on the upright or arm. Estimate size and mounting locations of these signs.

Check the vertical support for plumbness using a 4 foot level. Record any tilt as inches per length of level (i.e. 1 ½ inches in 4 feet), either towards the roadway or away from the roadway. Also, measure and record any longitudinal tilt (i.e. upright tilts 2 inches in 4 feet north or south).

PRIOR TO INSPECTION OF INTERIOR OF BREAKAWAY BASE REVIEW SAFETY REQUIRMENTS IN SECTION III b.

d. Inspection of Base: Using a permanent marker, mark the corresponding bolt numbers on the vertical support for future reference. For frangible bases (Breakaway) top nut & bolt shall be labeled T1-T4. The bottom anchor bolts shall be labeled B1-B4. Use the following bolt number sequence, begin with right back quadrant away from traffic, and face roadway numbering in a clockwise order. Nut covers or base plate covers (if any) are to be removed. Note removal of

the covers on the report. Do not replace nut covers or base plate covers on top of the breakaway base. Nut covers can typically be removed with either a socket wrench or screwdriver. Remove any accumulated debris under the covers prior to inspection.

e. Upright to breakaway base (bolts T1-T4): Measure and record the bolt diameter and the number of threads in one inch, along with the bolt circle diameter. Record the number, size, and type of washers present. Look for missing or damaged bolts or nuts (gouges, corrosion). Also, note any bolts that have been bent to align with holes in the base plate. Note any bolts that are lower than the top of the nut. If the bolt is lower, measure the depth and mark it on the inspection form in the box corresponding to the bolt number. Visually inspect any welds in the base (gussets, vertical support to base connection) looking for cracks or unusual welds. Also, note and record any damage (corrosion, cracks, gouges, dents) to the base, gussets, and vertical support. Replace missing nuts/washers/lock washers as needed.

Tightening of the bolt nuts can be done using an appropriately sized spud wrench, spanner wrench or socket wrench. The nut is tightened until no further movement takes place. Any broken anchor bolts should be easily identified as both the nut and the bolt will continue to twist with little applied torque. If only the nut rotates under the applied torque, complete the tightening. Note all the nuts that require tightening on the inspection report.

f. Breakaway base to foundation (bolts B1-B4): Determine the type of foundation (steel screw-in or concrete). Inspect the condition of the foundation, noting any spalling, cracks, and general deterioration. Measure and record the anchor bolt diameter and the number of threads in one inch, along with the bolt circle diameter. Record the number, size, and type of washers present. Look for missing or damaged anchor bolts or nuts (gouges, corrosion). Also, note any bolts that have been bent to align with holes in the breakaway base plate. Note any bolts that are lower than the top of the nut. If the bolt is lower, measure the depth and mark it on the inspection form in the box corresponding to the bolt number. Visually inspect any welds in the base (gussets, vertical support to base connection) looking for cracks or unusual welds. Note any leveling nuts on the report. Replace missing nuts/washers/lock washers as needed.

Tightening of the bolt nuts can be done using an appropriately sized spud wrench, spanner wrench or socket wrench. The nut is tightened until no further movement takes place. Any broken anchor bolts should be easily identified as both the nut and the bolt will continue to twist with little applied torque. If only the nut rotates under the applied torque, complete the tightening. Note all the nuts that require tightening on the inspection report.

II. Procedure for the Inspection of High Strength Bolts at Arm to Upright Connection.

a. Description: This section of the inspection procedure describes the requirements for inspecting the bolts connecting the luminaire arm to the upright. This connection is a single or double arm connection with two to four (possibly more) bolts per connection depending on the type of arm to upright connection. The arm to upright connection is a clamp connection with the arm welded to one side of the clamp. Locate bolts on the other side of the clamp (the side opposite traffic) with the clamp bolted around the upright. Record connection method in “arm to upright comments” box.

b. Field Inspection: With the through bolt connections and clamp connections, as a minimum, each bolt end should be at least flush with the nut. If there is not at least a flush condition between the bolt end and the nut, record this in the inspection report. Each bolt should have a flat washer on the bolt head end and a flat washer and lock washer on the nut end. Record any parts that are missing or not in their proper location. All bolts, nuts and washers should be galvanized. Record any signs of rust. Visually examine the contact area and record any gap.

All types of luminaire arm to upright connections require visual inspection of the welds. The vertical welds connecting plates to the sides to the upright are critical in nature and require extra attention. Pay close attention to welds wrapping around corners on gusset stiffener plates at the arm to upright connection. The arm may be two piece with a slip joint connection near the midpoint of the arm span. If a slip joint exists, visually examine the longitudinal seam weld at that location. Record any visible cracks, noting size and location. Record the total arm length.

III. Report Writing, Safety and Equipment

a. Reporting Procedure: All written reports shall be legible, accurate, and detailed. These documents will be used as evidence of work performed (pay item). Payment for work will not be made if data gathered are illegible or undecipherable. Photographs are to be dated and provided in jpg format on cd media, including an index to the pictures.

Any unusual or potentially dangerous conditions must be reported immediately to the Michigan Department of Transportation, Construction and Technology Support Area at 517-322-1235.

b. Safety: **Prior to inspection of breakaway base interior verify that electricity is OFF using a voltage detector.** All inspections and related work shall follow MIOSHA safety standards (use of safety apparel and equipment safety guards). Safety apparel and equipment (hard hats, leather gloves, harnesses, lanyards, safety glasses, safety shoes, safety vest) must be worn by all workers.

c. Equipment/Tool List:

Voltage protection gloves
24 oz ball-peen hammer
4 foot level
Box of rags for cleaning
12 foot tape measure
6 inch ruler
Round point shovel
Wrenches (Spud, Spanner or Socket)
Voltage detector
Screwdrivers (flathead and Philips)
Binoculars
25 foot collapsible survey rod
Report form: Light Standard Inspection
GPS unit
Digital camera
Cell phone

BREAKAWAY BASE LIGHT STANDARD INSPECTION

REPORT NO.		INSPECTED BY		DATE
REGION		COUNTY		ROUTE
CONTROL SECTION	JOB. NO.		INTERSECTION	
LOCATION			GPS UNIT #	LATITUDE: / LONGITUDE:
HEIGHT OF UPRIGHT	UPRIGHT DIAMETER		UPRIGHT TAPER	UPRIGHT TILT / ☐ GALVANIZED ☐ PAINTED ☐ ALUMINUM
UPRIGHT CONDITION			ARM TO UPRIGHT CONNECTION TYPE AND WELD CONNECTION	
NUMBER OF ARMS	ARM TYPE ☐ SINGLE ☐ DOUBLE		ARM LENGTH	
ARM TO UPRIGHT CONNECTION	NUMBER OF BOLTS		BOLT DIAMETER	BOLT CONDITION

UPRIGHT TO BREAKAWAY BASE CONNECTION

BREAK-AWAY BASE TO UPRIGHT BOLTS (dia., condition)	T1	T2	T3	T4
BREAK-AWAY BASE TO UPRIGHT NUTS (loose, missing, etc)	T1	T2	T3	T4
WASHER PRESENT	T1	T2	T3	T4
FLAT WASHER				
LOCK WASHER				

ANCHOR BOLT CONNECTIONS

BREAK-AWAY BASE TO FOUNDATION ANCHOR BOLT/NUT (dia., condition, loose, missing, etc.)	B1	B2	B3	B4	
PROJECTION OF FOUNDATION ANCHOR BOLT BEYOND NUT	B1	B2	B3	B4	
LEVELING NUT PRESENT ON FOUNDATION ANCHOR BOLTS	B1	B2	B3	B4	
FLAT WASHER TYPE AND NUMBER	TRIANGLE	RECTANGLE	ROUND	NONE	OTHER
LOCK WASHER	B1	B2	B3	B4	

ANCHOR BOLT/NUT COMMENTS (bolt diameter, bolt circle diameter, # of threads per inch, thread condition, plumbness, corrosion, I.D. #, etc)		
BREAKAWAY BASE THICKNESS AT FOUNDATION ANCHOR BOLT	BREAKAWAY BASE MAKE, MODEL, YEAR, AND CONDITION (cracked, broken, etc)	
BREAKAWAY BASE PROFILE AT ANCHOR BOLT FOUNDATION ANCHOR BOLT		FOUNDATION TYPE (steel, concrete)
NUT OR BASE COVER ☐ YES ☐ NO	HANDHOLE COVER ☐ YES ☐ NO	ACCESS PANEL ☐ YES ☐ NO

Appendix C - FHWA Approval letter of April 17, 1978, Union Metal A2852 breakaway transformer base

(13)

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
WASHINGTON, D.C. 20590

APR 1 7 1978

IN REPLY REFER TO:

HNG-32

Mr. R. J. Mohler
The Union Metal Manufacturing Co.
Box 8530
Canton, Ohio 44711

Dear Mr. Mohler:

Relative to the breakaway characteristics of your cast aluminum transformer base, Union Metal Model 2852, we have examined the following documents:

1. Monthly Progress Report No. 14, January 15, 1978, by ENSCO, Inc., Tests 221 and 225.

2. Letter dated January 26, 1978, from ENSCO, Inc. to Union Metal Manufacturing Co., relative to the results of tests 221 and 225 on cast aluminum transformer bases with a 50-foot mounting height pole.

3. Letter dated February 9, 1978, from The Union Metal Manufacturing Co., addressed to the Federal Highway Administration (FHWA) relative to ENSCO, Inc., tests 221 and 225.

4. The Union Metal Manufacturing Co., drawings:

   a. 1A-A2852-G5, "Cast Aluminum (356-T6) Transformer Base," dated March 31, 1971.

   b. P02-G94, "Anchor Clip," dated February 8, 1978.

   c. P06-G151, "50-Foot M. H. Structure A2852 Cast Aluminum Base Total Structure Wt. 1000#," undated.

   d. A2852-F2, "Cast Aluminum Transformer Base for 8" thru 10" Poles," dated November 21, 1969.

5. "Certified Report of Chemical Analysis and Mechanical Properties" issued by the Arrow Aluminum Casting Co., dated September 27, 1977.

6. Four pages of calculations from The Union Metal Manufacturing Co., extrapolating momentum change from tests at 20 mph to momentum change at 60 mph, and converting these momentum changes for 450 pound assemblies to momentum changes for 1000 pound assemblies.

Two pendulum tests were conducted by ENSCO, Inc., at the FHWA test facility at Riverdale, Maryland. Both tests were run at 20 mph with a pendulum weighing 2290 pounds. Both test articles were steel poles which, when equipped with mast arm, could provide for a luminaire mounting height of 50 feet. The actual height of the pole assembly tested was approximately 44.5 feet and weighed approximately 450 pounds. The test pole did not have mast arm or luminaire attached. The test results are as follows:

	Test 221	Test 225
Momentum change through impact	622 lb-sec	735 lb-sec

Using research conducted by ENSCO, Inc., and as reported in FHWA report FHWA-RD-76-36, "Safer Sign and Luminaire Supports," Task L, Final Report, the results of these two tests can be extrapolated as follows:

Momentum Change Through Impact

Vehicle Speed mph	Pole Assembly Weight Pounds	Test 221 lb-sec	Test 225 lb-sec
60	450	674	711
20	1000	831	944
60	1000	849	887

We have determined that pole assemblies as described below, which are mounted on Union Metal Manufacturing Co. cast aluminum transformer bases, model 2852, as depicted on Union Metal drawing A2852-F2, dated November 21, 1969, will meet the breakaway requirements of AASHTO "Standard Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals," and, therefore, are acceptable for use on Federal-aid projects when proposed by a State.

These pole assemblies must:

1. have a total weight of no more than 1000 pounds.

2. provide for a luminaire mounting height of no more than 50 feet.

3. be secured to the anchor bolts with cast iron, hot dipped galvanized anchor clips as depicted on Union Metal drawing P02-G94 dated February 8, 1978.

The cast aluminum transformer bases must be of alloy 356-T6 conforming to ASTM specification B-108. The bases that were tested were taken from a "lot" of castings which, for two test bars, had the following average mechanical properties:

Yield	--	23,850 psi
Tensile	--	35,600 psi
Elongation	--	3.63 percent

We anticipate that the States will require certification from The Union Metal Manufacturing Co., that castings furnished have essentially the same chemistry, mechanical properties, and geometry as the castings used in the tests and that the castings will meet the change in momentum requirements of the AASHTO specification.

Sincerely yours,

Frank L. Johnson

for Lester A. Herr
Chief, Bridge Division

Appendix D
FHWA Office of Engineering Policy Memorandum HNG-14

U.S. Department of Transportation
Federal Highway Administration

Memorandum

Subject: Action: Identifying Acceptable Highway Safety Features Date: JUL 25 1997

From: For: Director, Office of Engineering Reply to Attn. of: HNG-14

To:
Regional Administrators
Federal Lands Highway Program Administrator
Division Administrators
Federal Lands Highway Division Engineers

The Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) required the Secretary of Transportation to institute measures to enhance the crashworthy performance of roadside features to accommodate vans, mini-vans, pickup trucks, and 4-wheel drive vehicles. In recognition of this requirement, the 1993 National Cooperative Highway Research Program (NCHRP) Report 350, *Recommended Procedures for the Safety Performance Evaluation of Highway Features* (NCHRP Report 350), contains guidance for testing highway features with pickup trucks to assess the safety performance of those features. The Federal Highway Administration (FHWA) believes the pickup truck is an acceptable surrogate for the other vehicles cited in the ISTEA. Through a formal rulemaking process that culminated in a final rule in a notice in Volume 58, No. 135, of the Federal Register, dated July 16, 1993, the FHWA added Report 350 at paragraph 625.5(a)(13) of Title 23, Code of Federal Regulations (23 CFR). Since that time the "Guides and references" section of 23 CFR, Part 625, under which the NCHRP Report 350 was cited, has been removed. The NCHRP Report 350 is now cited in Section 16, Paragraph (a)(12) of the Non-Regulatory Supplement to the Federal-aid Policy Guide, Subchapter G, Part 625 (NS 23CFR 625). To further promulgate application of the guidelines in the NCHRP Report 350 a memorandum from the Office of Engineering, "Information: Procedures for Determining Acceptability of Highway Features," dated November 12, 1993, was sent to Regional Federal Highway Administrators and the Federal Lands Highway Program Administrator.

The effect of both the Federal Register notice and the November 1993 memorandum was a strong indication that, after five years from the effective date of the final rule in the notice, the FHWA would require all new installations of highway features on the National Highway System (NHS) that are covered in the NCHRP Report 350 to have been tested and found acceptable according to the guidelines in that report. Thus, the resulting nominal deadline for full compliance with the recommended guidelines in the NCHRP Report 350 was set at August 16, 1998. However, also in the Federal Register notice was a statement that "... the FHWA wants to assure all that during the scheduled transition period it will continually reassess its position."

In the spirit of that promise, an outline of the FHWA's current position follows:

- Except as modified below, all new or replacement safety features on the NHS covered by the guidelines in the NCHRP Report 350 that are included in projects advertised for bids or are included in work done by force-account or by State forces on or after October 1, 1998, are to have been tested and evaluated and found acceptable in accordance with the guidelines in the NCHRP Report 350. (The slight change from the previously implied deadline was made to take advantage of any benefit there might be in having the date coincide with the beginning of the Federal fiscal year. Citing the advertising date rather than the installation dated was done to minimize project timing problems that might lead to requiring the issuance of change orders to be in strict compliance with the cited deadline.) Note that breakaway support hardware previously found acceptable under the breakaway requirements of either the 1985 or 1994 editions of the AASHTO *Standard Specifications for Structural Supports for Highway Signs, Luminaires and Traffic Signals* are acceptable under the NCHRP Report 350 guidelines.

- Exceptions:

  1. For some types of breakaway supports the FHWA will accept pendulum testing and the use of the test results to calculate an estimate of high-speed breakaway performance. The FHWA will place limits on the maximum masses and heights of acceptable breakaway luminaire supports. For additional discussion and guidance on these items see the attached "Background and Guidance on Requesting Federal Highway Administration Acceptance of Highway Safety Features" (Submission Guidelines).

  2. The testing and acceptance procedures for truck-mounted attenuators and certain work-zone devices are modified in the guidance given in the Submission Guidelines.

  3. Bridge railings tested and found acceptable under other guidelines may be acceptable for use on the NHS. See the Submission Guidelines (attached) and Mr. Horne's May 30, 1997, memorandum, "Action: Crash Testing of Bridge Railings," for additional guidance.

  4. For reasons cited in the attached Submission Guidelines, for work zone crash cushions, freestanding concrete work zone traffic barriers, and portable, usually trailer-mounted, work zone devices, such as lighting supports, flashing arrow panels, temporary traffic signals, and changeable message signs, the deadline for compliance with the guidelines in the NCHRP Report 350 is October 1, 2002.

  5. For specific small, lightweight channelizing and delineating devices the Submission Guidelines provide for self certification by the developer on the basis of documented field experience or comparison with like acceptable devices.

  6. Traffic signal supports and utility poles are exempt from the crashworthiness requirements being addressed here. Actually, breakaway utility poles are expressly

covered in the NCHRP Report 350 and guidelines for testing breakaway sign and luminaire supports could reasonably be applied to traffic signal supports. Nevertheless, because of the structural requirements for utility poles and most traffic signal supports, the technical problems with making them breakaway, and the assumed net benefit to the public from allowing them, unshielded, within the clear zone, a requirement that they be made breakaway, historically, has not been imposed on them. On the other hand, they constitute real risks for motorists and all practicable measures should be taken through their location or a reduction in their numbers to reduce their risk to motorists. In addition, because of their low structural requirements, consideration should be given to making post-top-mounted traffic signal supports breakaway.

- The FHWA does not intend that this requirement (that new highway safety features installed on the NHS be proven crashworthy in accordance with the guidelines in the NCHRP Report 350) result in the replacement or upgrading of any existing installed features beyond what would normally occur with planned highway improvements. On the other hand, a State should have a rational, documented policy for determining when an existing non-standard feature should be upgraded.

- To aid the States and the FHWA in the evaluation of the in-service performance of the work zone and roadside features and the formulation of rational policies on the deployment and upgrading of these features, it would be highly desirable if there were inventory and accident data bases of sufficient detail, accuracy, and precision that one could use them to evaluate the field performance of specific highway feature designs. Existing or emerging videolog, GPS, GIS, data warehousing, and other technologies make this a reasonable goal. It is believed that significant steps have already been taken by some States that could lead to attainment of this goal. It is recommended that regional and division personnel working in the planning and safety areas work with their State counterparts to see what can be done to accelerate the improvement and application of these technologies and the dissemination of information on their application toward attainment of the goal.

Finally, a few words on the attached Submission Guidelines, they replace a similar document that was attached to the previously cited November 1993 memorandum. While the new document contains updated information and has been expanded to address more features, the principal reason for this new version is to better describe what must be submitted by those wishing to take advantage of the Headquarters service of passing judgement on the crashworthiness of a highway feature. These guidelines should be consulted early in the development of a qualification program for a highway safety feature. If it is likely that development tests will be used to document crashworthiness of a feature, the guidelines should be considered in setting up and conducting the development testing program for a new or revised feature.

An extra copy of this memorandum is being furnished to each Division Administrator for submission to their associated State highway agency.

Donald P. Steinke

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Attachment

Attachment

Background and Guidance on Requesting Federal Highway Administration Acceptance of Highway Safety Features

Introduction

Highway safety features, such as breakaway sign and luminaire supports, longitudinal barriers, crash cushions, and work zone traffic control devices, must demonstrate acceptable crashworthy performance to be accepted by the Federal Highway Administration (FHWA) for use on the National Highway System (NHS) within the clear zone or, particularly for work zone devices, within the roadway. From 1981 to 1993 the FHWA reviewed roadside safety hardware that had been crash tested in accordance with the procedures in the National Cooperative Highway Research Program (NCHRP) Report 230, *Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances* (Report 230). This document was never formally recognized by the FHWA. In May 1993 a revised testing procedures document, NCHRP Report 350, *Recommended Procedures for the Safety Performance Evaluation of Highway Features* (Report 350), was published. By a final rule in Federal Register Vol. 58, No. 135, dated July 16, 1993, the FHWA formally added Report 350 to 23 CFR under the "Guides and references" section, Part 625.5(a)(13). (This "Guides and references" section has since been removed from the CFR. The Report 350 citation has been transferred to Section 16, Guides and References, paragraph (a)(12), of the Non-Regulatory Supplement to the Federal-Aid Policy Guide, Subchapter G, Part 625, Design Standards for Highways (NS 23 CFR 625).) The FHWA will require, unless otherwise indicated, that all new installations of applicable highway features included in projects on the NHS advertised for bids or installed by state forces or under force account work on or after October 1, 1998, will have been found crashworthy according to the guidelines in Report 350, except as the guidelines may be modified in the guidance that follows.

Acceptance Letters

As a service to FHWA field offices, state and local highway agencies, and industry, the FHWA's Office of Engineering reviews crash test reports and other supporting documentation and issues acceptance letters to developers of crashworthy hardware. (Note that the term "developer," as used in these guidelines refers to individuals, companies, or organizations that invent, develop, modify, manufacture, sell, or promote highway safety hardware.) The FHWA does not, with rare exceptions, conduct crash testing for developers of safety hardware. Typically, the developer must contract with a testing agency that is recognized as capable of conducting full scale impact testing of highway hardware. Testing in compliance with FHWA accepted procedures is then performed on the feature. The results, in the form of a test report and related documentation, are submitted by the developer or, at the request of the developer, the testing agency to the Office of Engineering. If the testing and performance of the feature are acceptable and sufficient detail on the design and operation of the device are provided, the Office of Engineering will issue a letter

to the petitioner (the developer or other person requesting acceptance of a feature) indicating acceptability of the feature for use on the NHS and the Report 350 test level for which it qualifies. This letter may also cite limitations on the feature's acceptability, such as the maximum mass of pole that may be used with an accepted breakaway feature or other physical or installation requirements. Copies of acceptance letters are sent to the FHWA's regional offices so that they are kept informed of additions or changes to the list of acceptable hardware and, in turn, pass the information on to state highway agencies through FHWA division offices. Should the petitioner differ with the FHWA's finding on the crashworthiness of a feature the finding can be appealed in writing. The appeal should be directed to the Office of Engineering at the address given on the last page of this attachment and include a statement of the point(s) of difference with the FHWA, the action desired, and documentation supporting the claim(s) being made.

There are some features that, by their nature, are nearly certain to be safe and others that are so similar to currently accepted features that there is little doubt that they would perform acceptably. For these features, the FHWA may, on a case-by-case basis, not require qualification testing or may accept abbreviated or unique qualification procedures as the basis for their acceptance. Flexible delineator posts are an example of hardware that is unlikely to require full-scale crash testing. Barriers or breakaway supports that are substantially the same as previously accepted crashworthy hardware may also be accepted under this provision, again, on a case-by-case basis.

It should be noted that acceptance of a design by FHWA does not ensure acceptance or use by the various state highway agencies. They may reject a design or place limitations on its use for a variety of reasons—placing their own interpretation on test results, requiring additional testing, or requiring in-service evaluation. Also, should the FHWA discover subsequent to the issuance of an acceptance letter that the qualification testing was flawed, that in-service performance reveals unacceptable safety problems, or that the device being marketed is significantly different from the version that was crash tested, it reserves the right to modify or revoke its acceptance.

The FHWA may also revoke an acceptance if a device is promoted as acceptable under conditions that are significantly divergent from the test conditions. Any deliberate misrepresentation or withholding of the conditions of FHWA's acceptance of a feature by the supplier of a feature will be cause for withdrawal of acceptance.

Crashworthy hardware items other than those accepted by FHWA Headquarters, it should be noted, could be acceptable for use on the NHS. As already stated, the FHWA's Office of Engineering reviews test results and issues acceptance letters as a service to developers and users to help provide continuity and uniformity in evaluations. However, it is not a requirement that an acceptance letter be issued by the Office of Engineering for crashworthy devices to be used on the NHS. If, for a particular device, it can be demonstrated to the satisfaction of a state highway agency that a device has been tested and evaluated in accordance with acceptance procedures recognized by the FHWA, and the results are satisfactory, that device could be accepted by that state, with concurrence by its FHWA division office, for use on the NHS within that state. However, should this alternative course be followed, in the interest of technology transfer, the

NHS advertised for bids or constructed with state forces or through force account work on or after October 1, 2002, work zone crash cushions and freestanding concrete traffic barriers must be shown to be crashworthy under the guidelines in Report 350.

4. The last category, which is actually a subset of category 3, includes portable, usually trailer-mounted, devices such as area lighting supports, flashing arrow panels, temporary traffic signals, and changeable message signs which are often used in or adjacent to the traveled way. While they have significant value in the work zone by contributing to safer traffic operation, these devices may cause great harm to occupants of impacting vehicles. Even though accident experience to date shows that crashes with these devices are rare, it is believed that they should be made crashworthy and meet the recommended acceptance guidelines in Report 350 if they are to be used, unshielded, in the clear zone on the NHS. However, in the belief that, as currently configured and deployed, these devices provide a net benefit to motorists and that it is unlikely that crashworthy versions can be developed in time to reasonably meet the October 1, 1998, compliance deadline cited above, the FHWA is setting October 1, 2002, as the date at which it will no longer accept the unshielded use of devices in this category on roadways or within clear zones on the NHS unless they have been proven crashworthy. (In the interim, as should be done with these devices even if proven crashworthy, they should be positioned and operated in as safe a manner as practical. This would mean, where reasonable, placing them behind crashworthy barriers or shielding them with a TMA or crash cushion. For those devices that it is decided appropriate to operate unshielded within the clear zone, they should be highly visible, both in and out of service, and be removed from the clear zone as soon as practicable after they are no longer needed.)

Some work zone traffic control devices are normally used in a series to channelize traffic. There is the potential that singly some of these devices may have little effect on an impacting vehicle but, when struck in multiples, may cause vehicle instability or occupant compartment intrusion. Also, because of the nature of their configurations, many of these devices can be easily turned or upset under normal operating conditions. To address both of these possibilities, when testing devices that are typically installed in series, it is recommended that crash tests include two of these devices placed in a row aligned with the path of the test vehicle. For a 100-km/h test the devices should be spaced 6 meters apart and the second device should be either turned 90 degrees relative to the first or laid on the ground, whichever is judged the "worst case" orientation for the device in question.

Truck Mounted Attenuators

The guidelines in Report 350 for assessing the crashworthiness of truck mounted attenuators (TMAs) are to be followed except that, until state-of-the-art developments indicate that practical and economical TMAs can fully meet the guidelines in Report 350 under test 3-50, the FHWA will accept a modified test 3-50, provided an unmodified test 2-50 (70 km/h, small-car test with the host vehicle blocked to prevent movement) is run and passed. The modified 3-50 test the FHWA

division office, through its regional office, should submit the crash test reports and other documentation upon which its acceptance is based to the Office of Engineering for information and possible Headquarters concurrence and distribution.

Crash Testing: General

Developers who are new to the field of highway safety hardware may find Appendix A useful. It contains a list of testing agencies that have experience in testing roadside safety hardware for state highway agencies, developers, and the Federal Government. This list is not meant to be all-inclusive nor is it an endorsement of these organizations. It is intended to provide a starting point that developers can use in determining where they might have the appropriate tests performed. Other facilities in the U.S. or in other countries may also be qualified to satisfactorily perform the tests. FHWA reserves the right not to accept test results if the competence of the crash test laboratory that performed the test is uncertain or if non-standard test equipment or procedures were used. FHWA may accept the competence of a foreign laboratory based on certification through an FHWA recognized procedure, governing agency, or standards review organization.

Various test levels (combinations of vehicle size and impact angle and speed) have been included in the Report 350 crash test matrices to permit tailoring the performance and cost of highway safety features to meet specific site requirements. When developing a crash testing program for a particular device careful attention should be paid to selecting the appropriate test level. Selection procedures for the various test levels are yet to be developed. However, work on developing such procedures is currently (1997) underway under an NCHRP project. FHWA acceptance letters will acknowledge the test level to which a device has been crash tested and is acceptable. It will be assumed that until nationally recognized selection procedures exist user agencies will, by some consistent, rational means, determine where a feature of a demonstrated test level is appropriate for use.

Devices intended to serve as permanent or temporary traffic barriers (longitudinal barriers, terminals, or crash cushions) must, as a minimum, qualify under Report 350 test level 1 test procedures and acceptance criteria to be accepted for such service. Devices that do not qualify as traffic barriers may find use as channelizing devices or for delineation provided they meet Report 350 guidelines for work zone devices and are consistent with the *Manual on Uniform Traffic Control Devices* requirements. They will not, however, be acceptable for use where a longitudinal barrier is needed to shield a work area.

All hardware that is to be used with a device in service must be in place during the crash test, whether it is a functional part of the system or an ancillary feature such as a warning sign—sign supports need signs, delineator posts need delineators, breakaway luminaire supports need mast arms and the equivalent of luminaires, etc. Barriers that are to be used with glare screens, signs, luminaire supports, handrails, or other hardware mounted on top should be tested with these devices in place. An exception to this requirement may be a light-weight fabric or pliable membrane snow or debris cover if its effect on crash performance can be judged inconsequential.

The intention to use such a cover with a device and a full description of the cover must be specifically covered in any request for acceptance.

The developer should also carefully choose which version of a device is to be tested. If a number of different sizes are proposed for use, then the "worst case" conditions, if predictable, should be tested. It may be that "worst case" conditions are not obvious and more than one version of a device will need to be tested. The FHWA Office of Engineering is willing to review a proposed test program to assist in determining an adequate number of tests to fully qualify a device and its variants.

To date (1997), most crash testing has been done on level or nearly level test sites. The terrain on which a feature is located or over which an impacting vehicle may traverse (either pre- or post-impact) can have significant effects on the outcome of a crash into a given feature. Therefore, a request for acceptance should include, preferably in the test report, a discussion of the site conditions—foundation and topography—for which a feature is intended to be used and the limitations of the testing program to evaluate the range of expected service conditions.

Below is a section containing comments on specific aspects of testing various types of highway features. These comments are followed by a section on "Submission Requirements", which describes what needs to be supplied to the Office of Engineering when requesting FHWA review and acceptance of a crashworthy highway feature. Appendix B is a checklist citing information that FHWA has found to be essential in its evaluation of the crashworthiness of hardware. It is recommended that this list be carefully reviewed in designing a testing program and in preparing a request to the FHWA for acceptance of a feature.

Crash Testing: Specific Features

Sign and Luminaire Supports

Crashworthy sign and luminaire supports are designed to break away or yield when struck by a vehicle. When a proposed breakaway support design includes two or three posts within a 2.1-meter span all supports must be struck by the test vehicle. Testing conditions and evaluation criteria for determining acceptable breakaway performance are found in the AASHTO *Standard Specifications for Structural Supports for Highway Signs, Luminaires and Traffic Signals*, 1994, (Support Specifications) and in Report 350. Please note that soil conditions are critical when considering the crashworthiness of many breakaway supports. Supports qualified in "standard" soil may not work in "weak" soils and thus may not be acceptable in weak soils. The use of a concrete foundation or a soil plate will also affect the performance of the support and must be documented.

Full-scale crash tests, with the prescribed Report 350 test vehicle, are applicable to all types of breakaway hardware. Tests with pendulums or reusable bogie vehicles are acceptable for most breakaway supports, exceptions being base bending or yielding supports. These supports must

be tested using an automobile because no surrogate test devices have been approved that replicate the interaction between the vehicle and the support. Pendulum testing of base bending or yielding supports may be permitted on a case-by-case basis to evaluate the relative performance of supports that have previously been qualified using automobiles.

The support hardware must perform satisfactorily at impacts between 35 km/h and 100 km/h, per Report 350. Since the higher speed tests cannot be run on a pendulum test facility, FHWA has allowed high speed results to be estimated using a procedure previously detailed in the discontinued FHWA Notice N 5040.20, dated July 14, 1976. That procedure is described here in Appendix C. This extrapolation method, when checked, has nearly always been found to be conservative and could result in the rejection of breakaway features that would actually pass full scale high-speed tests.

Testing parameters and acceptance criteria for breakaway supports are as follows:

1. The key criterion for acceptable dynamic performance in the Support Specifications is a maximum change in velocity of 16.0 ft/sec (4.88 m/sec) in a 1,800-pound (818-kg) test vehicle. The velocity change to be compared to the maximum allowable in the standard is the occupant impact velocity. This is the calculated speed at which a hypothetical unrestrained occupant impacts the car's interior after traveling a distance of two feet (flail-space distance) relative to the vehicle after vehicle contact with the feature. Report 350 calls for a maximum velocity change of 5.0 meters per second (16.4 feet per second) based on a 0.6-m (1.97-foot) flail space distance. In adopting Report 350, the FHWA recognized this higher occupant impact velocity as an acceptable upper limit and also recognized the 35-km/h and 100-km/h (21.7-mph and 62.1-mph) test speed range and the 820 kg (1808-pound) test vehicle. Because Report 350 acceptance criteria are slightly less demanding than were the criteria in the 1985 or 1994 Support Specifications or the Report 230 guidelines, breakaway hardware meeting these earlier criteria do not have to be re-qualified to be accepted under Report 350 criteria.

2. The maximum stub height remaining after a support breaks away, measured above a 1500-mm chord, as specified in the Support Specifications, shall not exceed 100 mm. (This is intended to prevent the vehicle undercarriage from snagging on the broken stub and to minimize vehicle instability if a wheel hits the stub.)

3. The occupant compartment must not be penetrated nor seriously deformed. Maximum roof crush will be evaluated on a case-by-case basis. However, in no case when a breakaway pole falls onto a test vehicle will a roof crush greater than 150 mm (6 inches) be found acceptable.

4. Features, primarily luminaire supports, that are expected to contain electrical wiring are to be tested with non-energized wiring of the size, structure, and configuration expected to be used with the feature. The objective of including wiring in the test installation is to

evaluate both the effect the wiring might have on a support's breakaway performance and the potential for the creation of an electrical hazard when the support might be knocked down. Where alternative wiring designs are likely to be used with a support, the design expected to most adversely affect breakaway performance is to be used. (This criterion of testing with wiring in place has not been required in the past. The FHWA, however, will not require retesting of previously accepted supports tested without wiring. It should be noted that, while neither the current Support Specifications nor Report 350 call for testing supports with wiring in place, the requirement is expected to be included in the Support Specifications shortly.)

Because pendulum and bogie testing of luminaire supports, which, as indicated, the FHWA will accept, do not reveal the consequences of a support falling on the roof of an impacting vehicle and even automobile testing does not investigate the full range of potential consequences from a support falling on a vehicle, based on test observations and engineering judgement, the FHWA has set upper limits on the support masses and heights it will find acceptable even where analysis or testing appear to indicate acceptability of greater mass or height supports. The maximum acceptable luminaire support mass is 450 kg (992 pounds) and the maximum luminaire support height is 18.50 m (60.7 feet). These values are up from the limits of 272 kg (600 pounds) and 15.2 m (50 feet) cited a few years ago. Any further increase in these limits will have to be based on full-scale crash testing and an investigation of the range of vehicle roof crush characteristics that go beyond the recommended testing procedures in Report 350.

Traffic Barriers (Longitudinal Barriers, Transitions, and Crash Cushions and Terminals)

Report 350 contains recommended testing procedures, reporting requirements, and criteria for determining and documenting the acceptable crashworthy performance of traffic barriers. The required number of tests, test speeds, impact angles and locations, and test vehicles vary, depending upon the test level and whether the article to be tested is a longitudinal barrier, barrier transition, or terminal or crash cushion. If there is any question concerning the total number or type of tests to be run, the developer may wish to discuss this issue with the FHWA Office of Engineering beforehand and reach a preliminary agreement on an appropriate test matrix.

The required strength-test (containment-test) vehicle for the first three of the six test levels suggested for longitudinal barriers is a 2000-kg (4,409-pound) ¾-ton pickup truck. The strength-test vehicle for test level 4 is an 8000-kg (17,637-pound) single-unit truck. The strength-test vehicles for test levels 5 and 6 are 36 000-kg (77,366-pound) tractor semi-trailer combinations. The difference between the latter two test vehicles is that for test level 5 the trailer is a van-type and for test level 6 the trailer is a tanker.

Bridge railings are longitudinal barriers and are treated as such in Report 350. However, because of some unique history connected with their testing and acceptance they are covered separately below.

Bridge Railings

Bridge railings, as stated, are longitudinal barriers and are to be tested as such with regard to the application of Report 350. Their design is covered in both the AASHTO's *Standard Specifications for Highway Bridges* and the 1994 *AASHTO LRFD Bridge Design Specifications* (LRFD), which reflects the design approach in the 1989 AASHTO *Guide Specifications for Bridge Railings* (Guide Specifications). As can be inferred from comments below, the testing criteria in the LRFD have been effectively superseded by Report 350.

The FHWA policy of requiring crash tested bridge railings was established by the memorandum "Bridge Rails", dated August 28, 1986. Typically, individual states have sponsored the testing of their own bridge railings and implemented the new designs upon receipt of acceptable crash test results.

The LRFD and the Guide Specifications contain guidance for testing bridge railings that differs from the guidance in Report 350 in that they recognize only three "Performance Levels." These performance levels approximately match three test levels in Report 350, test levels 2, 4, and 5. The FHWA recommends that all bridge railing testing now be conducted in accordance with Report 350 and that Report 350 test levels 2, 4, and 5 be substituted for the 1994 LRFD performance levels 1, 2, and 3, respectively. (The AASHTO is considering, and is likely to adopt in the near feature, a revision in the LRFD to incorporate the six tests levels cited in Report 350.)

FHWA has issued two memoranda (the cited August 28, 1986, memorandum and one dated August 13, 1990) listing a total of 47 railing designs that met full scale test requirements at the time that they were tested and may be considered acceptable for use on the NHS at specified performance levels. A third memorandum dated May 30, 1997, updated these earlier listings. This new memorandum provides guidance on determining an acceptance test level equivalent to a Report 350 test level for bridge railings tested under the railing section of the LRFD, or it's predecessor, the AASHTO *Guide Specifications for Bridge Railings*, or other guidelines. It also identifies additional railings tested under the LRFD, Report 350, or other guidelines.

Work-Zone Traffic Control Devices and Miscellaneous Features

In addition to truck mounted attenuators (TMAs), which are covered separately below, Report 350 provides guidance for crash testing other work zone features—work zone signs, barricades, channelizing devices, etc.—and insubstantial features such as delineator posts. Because of the nature of these features some of the test procedures are less rigorous than those for other features. For example, under some conditions, low-speed tests may not be required and for tests of free-standing objects with masses less than 45 kg, reduced instrumentation is permitted. (See Report 350 section 3.2.3.2.) For determining this 45-kg limit, Report 350 exempts ballast mass from the mass of the feature if "... the ballast effectively does not contribute to the change in the vehicle's velocity upon impact with the device." However, the ballast mass, its location, and its means of attachment must be clearly described in the drawings and specifications to be provided

under section 6.1 of Report 350.

Note that FHWA acceptance of a device as meeting crashworthiness requirements does not imply that it has been determined that the device is in conformance to the *Manual on Uniform Traffic Control Devices* (MUTCD). Acceptance letters for crashworthy traffic control devices will carry a disclaimer to that effect. However, if, in the opinion of the FHWA, a crash tested device submitted for acceptance is clearly out of conformity with the MUTCD the entire submission may be returned to the petitioner.

There is a wide variety of devices used in work zones, some of which are not normally found on the roadside or in the traveled way outside of work zones. For purposes of determining the level of effort needed to demonstrate crashworthiness, work zones devices and miscellaneous features will be divided into four categories:

1. The first category contains those small and lightweight channelizing and delineating devices that have been in common use for many years and are known to be crashworthy by crash testing of similar devices or years of demonstrably safe operational performance. These include plastic or rubber cones and tubular markers, flexible delineator posts, and plastic drums with no lights, batteries, signs, etc. added. If ballast is used, it must be located at ground level in accordance with the manufacturers instructions. For devices to be included in this category there must be virtually no potential that they will penetrate windshields, cause tire damage, or have a significant effect on the control or trajectory of an impacting vehicle. FHWA will not issue letters of acceptance nor maintain a list of the many individual devices in this category. These devices may be allowed based upon the developer's self-certification if the device:

    a. is built to a specification for a device for which the crashworthiness has been validated by crash or surrogate testing, or

    b. is a type of device that is being accepted as being crashworthy on the basis of crash test experience with similar devices or years of demonstrably safe operational performance. (Simplified crash testing showing that a device poses no risk to impacting vehicle occupants may be used to support the manufacturers certification. This simplified testing must, as a minimum, be documented by a written report, observed by an independent, impartial observer, recorded on videotape, and include a means, other than the test vehicle's speedometer, for determining the vehicle speed at time of impact.)

Self-certification will be subject to approval by the individual highway agencies.

Devices with a top-mounted warning light will only be included in this category if they satisfy condition 1.a.

2. The second category includes devices that are not expected to produce significant vehicular velocity change, but may otherwise be hazardous. All or parts of the device may be substantial enough to penetrate a windshield or injure a worker or they may cause vehicle instability when driven over or should they become lodged under a vehicle. Testing of devices in this category will be required. However, they may, as mentioned above for devices of 45 kg or less, qualify for the reduced testing requirements cited in section 3.2.3.2 of Report 350. Lesser instrumentation than required in Report 350 may be acceptable. Depending on the device, videotaping may be substituted for high-speed film photography in recording test results and instrumentation in the vehicle may be omitted. Examples of this class are barricades, portable sign supports, intrusion detectors and alarms, and drums, vertical panels, or cones with lights.

Devices in this category could merit an FHWA acceptance letter unless it is determined that a blanket acceptance (or prohibition) is warranted based on experience with or testing of like devices. In order to help highway agencies evaluate the potential hazards to workers (bystanders) from work zone devices and determine any limitations to be placed on their use or location, the masses and trajectories of elements of a device launched in its testing must be recorded and reported.

If sufficient crash testing is done to indicate that a certain class of device, with any ancillary feature(s), is crashworthy, then this class may be moved to Category 1. FHWA will make the determination whether to move a class of devices to another category, although petitions from industry, documented by crash testing and design details, are welcome.

3. The third category is for hardware that is expected to cause significant velocity changes or other potentially harmful reactions in impacting vehicles. Hardware in this category must be tested to the full requirements of Report 350. If requested, individual letters of acceptance will be issued by the FHWA for crashworthy devices in this category. Barriers, fixed sign supports, crash cushions, and other work zone devices not meeting the definitions of category 1 or 2 devices are examples from this category.

Because of the large and expensive inventory, long life, and lack of alternative applications for work zone crash cushions and freestanding concrete work zone traffic barriers and the timing of the availability of Report 350 qualified hardware of these two types, the FHWA has concluded that it is appropriate to extend the deadline for requiring that these devices comply with the recommendations in Report 350. Therefore, until October 1, 2002, the FHWA will accept the use of work zone crash cushions and freestanding concrete work zone traffic barriers on the NHS, provided they have been crash tested and found acceptable under procedures and criteria at least as stringent as those recommended in Report 230, assuming the small test vehicle had a mass of 820 kg (1800 pounds). (Actually, there are many concrete work zone barriers that do not meet these criteria and that should be phased out of service as soon as possible.) To be used on projects on the

2. Windshield Damage

   a. None
   b. Minor chip or crack
   c. Broken, no interference with visibility
   d. Broken and shattered, visibility restricted but remained intact
   e. Shattered, remained intact but partially dislodged
   f. Large portion removed
   g. Completely removed

3. Device Damage

   a. None
   b. Superficial
   c. Substantial, but can be straightened
   d. Substantial, replacement parts needed for repair.
   e. Cannot be repaired

will accept for qualifying a test level 3 TMA is a 100-km/h small-car test where the host vehicle only has its brakes set and is in second gear. This assumes all other Report 350 test level 3 requirements are met. (For information and comparison with other TMAs, the FHWA suggests that the optional tests 2-52 and 2-53 or 3-52 and 3-53, as appropriate, be run and reported on all TMAs, even though TMAs may be accepted without passing these tests.)

A recommended mass for the TMA host vehicle, which will affect a TMA's performance in an unblocked test, is given in Report 350. The mass of the host vehicle, the mass of any ballast in the host vehicle, and the manner in which the ballast is secured in the host vehicle are to be reported in the test report. Also, any structural features or modifications required in the host vehicle to receive the tested TMA are to be reported.

Submission Requirements

Items submitted with a request for an FHWA finding that a feature is crashworthy and acceptable for use on the NHS must fully identify: a) the feature(s) tested; b) the conditions and results of the testing; and, if acceptance is being sought for any variations in design or construction details or procedures from those covered in the documentation of the testing of the feature, c) the complete design, construction, and installation details and specifications for the version(s) of the feature for which acceptance is being sought. It will be the responsibility of the petitioner to provide documentation of the applicability of the testing actually done to assess the acceptability of a feature or features differing from the tested article(s). This documentation is to be included with the request for acceptance and be sufficiently complete and detailed to fully support the conclusion of applicability.

Because the acceptance letter from the FHWA Headquarters is copied to FHWA field offices to notify those offices of Headquarters action, information is included with the acceptance letter that might otherwise not be necessary to include. One such item is a copy of a letter-sized (8.5"x11" or I.S.O. A4)(216 mm x 279 mm or 210 mm x 297 mm) engineering drawing or set of engineering drawings describing the accepted feature in sufficient detail and specificity that an observer in the field could use the drawing(s) to confirm that a purported installation of the accepted feature is in substantial conformance with what was found acceptable. Thus, two separate copies of a high-quality, reproducible, letter-size, engineering drawing or set of drawings showing all pertinent details and installation requirements of the version(s) of the feature for which acceptance is being sought are to be included with the request for acceptance. (These can often simply be copies or reductions of a drawing or drawings included with the documentation of the crashworthiness of the feature.) Additional guidance on items to be included with a request for acceptance of a feature is given below.

Report 350 contains rather complete guidance on the acquisition, reporting, and analysis of data on the testing of highway features. Appendix D at the end of this attachment is a table containing suggested evaluation factors and terminology that the FHWA suggests using as a supplement to Report 350 to provide a standard evaluation format for the visual assessment of test results.

A submission requesting FHWA acceptance of a highway feature must include two copies of a test report prepared according to the guidance in Chapter 6 of Report 350 showing, except as modified in these guidelines, that Report 350 testing procedures were followed and that Report 350 acceptance criteria were met. Note that it is not sufficient to report the nominal test conditions, design details, or specifications. The tolerances and ranges in these must be evaluated against the actual test conditions and the details of the tested device to determine the relevance of the testing and the acceptability of the device and the proposed tolerances and specifications related to it. Therefore, in setting up and conducting tests and reporting test results, particular attention should be given to the discussions concerning test articles covered in Chapters 2, 4, and 6 of Report 350. The objective is to accurately report the as-built foundation conditions, test article geometry, and material characteristics of what was actually tested, not just the nominal design dimensions and specifications for the feature, which, as indicated below, should also be reported. Ideally, all materials for a test installation should be examined before they are installed to ensure that they are representative of what will actually be supplied in service, with special vigilance for elements that, while within specifications, might falsely represent performance under service conditions. This process may require obtaining mill certification reports or actually running physical material tests on critical components of a feature. All materials used in appurtenances shall be declared, using chemical rather than proprietary names to describe synthetic materials. Descriptions and material specifications for all components, including fastener hardware, should be included or referenced.

In addition to two copies of test reports and a VHS cassette video of the full sequence of tests, the following must also be supplied:

- The previously cited two sets of a reproducible letter-size drawing or set of drawings showing the feature and its installation in sufficient detail to be used to make dimensional checks of service installations,

- If not included in the test report, two complete sets of material and installation specifications for the proposed production model of the feature, including copies of any cited specifications (except for AASHTO or ASTM specifications frequently used in the highway field).

- Because of FHWA's regulation regarding the use of proprietary products on Federal-aid projects, the request for acceptance must identify any patent or proprietary rights held on the feature or elements of the feature for which acceptance is sought. If the feature is proprietary a statement will be included in the acceptance letter indicating the regulations that must be meet if the feature is to be specified on Federal-aid projects.

The following additional documentation is desirable and may be required:

- Two sets of prints of photos included in the test report. These will be required unless the reproductions in the test report are near photo-print quality. (Experience has shown that half tone and xerographic reproductions of photos are often not adequate for review of before and after conditions or failure details.)

- One set of 16-mm film coverage of tests. This will be required if the video copy of this coverage is not of sufficient quality to be used in interpreting the test results.

Confidentiality of Submitted Items

The FHWA recognizes that some of the items and information it needs to evaluate the crash worthiness of a feature may be proprietary and as such a petitioner may want them to be held in confidence. Within the limits of law and the guidance below, the FHWA will honor written requests for confidentiality. However, in the interest of advancing technology, if a feature is found acceptable, unless the petitioner requests otherwise, the submitted films and video tapes may be sent to the FHWA/National Highway Traffic Safety Administration National Crash Analysis Center (NCAC), which makes such items available to the public without restriction. If the petitioner requests that these items not be sent to the NCAC or if the items are copyrighted, the information will be retained in the Office of Engineering and, upon request, will be available for viewing by interested individuals. The FHWA will not consider the test results or related photographic documentation or test data as confidential. However, it will respect restrictions on copying any copyrighted items, except that the letter sized drawings to be submitted for FHWA use in preparation and distribution of an acceptance letter must not be copyrighted. Items, such as detailed design drawings or specifications needed to document the testing of a feature or features as well as the exact character of the feature or features for which acceptance is sought, that the petitioner wishes to declare proprietary and confidential must be so marked and physically separated from the body of the test report or reports.

Addressing Requests for Acceptance

Submissions requesting acceptance of features should be mailed to:

DIRECTOR, OFFICE OF ENGINEERING
FEDERAL HIGHWAY ADMINISTRATION (HNG-1)
400 7TH ST. SW
WASHINGTON, DC 20590

HNG-14
25 Jul 97

APPENDIX A

Testing Agencies with Significant Experience in Testing Roadside Safety Features*

California Department of Transportation **
Box 19128
5900 Folsom Boulevard
Sacramento, CA 95819

Contact: Mr. Richard Peter
(916)227-7257 FAX: (916)227-7117

Calspan Transportation Sciences Center
P.O. Box 400
4455 Genesee Street
Buffalo, NY 14225

Contact: Mr. Saverio Pugliese
(716) 631-6839 FAX: (716)631-6843

E-Tech Testing Services
3617-B Cincinnati Avenue
Rocklin, CA 95765

Contact: Mr. John LaTurner
(916) 645-8188 FAX: (916) 645-3653

ENSCO, Inc.
5400 Port Royal Road
Springfield, VA 22151

Contact: Mr. Dale Stout
(703) 321-9000 FAX: (703) 321-7863

Southwest Research Institute
P.O. Box 28510
San Antonio, TX 78284

Contact: Mr. John W. Strybos
(210) 522-2449 FAX: (210) 522-3042

Texas Transportation Institute
Texas A&M University
College Station, TX 77843

Contact: Dr. C. Eugene Buth
(409) 845-6375 FAX: (409) 845-6107

University of Nebraska - Lincoln
Civil Engineering Department
W350 NEB Hall
Lincoln, NE 68588-0531

Contact: Dr. Dean L. Sicking
(402) 472-9332 FAX: (402)472-8934

Transportation Research Center Inc.
10820 State Route 347
East Liberty, Ohio 43319-0367

Contact: John C. Stultz
(937)666-2011 FAX: (937) 666-5705

Crash Safety Research Center
Pennsylvania Transportation Institute
Pennsylvania State University
201 Research Office Building
University Park, PA 16802

Contact: Robert J. Wollyung
(814) 865-7931 FAX: (814) 865-3039

Federal Outdoor Impact Laboratory ***
Turner Fairbank Highway Research Center
6300 Georgetown Pike
McLean, VA 22101

Contact: Mr. Richard E. King
(703) 285-2468 FAX: (703) 285-2679

* Some agencies may not have the capability to conduct all Report 350 tests.

** Services usually limited to State-sponsored research.

*** Testing usually limited to State- or FHWA-sponsored research.

APPENDIX B

Crashworthy Features - FHWA Acceptance Request Submission Checklist

Following is a listing (not necessarily complete) of items to be included with a request for FHWA review and acceptance of a crashworthy highway feature. Failure to supply these items, if applicable to the feature, or the submission of listed items that are incomplete or inaccurate or of poor graphic or visual quality, will delay processing a request for a feature's acceptance. To reduce the potential for problems caused by insufficient information at submission time or undesired restrictions being placed on the acceptability of a feature, it would be prudent to consult this checklist when developing the testing plan and procedures for demonstrating the acceptability of a feature.

1. Two copies of acceptance qualification test report(s) and related supporting documentation, such as films, videos, photographs, etc., prepared in accordance with guidelines in NCHRP Report 350 and containing the following: _____

   A. Information to be included on article(s) tested:

      1.) Complete engineering drawings of as-tested feature(s) showing actual dimensions of all critical elements and their locations. Note that ancillary hardware, such as signs mast arms, lights, electrical wiring, glare screens, handrails ,etc., that are to be used with a feature is to be tested with it and needs to be fully described. In addition, any items, such as snow or debris covers, that are to be used with a device but are omitted from tests are to be identified and fully described. Further, for work zone features that are to be tested in pairs, the locations of the individual features are to be given, along with a discussion of the basis for selecting the tested orientation. _____

      2.) Complete descriptions of the material properties of all critical elements of the tested features(s). _____

      3.) Description of installation or erection procedures. _____

      4.) Complete description and characterization of foundation or mounting conditions, including special test mounting structures, support pavement, soil types(s), soil placement and compaction, soil moisture content, etc. _____

      5.) Documentary video (VHS preferred) and or photographs of test installation(s). _____

B. Information to be included on test(s) conducted:

1.) Complete detailed information on relevant features of the test vehicle(s) or testing device. _____

2.) Complete, precise information on test(s):

a.) Names of principals responsible for conducting test(s) _____

b.) Date(s) and time(s) _____

c.) Location(s) _____

d.) Current (at test time) and antecedent (10 days ±) weather and groundwater conditions—particularly, anything that might affect material properties or foundation conditions. _____

e.) Complete information on test instrumentation and test procedures, including identification of and justification for any deviations from Report 350 guidelines. _____

f.) Complete information on actual impact conditions (impact location, speed, angle, etc.) and a showing that the actual conditions were within allowable tolerances. _____

g.) Complete report on test results as recommended in Report 350, plus documentation for any inferences or extrapolations, such as estimating high-speed breakaway performance of a device on the basis of performance in a low-speed pendulum test. _____

3.) Composite video copy (VHS preferred) of test films. (The copies of the test films to be available if requested.) _____

4.) Documentary video and photographs and measurements of post-crash conditions of feature(s) and test vehicle(s) or test device(s). The information submitted with the initial acceptance request should be sufficient to clearly illustrate the after-test conditions of the tested feature and the test vehicle or device. However, all the information gathered, which should be sufficient to permit a detailed postmortem analysis of the crash results, need not be submitted initially but should be available to clarify any questions that might arise during FHWA's evaluation of the acceptability of a feature. _____

C. Certification of the capability of the testing organization may be required. (Currently no formal certification procedures have been adopted in the U.S.)

2. Two sets of documentation describing the feature(s) and service conditions (including test level and site and terrain and foundation conditions) for which acceptance is requested (preferably to be included as part of the test report and related documentary materials and supported by evaluations by the testing agency).

   A. Complete, accurate, and legible engineering drawings and specifications covering manufacture and installation of the feature(s), including material and dimensional tolerances and any required installation limitations or procedures. In addition to the drawings just cited, unless they meet the following criteria, a drawing or drawings suitable for reproducing by photo copying and that show sufficient details and dimensions to permit one to confidently identified the feature for which acceptance is requested are to be supplied. Desirably, these drawings will be 8.5" x 11" (216 mm x 279 mm). However, I.S.O. A4 or 8.5" x 14" (210 mm x 297 mm or 216 mm x 356 mm) will be accepted. These drawings are intended for attachment to the acceptance letter, if issued, copies of which will be distributed to FHWA field offices.

   B. Complete description and chronology of any deviation(s) between the tested feature(s) and test installation conditions and the service design and installation conditions for which FHWA acceptance is sought, which would include the range in sizes or details of a feature for which tests of one, or at least less than all variations, are presented to show acceptability of the full rang. Along with this information, an independent assessment by a qualified organization, preferably the testing agency, of the significance these deviations might have on the in-service performance of the feature. Deviations to be evaluated will, of course, include differences between the test site terrain, which is to be described in detail, and expected service site terrains.

3. The request for acceptance must identify any patent or proprietary rights held on the feature or elements of the feature for which acceptance is sought.

4. Proprietary information submitted that the petitioner wishes the FHWA to treat as confidential should be so marked and physically separated from information on the conduct and the results of tests on the feature for which acceptance is requested, which the FHWA will make available for public inspection. Items that the FHWA will hold open for public inspection that the petitioner does not wish reproduced should be copyrighted. However, a non-copyrighted summary of test results should be included in the submission, along with the letter-sized drawings cited in 2.A., which must not be copyrighted.

APPENDIX C

Estimating High-Speed Breakaway Performance from Low-Speed Test Results

The following paraphrased and annotated excerpt from the discontinued FHWA Notice N 5040.20, "AASHTO Standard Specifications for Structural Supports for Highway Signs, Luminaires and Traffic Signals," dated July 14, 1976, presents formulas for estimating the high speed (60 mph or 100 km/h) breakaway performance of a signpost, luminaire support, or other breakaway device tested at low speed (20 mph or 35 km/h). These formulas were developed under the FHWA study, "Safer Sign and Luminaire Supports." The study results are contained in reports FHWA-RD-76-32, -33, -34, and -35, dated from February to October 1976.

From:

$$(\Delta MV)_H = \frac{V_L}{V_H}(\Delta MV)_L + b\left(V_H - \frac{V_L^2}{V_H}\right)$$

we obtain, in customary U.S. units [NCHRP Report 230 test speeds (29.3 to 88 ft/s)]:

$$(\Delta MV)_H = \frac{1}{3}(\Delta MV)_L + b(78.2\ ft/s)$$

or, in SI units [NCHRP Report 350 test speeds (9.72 to 28.78 m/s)]:

$$(\Delta MV)_H = 0.35(\Delta MV)_L + b(24.38\ m/s)$$

where:

ΔMV = vehicle momentum change
= vehicle mass (M) x vehicle velocity change ($V_{(L\ or\ H)} - V_X$)
$(\Delta MV)_L$ = measured vehicle momentum change in the low speed test
$(\Delta MV)_H$ = computed vehicle momentum change at the higher speed
V_L = measured impact vehicle velocity during low speed test

$$b = 1.1M_p\left(\frac{R^2}{R^2 + D_o^2}\right)$$

V_H = extrapolated vehicle velocity at the higher speed
M_p = mass of support
D_o = distance from support impact point to support c.m.
R = radius of gyration of support about its c.m.

This formula is considered acceptable for supports that break free with little or no bending in the support. It has not been tested and therefore should not be used with base bending (yielding) supports.

APPENDIX D

Suggested Evaluation Factors

Passenger Compartment Intrusion

1. Windshield intrusion

   a. No windshield contact
   b. Windshield contact, no damage
   c. Windshield contact, no intrusion
   d. Device embedded in windshield, no significant intrusion
   e. Partial intrusion into passenger compartment
   f. Complete intrusion into passenger compartment

2. Body Panel Intrusion (Yes or No)

Vehicle Control and Threat to Bystanders or Other Vehicles

1. Physical loss of Control

2. Loss of Windshield Visibility

3. Perceived Threat to Other Vehicles from Debris or Vehicle Trajectory

4. Debris on Pavement

5. Mass, Size, Shape of Significant Debris

6. Trajectories of Vehicle and Significant Debris

Vehicle and Device Condition

1. Vehicle Damage

   a. None
   b. Minor scrapes, scratches, or dents
   c. Significant cosmetic dents
   d. Major dents to grill and body panels
   e. Major structural damage