Research Record

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An Enlightening Experience

MDOT's Investigation of Tower Lighting Units Yields New Inspection Procedures

Nearly 30 years ago, the Michigan Department of Transportation (MDOT) began installing high-mast lighting systems, commonly referred to as High-Mast Luminaires (HML), or tower lighting units, at high-traffic volume interchanges and bridges throughout the state. The purpose of the HML is to provide uniform, widespread lighting to help illuminate the entire interchange geometry. This is particularly useful to drivers unfamiliar with an area, and in poor weather conditions. Anyone who has driven at night on any of Michigan's major trunklines is most likely familiar with the appearance and benefits of the HML structures.

There are currently over 400 HML located around the state, with a majority of them being located in the Metro Detroit area. There are 224 HML that were erected prior to 1981. These HML were fabricated using A-588 weathering steel. The potential for corrosion with these older HML is greater than with the HML that were erected after 1981, which are fabricated with A-572 galvanized steel.

These lighting systems are typically 24 to 38 m tall. The poles are typically circular or twelve-sided, and contain a fixture ring comprised of four to eight lighting heads. This fixture ring can be lowered via an internal cable system for routine maintenance.

Inspection Initiative

Beginning in 1991, MDOT began an inspection program to determine the overall physical condition of Michigan's HML structures. This study was initiated due in part to the fact that many of these HML were approaching 20 years of service. In addition, the Maryland Department of Transportation had reported that they were experiencing corrosion and cracking in some of their A-588 weathering steel HML poles. Subsequent reports of corrosion and cracking from both Indiana and Illinois further spurred on the project, and prompted the Structural Research Unit of the Construction and Technology (C&T) Division of MDOT to refine and intensify the inspection process.

1992 Inspection Results

In 1992, the Structural Research Unit inspected a representative number of HML. This involved an extensive inspection of one HML per interchange, with a visual inspection of every fifth HML. If problems were discovered at an interchange, every pole was then given a visual inspection. This procedure helped streamline the process, as problem areas and tendencies could be fairly quickly identified.

Common Problems

During the initial inspections carried out in 1992, there were five common problem areas that were noted. These included cracks in the longitudinal weld, partial penetration welds in the slip joint area, corrosion, improperly installed anchor bolt nuts, and HML bending.

Cracks in the Longitudinal Weld

It was found that 19 of the A-588 weathering steel HML had cracks in the longitudinal weld. Eighteen of the cracks were located in the weld at the slip joint. Each slip joint ranges between 600 mm and 900 mm, depending on the height of the structure. Cracks were typically found at the first and/or second slip joint, and were between 24 mm and 432 mm in length. The nineteenth crack was 430 mm long, and found in the longitudinal weld away from the slip joint.

A repair procedure was developed to address the longitudinal weld cracking. This procedure is discussed later in this article.

Partial Penetration Weld in the Slip Joint Area

This common problem affected 146 HML, located at 16 different interchanges. Based on the MDOT and AASHTO Standard Specifications, slip

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joint weld areas are supposed to have full penetration welds. Ultrasonic testing was used to detect partial penetration welds while testing a representative number of HML. Partial penetration welds can contribute to increased local stresses in these critical areas, which in turn can increase the probability of cracking.

Corrosion

Nearly all of the A-588 weathering steel HML had minor surface corrosion, particularly near the base. It was also found that nearly all of the HML had potential for corrosion, due to location and/or installation.

Internal Corrosion

The inside of the HML were visually inspected near the base, and ultrasonically tested outside of the base. The ultrasonic testing was used to verify the metal thickness near the base of the structure. At eight interchanges, it was found that the bases were completely sealed. This was cause for concern, as the sealed bases allowed water buildup on the inside of the structures. This water accumulation could expedite significant corrosion development from the inside of the structure near the base. At seven of the interchanges, which accounted for 74 HML, grout was used to fill the area between the base plate of the structure and the foundation. This grout was easily removed with a small sledge, which allowed proper ventilation through the HML.

At the eighth interchange, which accounted for four HML, the leveling nuts were improperly installed. Rather than having a set of leveling nuts located below the base plate of the structures, and a set of anchoring nuts located above the base plate to secure the structure, both groups of nuts were located above the base plate (see Figure 1). This placed the base plate flush with the foundation of the structure, and created the same ventilation and drainage problems noted above. This problem was more difficult to resolve, as the HML had to be removed and reinstalled with the leveling nuts relocated to the proper location below the base plate.

Figure 1: Improperly installed anchor bolt nuts

External Corrosion

It was discovered that 57 of the HML had site-specific conditions that could promote external corrosion. The two most notable conditions existed where HML were located adjacent to the roadway and exposed to salt spray, and where HML were located in low-lying areas like ditchlines and median depression. The bases of these HML were typically covered with soil and gravel.

Improperly Installed Anchor Bolt Nuts

In addition to the improperly installed anchor bolt nuts mentioned earlier, it was also found that 29 HML had loose anchor bolt nuts. In addition to sounding the nuts for tightness, ultrasonic testing was done to determine if there were any flaws in the anchor bolts. None of the bolts that were tested were found to have flaws.

Based on the findings of loose anchor bolt nuts, the *High-Mast Luminaire Anchor Bolt Tightening Procedure* memorandum for tightening loose anchor bolt nuts was sent out in February of 1992. The memorandum outlines the proper steps for tightening the bolts, ranging from cleaning threads to providing a table for proper nut/bolt torque based on the bolt diameter and the number of threads per mm.

During the inspections, it was discovered that a large percentage of the anchor bolt nuts were tack-welded to the base of the HML to lock them in place. These welds can create highly concentrated localized stress between the nuts and the base that can eventually crack and propagate. Based on this, it was determined that tack-welds should no longer be used.

Bending

Nearly all of the HML that were inspected exhibited some minor bending near the top of the pole. However, four HML were found to have bending at the top that was in excess of 1.22 meters (see Figure 2). These structures were the first HML installed by MDOT, and have a significantly smaller cross-section at the top of the structure than the rest of the HML located around the state. This bending is not critical at the moment; however, these HML will be closely monitored as they are more susceptible to weld cracks due to the increased tensile stress in the slip joint areas.

1994 Inspection Results

MDOT performed a second round of inspections on the HML in 1994. These inspections were more centered on the base of the HML, and focused on many of the problem areas found during the 1992 inspections. These areas included: gaps between the leveling nut and HML base plate; loose leveling and top nuts; anchor bolts out of plumb; anchor bolts not fully engaged into the nut; missing washers; nuts and washers tack-welded to base plate; missing or damaged rodent screens; grout under the base plate; anchor bolts and nuts with little or no galvanizing remaining.

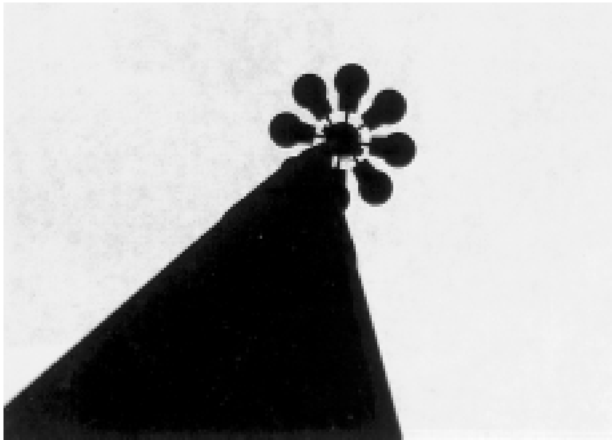

Figure 2: Severe bending at the top of an HML

Testing and Repair

Based on the cracking found in the A-588 weathering steel HML at the slip joint area, a repair procedure was developed. It was decided that rather than replace the defective HML at an estimated $35,000 per pole, it would be more cost effective to repair the existing cracked structures. It is estimated that the remaining service life of the repaired HML is approximately 10-15 years.

Procedures

The following steps were used to inspect and repair each of the defective HML:

1. The area around the crack region was ground to remove any irregularities on the surface of the A-588 weathering steel. This created a smooth surface that was essential for accurate ultrasonic testing.
2. The length of the crack and the location of the crack tip in the weld area was found through ultrasonic testing.
3. A 38.1 mm diameter hole was drilled at the crack tip to relieve residual tensile stresses. The hole also precluded further crack extension.
4. Dye penetrant testing was performed to confirm the crack did not extend beyond the upper end of the hole.
5. The area surrounding the hole, and the weld area around the hole were painted with a zinc-based paint to prevent further corrosion of the HML. The hole was then plugged with a rubber stopper.

Cores were removed from the holes drilled at the crack tip. These cores were further examined in the laboratory. After being polished and etched, it was found that all the cracks were contained within the weld or in the adjacent heat-affected zone.

In addition to determining the extent of the cracking, providing a means of repairing the cracking, and preventing further cracking in the longitudinal joint areas, the researchers needed to understand the cause of the cracking. It appears that the cracking is the result of defects in the longitudinal welds, combined with high residual stress fields that allows stress corrosion cracking (SCC) to occur. This type of cracking is generally associated with weathering steels, as the stress normally needed for initiation do not normally occur. However, stress studies performed by the Illinois Department of Transportation indicated that the material used in the manufacture of some of the poles was cold worked to the point that higher than normal residual stresses existed adjacent to the weld areas. This in turn allowed smaller defects to create the greater stress intensity factors necessary for SCC.

Collar Design

The Structural Research Unit designed a 100 mm wide by 6 mm thick collar that wrapped around the area of the crack to replace any lost material, and to reduce the stress intensity in the area of the blunted crack tip. The collars were constructed with A-588 weathering steel to ensure compatibility, and to help eliminate the need for future maintenance. The collars were constructed with 25 mm diameter A325 Type 3 bolts and high strength connection lugs (see Figure 3). The bolts were tightened to 133 kN, which applied a circumferential stress of 207 Mpa into the pole. This load was chosen because it provides the desired amount of compressive force across the crack, minimizes the chance of future corrosion between the collar and the HML, and allows reserve capacity in the event of high-wind situations. The bolts are positioned perpendicular to the crack surface.

All of the defective A-588 weathering steel HML were repaired in this fashion by the Structural Research Unit. Subsequent inspections of the collars have shown through the tension in the bolts that they are sustaining the desired load. One minor problem with the collar design is that the collar can interfere with the lowering of the fixture ring during maintenance.

Figure 3: Collars installed over crack on HML

Conclusions

Based on the results of the studies, and the repairs used to address the common problems, an inspection program has been developed to ensure the integrity of all the HML statewide. The procedures will assist in recognizing and preventing future problems within the HML population around the state.

Current MDOT HML Policy

MDOT has developed the following policies based on the results of the research:

1. Michigan's HML are currently inspected once every two years. The inspections include a visual inspection of the HML from the ground using binoculars, and ultrasonic inspection of the anchor bolts.
2. Anchor bolts are tightened to just below their yield point to prevent nut loosening, increase fatigue life, provide an even distribution of stress, and compensate for bolt/nut relaxation.
3. Grout is no longer used under the base plate of the HML. This promotes air circulation on the inside of the pole to reduce the likelihood of corrosion.
4. Tack welds on anchor bolt nuts are no longer used
5. HML are no longer located within a ditch line. HML are placed at least 10 m from the roadway to minimize the amount of salt spray reaching the pole.

Updated Weld Penetration Inspection Procedure

To better insure that quality full penetration butt welds are achieved at the slip joints of HML's, MDOT has recently developed a specification for ultrasonic inspection of the welds. This new specification is not only used to inspect existing HML, but it is also a requirement for fabricators supplying HML to contractors. Previously, MDOT specifications for fabricators required magnetic particle inspection of the full penetration butt welds. Magnetic particle inspection was used for the inspection procedure because the American Welding Societies Structural Welding Code (ANSI/AWS D1.1-96) does not provide an acceptance criteria for full penetration butt welds in materials thinner than 8 mm. Using the extensive experience gained from this research project, including the numerous inspections of Michigan's HMLs, MDOT developed a specification for ultrasonic testing of the full penetration butt welds. For the thin material thicknesses used on HMLs, Michigan uses a smaller diameter and higher frequency search unit when doing ultrasonic inspections. MDOT's new specification sets the acceptance/rejection criteria according to table 6.3 of AWS D1.1-96 for 8 mm material thickness, except that the values shown in the table are reduced by 10 dB. The 10 dB reduction is to account for the thinner material being tested and the modified frequency and diameter of the search unit. For a more detailed explanation of the testing procedures and requirements, please refer to the MDOT *Special Provision for Tower Lighting Units* that was approved on June 5, 2000.

Contact Information

For more information regarding this study, contact Dave Juntunen at (517) 322-5707, or via email at JUNTUNEND@mdot.state.mi.us. For more information regarding the *High-Mast Luminaire Anchor Bolt Tightening Procedure*, the *Procedure for the Inspection of High-Mast Luminaires*, the High-Mast Luminaire Inspection form, and the MDOT *Special Provision for Tower Lighting Units*, contact Steve Cook at (517) 522-5709, or via email at cooksj@mdot.state.mi.us.

Reference Material

Much of the text within this Research Record was used with permission from the following report:
Inspection and Repair of High-Mast Luminaires (HML)
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Report Number: R-1342
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Michigan Department of Transportation
Construction and Technology Division
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Editor's Correction

Please note that in Research Record, Issue # 88, it was stated that MDOT currently uses latex-modified concrete for standard overlays. Although this information is correct, the article implied that the is the only type of concrete used for standard overlays, which is incorrect. In addition to using latex-modified concrete, MDOT also uses silica fume modified concrete (SFMC) in their standard overlays.

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