Fatigue Evaluation of Reinforced and Unreinforced Hand Holes in High-Mast Lighting Towers

tech transfer summary

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RESEARCH PROJECT TITLE
Fatigue Evaluation of Reinforced and Unreinforced Hand Holes in Light Poles

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The Bridge Engineering Center (BEC) is part of the Institute for Transportation (InTrans) at Iowa State University. The mission of the BEC is to conduct research on bridge technologies to help bridge designers/owners design, build, and maintain long-lasting bridges.

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This project evaluated high-mast lighting pole specimens with two different hand hole opening ratios by conducting fatigue tests to better understand the influence of hand holes on the fatigue resistance of these tall structures.

Problem Statement

Hand holes are openings at the base of high-mast lighting towers that provide access to electrical wiring inside the structure but also create an irregular shape on the base part of the structure, which can result in stress concentration and a high stress level around the opening. Yet, there are few studies on the influence of the hand hole on performance of a high-mast lighting structure and its fatigue performance.

Goal

The goal of the research was to identify the fatigue resistance of high-mast lighting pole specimens with different opening ratios of the hand hole, specifically those at a higher percentage to the code values.

Background

High-mast lighting structures have been widely used to illuminate large areas such as freeways, airports, stadiums, and sports facilities throughout the nation and across the world. Generally, these structures are composed of a high-mast tapered pole and luminaire assembly installed at the tip of the pole. Typically, the height of these structures can be from 50 ft to 150 ft.

The current design standard requires that the width of the opening shall not be greater than 40% of the tube diameter. It also specifies that when calculating the nominal stress at the hand hole, it should be magnified by a stress concentration of 4.0.

In some pole structures with a small diameter, the design standard is actually difficult to follow. A limited review of the currently fabricated structures showed that openings as large as 87% of the pole diameter have been used. The application of the stress concentration factor of 4.0 on these poles results in either increasing the thickness of the tubes or increasing the dimeter of the tube, which leads to a much more expensive pole and overall luminaire system.

In addition, because of the slenderness and the large mass of the structure itself, a high stress level usually appears at the base part of the structure while the structure is vibrating. At the same time, low structural damping causes stress cycles at the base part of the structure to easily accumulate, and eventually fatigue damage is created on the structure. Thus, failures and cracking of high-mast lighting structures have been frequently reported.

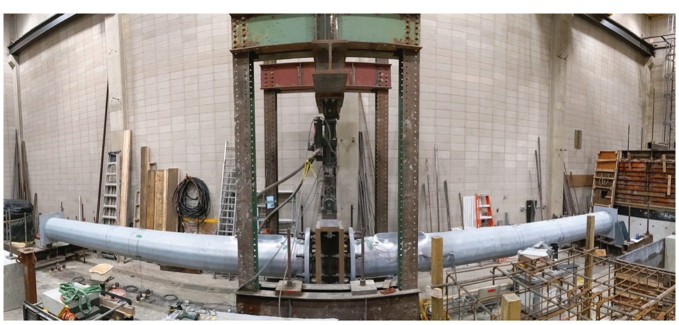
Project Description

- **Finite element analysis.** Finite element models of two previously built specimens were used that had a hand hole opening ratio of 46%. Two additional specimens were built that had the same base-plate-to-tube connection as the initial specimens but an increased hand hole opening with a ratio of 54%. Thus, four different pole specimen models were built to study the influence of the hand hole.

- **Static analysis.** Using the finite element analysis models, a static analysis was conducted by applying a simulated 1 kip static load in both directions at the top surface of the top plate to compare the stress response at the base.

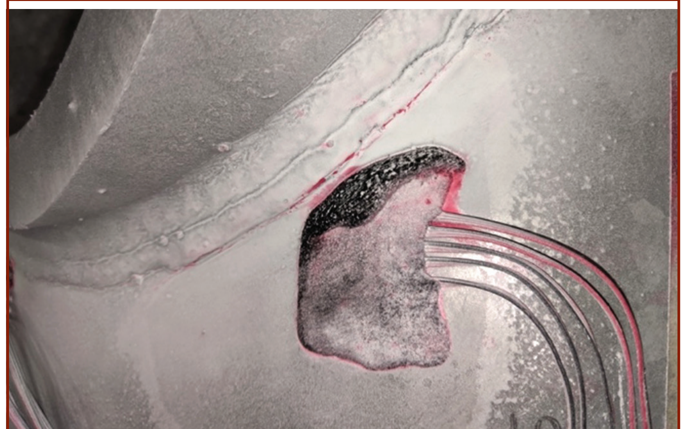
- **Fatigue tests:**
  - The research team selected two specimens equivalent to those from previous tests, and others that showed the maximum stress range at different locations and with different hand hole opening ratios, to study their fatigue resistance in laboratory tests. Two of each specimen type were purchased and instrumented with strain gauges and displacement sensors that were connected to a data acquisition software package. The two specimens were tested together and two fatigue tests were conducted.
  - Static testing was conducted before the fatigue test to determine the required fatigue load at the loading box.
  - In addition, before each fatigue test, the team conducted an inspection of the specimens through both a dye penetrant test and a magnetic particle test to ensure they were in good condition before initiating the fatigue tests. The same tests were also conducted at different numbers of cycles to continue checking the condition of the specimens.
  - Fatigue tests were conducted at a nominal stress range of 8 ksi and 16 ksi, and the fatigue resistance of both specimens was determined by American Association of State Highway and Transportation Officials (AASHTO) fatigue category. The fatigue tests continued until fatigue failure appeared.

- **Parametric study.** Additional finite element models with different opening ratios were built to conduct a parametric study to observe the change of the stress response at the pole base based on the results from the fatigue tests.

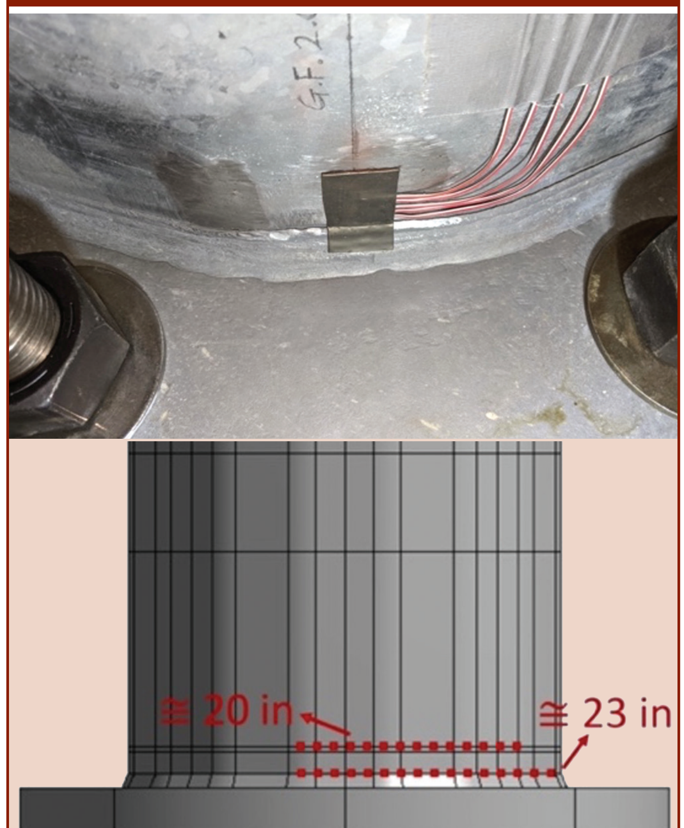


Fatigue experiment setup

Specimen A-1, with 46% opening ratio hand hole, showed no indications with dye penetrant test after 1,000,000 cycles at 8 ksi



Specimen B-1, with 54% opening ratio hand hole, showed few indications with dye penetrant test after 1,000,000 cycles at 8ksi



Specimen B-2, with 54% opening ratio hand hole, showed fatigue cracks at the back side of the base-to-tube connection after 115,000 cycles at 16 ksi

Fatigue test results

Key Findings

- The fatigue resistance of the base-to-tube connection decreased as the opening ratio of the hand hole increases. The specimen with an opening ratio of 46% had a fatigue resistance of its base-to-tube connection higher than Category E′ and possibly lower than Category E. The specimen with opening ratio of 54% had a fatigue resistance of its base-to-tube connection near the lower limit of Category E′. The parametric study found that, as the opening ratio increases, there's a slightly increasing trend of stress at the base-to-tube connection. This could be why fatigue resistance decreases at the base-to-tube connection.
- The fatigue resistance of the hand-hole-to-tube connection might be higher than the base-to-tube connection, as no fatigue cracks were observed around both larger and smaller hand holes in either fatigue test.
- The location of fatigue cracks on a high-mast lighting pole specimen might not completely relate to the stress response, as fatigue cracks were only observed at the base-to-tube connection. However, the stress response at the base-to-tube connection was lower than the stress response at the hand hole corners. There might be other factors such as the geometry near the discontinuities that determine where a fatigue crack will occur on a pole specimen.

Implementation Readiness and Benefits

This project, which evaluated two high-mast lighting pole specimens with different hand hole opening ratios, represents an initial effort to better understand the influence a hand hole has on the structure's fatigue performance.

However, at this point, additional tests on different specimen types with different opening ratios are needed to do the following:

- Identify their fatigue resistance category and scalar more precisely
- Develop the relationship between the opening ratio and fatigue resistance, which manufacturers could use to determine the appropriate opening size based on the required fatigue resistance

Ultimately, the results of additional tests will help the research team to develop recommendations to amend Iowa Department of Transportation (DOT) specifications as they relate to these structures.