Evaluating Fatigue Performance of Sign, Signal and Luminaire Structures

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Summary

Fatigue performance of welded connections in highway signs, signals and high level luminaire structures are being evaluated as part of ongoing research under NCHRP Project 10-70. Most of the fatigue cracking in service has been reported in tube-to-end plate welds at a relatively short life due to the large secondary out of plane stresses in the tube walls. The existing AASHTO specification is often inadequate in designing these structures against service limit state of fatigue. This paper presents evaluation of welded connections in 12 full size sign/signal and high level luminaire structures.

Keywords: sign structures; signal structures; high-mast structures; fatigue; tube-to-transverse plate connection; socket connection; hot-spot stress.

1. Introduction

In the past two decades, fatigue cracking of highway sign, luminaire and traffic signal structures has been increasingly reported all over the United States. Most of the highway sign, luminaire and traffic signal structures are cantilevers, built with thin-walled hollow shapes of circular or multisided cross section. Because of their inherent dynamic characteristics and cross-sectional shapes, these flexible structures experience large number of stress cycles from wind induced vibrations that impart fatigue damage to the various welded connections.

The primary load carrying mechanism in these thin tubular structures is through in-plane membrane stresses. In the vicinity of the tube-to-end plate connection, however, the compatibility requirement introduces out of plane flexural deformation that translates into out-of-plane bending stresses through the thickness of the tube wall. The superposition of large out-of-plane flexural stress on to the in-plane membrane stress magnifies the local stress on the tube surface.

Fatigue cracking of the subject structures in service has initiated mostly from the weld termination on the tube wall either at the pole-to-base plate connection, or the arm-to-end plate connection. In addition, fatigue cracking has been reported in hand hole frame-to-pole connection and the gusset-to-pole junction in the mast arm-to pole box connection, also initiating at the weld toe. Fatigue cracking at the weld toe precipitates due to stress concentration at the weld bead geometry, presence of crack-like slag inclusion micro discontinuities that act as initial flaws, and high tensile residual stress inherent to the welding process, which promotes crack propagation. In these thin walled tubular structures, the in-plane membrane stress near the weld toe is augmented by the out-of-plane bending stress leading to fatigue cracking.

The fatigue design guidelines in the current *AASHTO Standard Specification for Structural Supports for Highway Signs, Luminaires, and Traffic Signals, 4th. Edition,* do not consider the out-of-plane deformation associated with the connection geometry and as such, nonconformities were noted between the recommended fatigue categories and the limited test results for some details that were obtained after publication of the specification. To provide basis for upgrading the specification, a research program is currently underway at the ATLSS Centre, Lehigh University. This paper

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discusses the findings of studies conducted under Task 7 of the test program as part of validation of experimental and analytical protocols.

2. Experimental studies

Twelve full scale specimens divided equally into four specimen types identified as Type I, II, VII and X were tested. Specimens Type I and II were round and Type VII and X were multisided. The round specimens and the specimens Type VII were pole and mast arm assemblies representing highway sign and traffic signal structures. The three specimens Type X represented high-level luminaire structures. All specimens were hot-dip galvanized.

3. Discussion of results

The S-N plot of the fatigue test results were plotted along with the fatigue design curves from the AASHTO LRFD Bridge Design Specification. In addition, the predicted fatigue lives of the various critical details determined by the hot-spot stress methodology suggested in the *Det Norske Veritas (DNV) Recommended Practice DNV-RP-C203: Fatigue Design of Offshore Steel Structures* for tubular joints in the finite life regime were included in the plots. The hot-spot stress was determined from the Finite Element Analyses (FEA) of three dimensional models of the structures containing all the features namely, the poles, the mast arms, all the fixtures and fasteners, and the nominal weld geometry.

The arm tube-to-end plate socket connection in the round specimen Type I exhibited a large spread in fatigue resistance. The least fatigue resistance exhibited by this detail was slightly less than Category E´ design curve. The analytical prediction of fatigue life for this detail was slightly less than AASHTO Category E´. Despite early initiation of fatigue cracks in the tube-to-end plate socket connection in the multi-sided specimen Type VII, a fatigue resistance close to AASHTO Category E´ was exhibited by the mast arms and the poles when the cracks grew up to a cumulative length of 127 mm. The tube-to-base plate socket connection in the high-mast specimen Type X also exhibited a large spread in fatigue resistance. The predicted fatigue performance for this detail was Category E´ and this detail achieved the AASHTO Category E´ fatigue resistance at the least life. When tested at the stress range level above the AASHTO Category D CAFT, one of these details exceeded the upper bound estimate of Category D, suggesting that the test stress range was probably close to the CAFT of this detail. The existing specification does not distinguish between the fatigue performances of round and multisided cross sections and classifies all socket connections as Category E´ irrespective of the relative stiffness of the tube and the end plate.

Both the arm backing ring-to-tube seal welds and the tube-to-end plate full-penetration welds in the Type II specimens exceeded the Category E fatigue resistance. The hot-spot stress method predicted a Category E fatigue resistance for the arm backing ring seal weld, but classified the arm full-penetration weld as a Category E´ detail. In the current specification, groove welded tube-to-end plate connections are classified as Category E.

4. Conclusions

The research demonstrated that the geometric parameters have a significant effect on the fatigue performance of connection details in the subject structures. The fatigue design provisions in the current AASHTO specification for these structures do not consider the out of plane bending effect resulting in discrepancies between the specification recommendations and actual performance. The hot-spot stress based analytical protocol demonstrated sufficient promise in predicting a lower bound estimate of the fatigue performance of a connection detail. Due to the inherent scatter in fatigue lives primarily associated with the uncontrolled variables such as the weld toe geometry and the micro discontinuities, the lives of 97.5% of a detail population are expected to be higher than this lower bound estimate. The larger scatter in the test results exhibited by the welded connections was due to the large variation in the global weld angle. Additional analytical and experimental studies are currently ongoing, including fatigue testing of more than 60 full size specimens. The findings of this study and the studies by other researchers will provide the basis for updating the AASHTO specification.