WIND LOADS ON DYNAMIC MESSAGE CABINETS AND BEHAVIOR OF SUPPORTING TRUSSES

August 2013

RESEARCH PROJECT TITLE
Wind loads on dynamic message cabinets and behavior of supporting trusses

SPONSORS
Iowa Highway Research Board (TR-612) and The Federal Highway Administration

PRINCIPAL INVESTIGATORS

George Constantinescu
Asghar Bhatti
Department of Civil and Environmental Engineering
The University of Iowa
Iowa City, IA
319-384-0630
sconstan@engineering.uiowa.edu
319-335-5656
mabhatti@engineering.uiowa.edu

Terry Wipf
Brent Phares
Department of Civil, Construction and Environmental Engineering & The Bridge Engineering Center at the Institute for Transportation, Iowa State University,
Ames, IA

Objectives

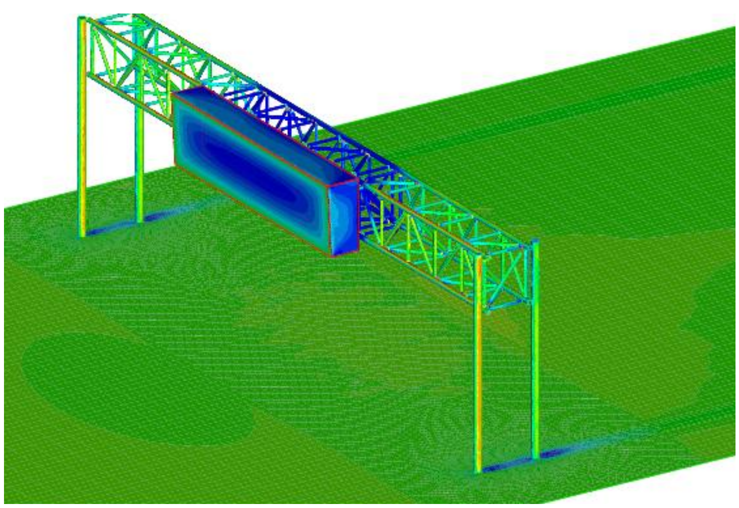
The objectives of this study are to investigate wind and thermal effects on the bridge type overhead trusses supporting Dynamic Message Sign (DMS) cabinets. The goal is to understand the behavior causing cracking in some truss members and to improve current design specifications and methods.

Problem Statement

Large DMS cabinets have been increasingly used on freeways, expressways and major arterials to better manage traffic flow by providing accurate and timely information to drivers. Overhead truss structures are typically employed to support these DMS cabinets allowing for wide displays over traffic lanes. Since the DMS cabinets have larger depth and are heavier than the usual highway signs there is some concern that the truss structures supporting these large and heavy signs are subjected to much more complex loadings than are typically accounted for in the codified design procedures. Some of these structures have required frequent inspections, retrofitting, and even premature replacement. Two manufacturing processes are primarily utilized on truss structures - welding and bolting. Recently, cracks at welding toes were reported for the structures employed in some states. Extremely large loads (e.g., due to high winds) could cause brittle fractures, and cyclic vibration (e.g., due to diurnal variation in temperature or due to oscillations in the wind force induced by vortex shedding behind the DMS) may lead to fatigue damage, as these are two major failures for the metallic material. Other factors that can contribute to the development of cracks are fatigue induced by wind loads associated with the passage of trucks underneath the DMS cabinets. Wind and strain resulting from temperature changes are main loads that affect the structures during their lifetime.

Approach

The study is divided into two parts. The Computational Fluid Dynamics (CFD) component and part of the structural analysis component of the study were conducted at the University of Iowa while the field study and related structural analysis computations were conducted at Iowa State University.

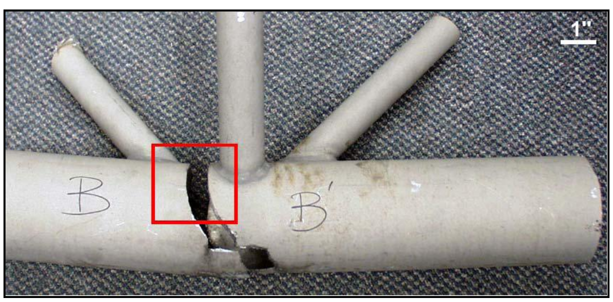


DMS cabinet attached to a truss. CFD was used to estimate wind induced pressure forces on the DMS and the truss members and then to estimate stresses and deformation of truss members

The CFD simulations were used to determine the air-induced forces (wind loads) on the DMS cabinets and finite element analysis was used to determine the response of the supporting trusses to these pressure forces. The numerical simulations model used the same trusses that were selected for the field monitoring study.

The field observation portion consisted of short-term monitoring of several trusses and long-term monitoring of one truss supporting DMS Cabinets. The trusses were instrumented with strain gauges, accelerometers, and pressure gauges. The short-term monitoring involved taking measurements over one or two days. The long-term monitoring field study extended over several months. Long-term field monitoring of one of the overhead truss structures in Iowa was used as the research baseline to estimate the relationship between diurnal temperature changes and fatigue damage. Finite element modeling was developed to estimate the strain and stress magnitudes, which were compared with the field monitoring data. As part of the analysis, the stress occurring under extreme thermal conditions were estimated. Fatigue life of the truss structures was also estimated based on AASHTO specifications and the numerical modeling. Analysis of the data focused on trying to identify important behaviors under both ambient and truck induced winds and the effect of daily temperature changes.

View of a strain gage attached on a truss member



Picture showing a crack developing at the welding heat zone

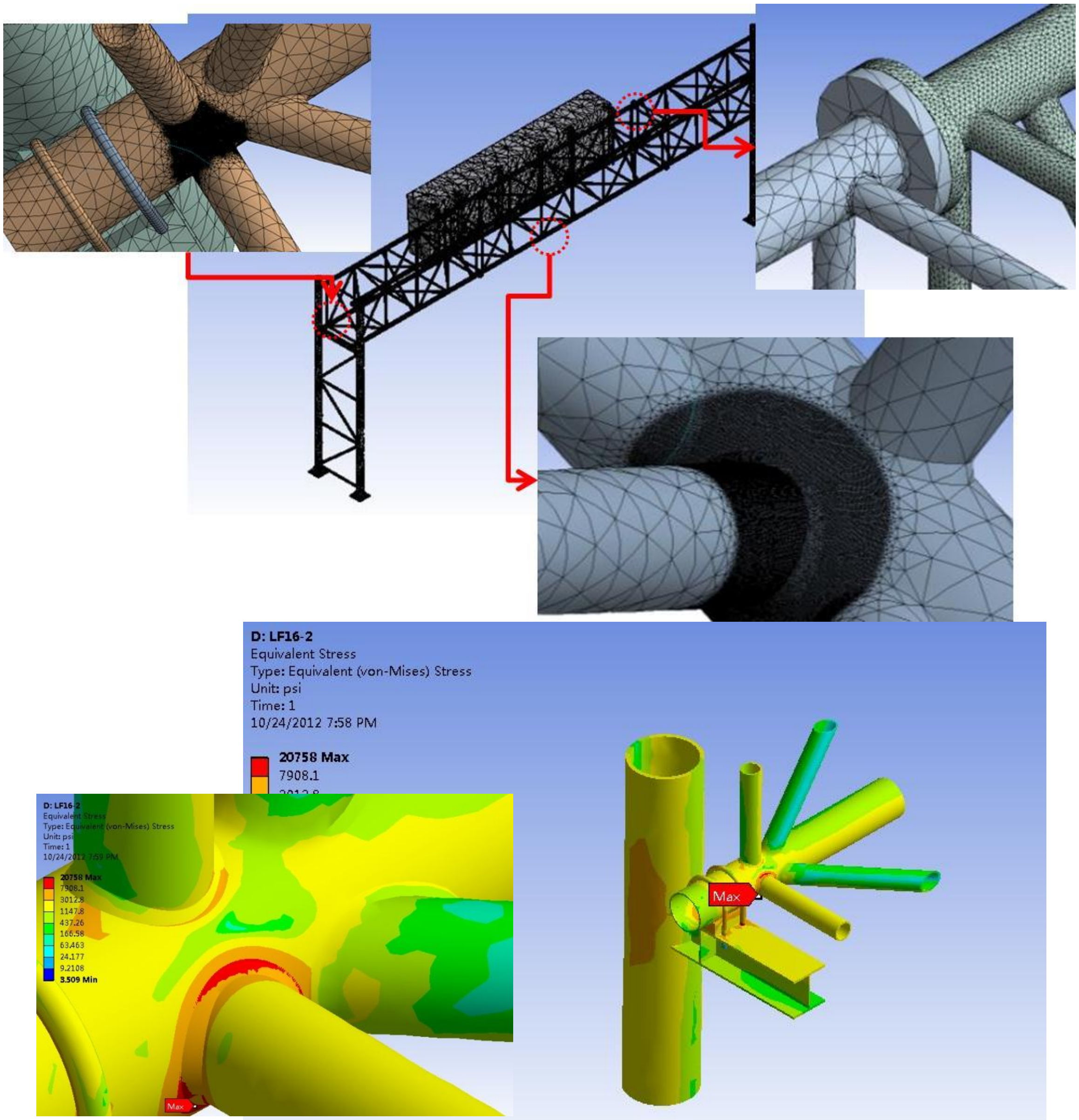
Key Findings

Results of the CFD investigation, field experiments and structural analysis of the wind induced forces on the DMS cabinets and their effect on the supporting trusses showed that the increase in wind pressure due passage of trucks is fairly minimal and cannot be responsible for the problems observed in the trusses supporting DMS cabinets.

The data collected as part of this study points towards the effect of the thermal load induced by cyclic (diurnal) variations of the temperature as a main cause for the problems observed at trusses supporting the DMS cabinets. The temperature induced strains measured at the trusses that were monitored far exceeded any strains resulting from the increased wind pressure due to passage of trucks. Although the frequency of the thermal load is low, results showed that when temperature range is large the stress range would be significant to the structure, especially near welding areas where stress concentrations may occur. Moreover, stress amplitude and range are the primary parameters for brittle fracture and fatigue life estimation.

The data collected data as part of the truss monitoring programs provided a wealth of information that allows understanding the structural behavior of the trusses and can be used to include thermal influence in AASHTO specifications for design of trusses supporting traffic signs. This is one of the few studies where truss structures were tested to understand the thermal response.

The main conclusion of the study is that thermal induced fatigue damage of the truss structures supporting DMS cabinets is likely a significant contributing cause for the cracks observed in such structures.



Mesh used in 3D solid model of the truss and DMS. The model allowed estimating used the thermal and normal strain distribution. The bottom figure shows the maximum stress area predicted by the 3D model

Recommendations for Future Research

The study identified two other possible causes for fatigue damage that we think should be considered in a future study:

1) Cyclic oscillations of the total wind load associated with the vortex shedding behind the DMS cabinet under high wind conditions. These oscillations develop even under steady wind conditions due to the unsteady vortex shedding which takes place in the air wake of the flow past the cabinets. A resonance condition, causing large amplitude relatively steady vibrations of the support trusses can occur if the frequency of shedding coincides with a natural vibration frequency of the DMS cabinet. Vortex-shedding can occur at relatively low wind speeds and thus, even if the structure has enough strength, such large oscillations may contribute to premature fatigue failure

2) Fabrication tolerances and induced stresses due to fitting of tube to tube connections. Although inconclusive here, it is believed that fabrication may play an important role in the development of fatigue cracks. However, given the variety of different fabrication styles and potential fabrication errors, there are likely multiple causes for the development of cracks.