Effect of Wind Induced Unsteady Vortex Shedding, Diurnal Temperature Changes, and Transit Conditions on Truss Structures Supporting Large Highway Signs

March 2018

RESEARCH PROJECT TITLE

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SPONSORS

Iowa Highway Research Board (TR-687) and The Federal Highway Administration

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Problem Statement

Overhead truss structures are typically employed to support dynamic message sign (DMS) cabinets allowing wide display over more lanes. DMS cabinets are much heavier than typical highway signs. The current American Association of State Highway and Transportation Officials *LRFD Standard Specifications for Structural Supports for Highway Signs, Luminaries and Traffic Signals* (AASHTO 2015), which is the main document used for design of sign support structures by state DOTs in the US, does not give clear guidance for estimating wind loads in these situations. This increases the uncertainty in estimating stresses induced in the members of the truss structure supporting the DMS cabinet. Having detailed understanding of stresses caused during the service life of the trusses supporting DMS cabinets is crucial for their safe and economic design. In recent years, there is increasing evidence that the truss structures supporting a variety of large and heavy signs are subjected to much more complex loadings than those typically accounted for in the codified design procedures. Consequently, some of these structures have required frequent inspections, retrofitting, and even premature replacement. To reliably predict the behavior of these structures, and to design them properly, detailed knowledge of the wind forces acting on the signs and the truss members is obviously necessary. Besides wind loading the highway sign structures may be subjected to fatigue induced by stresses caused during the transport of trusses to the site and those caused by large diurnal temperature variations.

Objectives

The first objective of this study is to accurately estimate unsteady wind loads acting on the DMS cabinets and other traffic signs and on the members of the truss structures supporting these signs. The cyclic oscillations of the total wind load associated with vortex shedding behind traffic signs may be a main contributor to premature fatigue failure. This is because these cyclic oscillations, that occur even under steady incoming wind conditions, can create a resonance condition. The second objective is to investigate possible fatigue failure due to vibrations during transportation from fabricator to the site where the truss and DMS cabinet will be deployed. The third objective is to investigate diurnal temperature effects on the fatigue life of structures.

Approach

The study is divided into two parts. The computational fluid dynamics (CFD) study related to the first objective, was conducted by the University of Iowa. The truss monitoring during its transport and investigation of diurnal temperature effects related to second and third objectives were conducted by Iowa State University.

Detailed CFD simulations were conducted to determine the air-induced mean (time-averaged) wind forces on the DMS cabinets and normal traffic signs of different configurations of interest to the Iowa DOT. The time-accurate simulations resolve the large scale turbulent eddies in the wake of the sign and take into account the unsteady wind loads associated with vortex shedding behind the sign. Based on this information, the mean drag coefficients for the DMS cabinets and other traffic signs were estimated. The CFD simulations also provided the time series of the instantaneous drag coefficient, based on which the main variables required to perform a structural fatigue analysis of the truss support structure can be estimated. A detailed vulnerability assessment of sign support structures during transportation was conducted.

To investigate the possibility and extent of damage during transportation, a detailed experimental and numerical study was conducted. One span of an overhead DMS-support truss was instrumented with strain gauges to measure the stress/strain induced during transportation. A numerical model was developed to quantitatively characterize vibration induced by the road profile. Several types of road roughness profiles were considered. Besides the data collected from the field, a detailed finite element model of the complete structure was created to obtain an in-depth understanding of the potential modes of damage and failure. Results of a fatigue analysis based on real time field monitoring of DMS support structures under long-term environmental conditions were also reported. Beside the experimental study, a detailed finite element model was developed to investigate the fatigue life of the most critical parts of structure.

Key Findings

A significant finding of this study is that AASHTO 2015 underestimates the wind drag coefficient for signs by as much as 25% (see Figure 1). At the same time, the CFD results show that the *Minimum Design Loads for Buildings and Other Structures* (ASCE/SEI 7-10) recommendations for the design of aluminum sign structures is too conservative. The other main contribution of Part I is to propose a relatively simple procedure to estimate drag forces on the members of the support structure (e.g., truss). The current procedures to estimate wind loads on the members of the supporting structures are based on many simplifying assumptions and are not straightforward to apply for practical cases (e.g., as described in NCHRP Project 17-10(2), various AASHTO and ASCE specifications, and design manuals used by state DOTs). The proposed procedure is much simpler and less confusing than current procedures used by the Iowa DOT.

A main finding of the fatigue analysis conducted for the truss structure is that transportation over a few hours can cause fatigue damage similar to up to months of in-service loading. Based on both the experimental and the numerical studies, it was found that the diurnal temperature variations do not have a major effect on the truss structures used to support highway signs in Iowa.

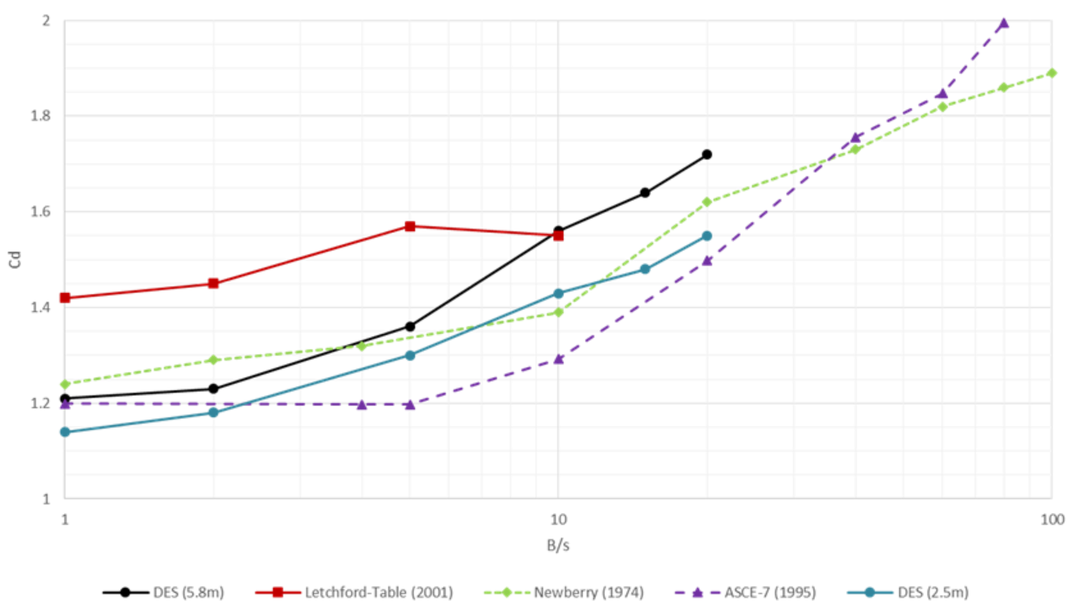

Figure 1. Effect of sign aspect ratio on the mean drag coefficient for a fixed clearance ratio. The figure shows variation of drag coefficient with relative ground clearance height for the present numerical simulation results for the rectangular sign with a height *s*=5.8 m=19 ft. Also shown are the experimental results reported by Letchford (2001), Newberry and Eaton (1974) and the ASCE-7 (1995) standard.

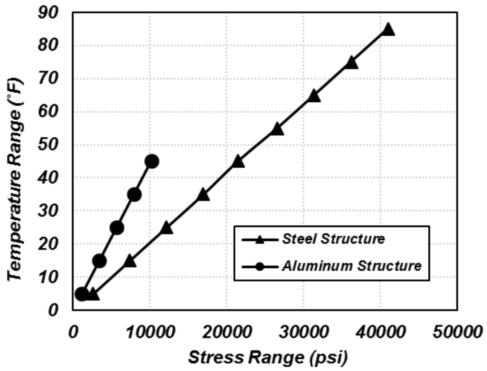

Figure 2. Correlation between temperature range and the stress range derived from the finite-element models of steel and aluminum DMS-support structures.

Moreover, it was demonstrated that a 1-D linear element of truss steel structure experiences significantly higher stresses than an aluminum one. However, the steel structure has roughly 30% more fatigue life comparing aluminum structure. A direct comparison of the two truss structures indicated that the steel structure has a highly better fatigue performance (Figure 2). Comparing two different cycle counting method, i.e. rainflow and daily cycle counting methods, it was concluded that the daily cycle counting method underestimated the fatigue life, while the rainflow cycle counting method was more accurate for fatigue analysis.

Recommendations For Future Research

A main recommendation from the present study is to increase the mean drag coefficient values in the AASHTO 2015 standard (*LRFD Standard Specifications for Structural Supports for Highway Signs, Luminaries and Traffic Signals*) by about 25%. Another recommendation supported by the findings of the present study is that AASHTO should provide more information on how the drag coefficient of the traffic sign varies with the shape of the sign and other geometrical parameters affecting the value of the wind loads.

Present work strongly suggests that using data from numerical simulations of forces acting on the members of the truss supporting a highway sign, it should be possible to develop a new methodology to estimate wind loads on the members of the structures supporting highway signs. Future work should focus on developing recommendations on how to split the support structure into different regions and provide values of the drag coefficients to be used for the unshielded and shielded members within these regions. These recommendations can replace present procedures to estimate wind loads on trusses used by the state DOTs that are not easy to implement, are fairly simplistic and subject to large errors.

Related to fatigue analysis, it is recommended that future trusses be constructed using steel members with connection details similar to those studied in the present work. It is also recommended that additional monitoring of trusses during transportation be conducted with the goal of developing best practices for transporting these trusses. The present study identified that a disproportionate percentage of fatigue life was used during transportation. Other anecdotal evidence illustrates that in some cases 100% of fatigue life has been used, resulting in cracked members upon delivery. The apparent main contributing factor appears to be the means and method of securing the truss during transportation. The development of a best practices guide would represent an important step in ensuring that upon installation trusses are in the best possible condition.