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Transportation Literature Search

Sign Support Connection Fatigue

Prepared for
Wisconsin Highway Research Program
Structures Technical Oversight Committee

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Transportation Literature Searches are prepared for WisDOT staff and principal investigators to heighten awareness of completed research in areas of current interest. The citations below are representative, rather than exhaustive, of available English-language studies on the topic. Primary online resources for the literature searches are OCLC's WorldCat and TLCat, U.S. DOT's TRIS Online, the National Transportation Library (NTL), TRB's Research in Progress (RiP) and other academic, engineering and scientific databases as appropriate. Links to online copies of cited literature are noted when available. Hard copies may be obtained through the WisDOT Library at library@dot.state.wi.us or 608-264-8142.

SUMMARY
In our search of the above databases, we found 16 documents that pertain to fatigue problems in sign support connections and to sound sign support design. Four of these were published in 2005, six in 2004, four in 2003 and two in 2000. Federal agencies published three of these; states including Alabama, Connecticut and Ohio published four (Alabama produced two); academic journals and conference proceedings issued five; and the remaining four include one trade news monthly article and three M.S. theses. No Research in Progress currently addresses fatigue issues in sign supports.

KEYWORDS
Sign support, fatigue, connection, weld, bolt.

CITATIONS

Title: Dynamic load environment of bridge-mounted sign support structures: a special student study
Author(s): Bartlomiej Francisze Zalewski, Arthur A. Huckelbridge
Date: September 2005
Doc ID/URL: Report No. ST/SS/05-002. http://www.dot.state.oh.us/research/2005/Structures/134153-FR.PDF
Description: 67 pp.
Contents: An investigation was conducted into the failure of a welded aluminum truss sign support structure on an existing interstate highway bridge. The investigation was conducted in three main steps; 1) fatigue testing in the laboratory of surviving segments of the failed sign, 2) collection of dynamic response data of the identical replacement structure in situ, and 3) finite element modeling and simulation of the bridge and truss structural system. The welded aluminum space truss indicated a typical fatigue failure, with a fatigue crack initiating at a welded chord/diagonal connection detail (AASHTO fatigue category ET; CAFL = .44 ksi). Fatigue testing in the laboratory of surviving segments of the structure produced an identical fatigue failure at a similar location after 3,000,000 load cycles at a 1 ksi stress range. Field monitoring of acceleration data at three different locations of the in-situ truss was conducted in order to characterize the dynamic behavior of the truss and the bridge structural system. A finite element model of a segment of the multi-span bridge which included the mounting location of the sign support truss, was assembled. In the modeling of the truss a moving traffic load, consisting of a single truck, was considered. A modal time history analysis for moving vehicle loads was performed. The analysis results indicated that the failure was a classical fatigue rupture, induced primarily by the dynamic effect of moving truck traffic on the bridge. Even though inferred cyclic stress levels were well below the CAFL for the detail in question, the extremely high number of low amplitude traffic-induced stress cycles (in the hundreds of millions), combined with the absence of an endurance limit for welded aluminum, resulted in the observed failure. (A typical truck passage resulted in roughly 75 stress cycles in the truss, due to the low damping and extended time of vibration

decay.) The predicted lifetime of the replacement sign support structure is approximately that exhibited by the original structure, namely thirty to forty years.

Title: Practical fatigue/cost assessment of steel overhead sign support structures subjected to wind load
Author(s): J.W. Van de Lindt, T.M. Ahlborn
Date: September 2005
Doc ID/URL: *Wind and Structures*, Vol. 8 (5), September 2005: 343-356.
Description: 14 pp.
Contents: Overhead sign support structures number in the tens of thousands throughout the trunk-line roadways in the United States. A recent two-phase study sponsored by the National Cooperative Highway Research Program resulted in the most significant changes to the AASHTO design specifications for sign support structures to date. The driving factor for these substantial changes was fatigue related cracks and some recent failures. This paper presents the method and results of a subsequent study sponsored by the Michigan Department of Transportation (MDOT) to develop a relative performance-based procedure to rank overhead sign support structures around the United States based on a linear combination of their expected fatigue life and an approximate measure of cost. This was accomplished by coupling a random vibrations approach with six degree-of-freedom linear dynamic models for fatigue life estimation. Approximate cost was modeled as the product of the steel weight and a constructability factor. All objective function was developed and used to rank selected steel sign support structures from around the country with the goal of maximizing the objective function. Although a purely relative approach, the ranking procedure was found to be efficient and provided the decision support necessary to MDOT.

Title: New Wind Design Criteria for Traffic Signal Support Structures
Author(s): Fouad H. Fouad, Elizabeth Calvert
Date: August 2005
Doc ID/URL: UTCA Report 04219
Description: 49 pp.
Contents: The American Association of State Highway and Transportation Officials (AASHTO) Standard Specifications for Structural Supports for Highway Signs, Luminaries and Traffic Signals has been revised in its entirety through a major research project conducted under the auspices of the National Cooperative Highway Research Program (NCHRP Project 17-10). The new document was approved in 1999 by all state departments of transportation for adoption by AASHTO and was published in 2001. The revisions include updated provisions and criteria for extreme wind loads and new provisions and criteria on fatigue design. These provisions differ considerably from those in previous editions of the specifications. The impact of the new wind load and fatigue provisions on the design of traffic signal supports from the standpoint of safety and economy had not been studied and was the main goal of this project. Wind load calculations and design of a span wire traffic signal structure in Alabama were performed using the design criteria in both the 2001 AASHTO specifications and the 1994 edition of the specifications. The results were compared and the impact of the 2001 specifications on design of span wire traffic signal structures in Alabama was illustrated.

Title: Design of cantilevered overhead sign supports
Author(s): Fouad H. Fouad, Elizabeth Calvert
Date: 2005
Doc ID/URL: *Transportation Research Record 1928*, 2005: 39-47.
Description: 9 pp.
Contents: The AASHTO 2001 Standard Specifications for Structural Supports for Highway Signs, Luminaires and Traffic Signals include revised wind load provisions and new criteria for fatigue design. These provisions and criteria differ considerably from those in previous editions of the specifications, and their impact on the design of cantilevered overhead sign supports has not been fully studied. This study assesses the effect of these provisions and criteria on the design of cantilevered overhead sign support structures with the horizontal support composed of a four-chord truss. Wind and fatigue load design calculations of typical structures, located at sites across the United States, were performed with the design provisions of the 2001 supports specifications and compared with design in accordance with the previous edition of the specifications. The induced forces in the primary members of the cantilevered sign support structure were calculated, and corresponding member sizes and weights were estimated. The results of the study demonstrated the effect of the wind and fatigue load provisions on the design of cantilevered overhead sign support structures.

Title: AASHTO 2001 Design of Overhead Sign Supports
Author(s): F.H. Fouad, E.A. Calvert
Date: March 2004
Doc ID/URL: UTCA Report 02216, Final Report. http://utca.eng.ua.edu/projects/final_reports/02216fnl.pdf
Description: 101 pp.
Contents: The American Association of State Highway and Transportation Officials (AASHTO) "Standard Specifications for Structural Supports for Highway Signs, Luminaires and Traffic Signals" was revised in its entirety through a major research project conducted under the auspices of the National Cooperative Highway Research Program (NCHRP) Project 17-10. The new document was approved in 1999 by all state departments of transportation for adoption by AASHTO and was published in 2001. The revisions include updated provisions and criteria for extreme wind loads and new provisions and criteria on fatigue design. These provisions differ considerably from those in previous editions of the specifications. The impact of the new wind load and fatigue provisions on the design of cantilevered overhead sign supports from the standpoint of safety and economy had not been studied and was the main goal of this project. wind load and fatigue calculations and design of a cantilevered overhead sign support in Alabama were performed using the design criteria in both the 2001 AASHTO specifications and the 1994 edition of the specifications, using SABRE, a structural analysis package for overhead sign support structures. The results were compared and the impact of the 2001 specifications on design of cantilevered overhead sign support structures in Alabama was illustrated.

Title: Design of Structures 2004
Author(s): Transportation Research Board (corporate author)
Date: 2004
Doc ID/URL: *Transportation Research Record 1892*, 2004.
Description: 271 pp.
Contents: This Transportation Research Record contains 27 papers on the design of structures. The papers are presented in eight parts. Part 1, General Structures, discusses bridge aesthetics, overhead sign support structures, integral abutments supported by steel H-piles, composite bridge deck replacement, spandrel walls in masonry arch bridges, and strengthening of channel beams in bridge superstructures. Part 2, Steel Bridges, looks at steel orthotropic decks, a live load distribution factor equation, and behavior under superload permit vehicles. Part 3, Concrete Bridges, examines steel fiber concrete in end zones of girders, monitoring of box-beam bridge for superloads, and current practice for high strength concrete prestressed girder design. Part 4, Dynamics and Field Testing of Bridges, addresses simulated flood and earthquake damage of a bridge substructure; field monitoring of an integral abutment bridge; radar, impact-echo, and ultrasonics for testing concrete structures and metallic tendon ducts; and field testing of a curved-steel box-girder bridge. Part 5, Seismic Design of Bridges, discusses the seismic retrofit of flared reinforced concrete columns in a multispan viaduct. Part 6, Tunnels and Underground Structures, examines decision aids for tunneling and predicting tunneling-induced ground movement. Part 7, Culverts and Hydraulic Structures, examines polyvinyl chloride pipes in clayey backfill and an old brick culvert slip lined with a corrugated steel culvert. Part 8, Structural Fiber-Reinforced Plastics, discusses strengthening of steel structures and bridges with carbon fiber-reinforced polymers, fatigue behavior of a prestressed tubular fiber-reinforced polymer bridge deck, and hybrid bridge strengthening.

Title: Cost and performance comparison of U.S. overhead sign support structures
Author(s): T.M. Ahlborn, J.W. Van de Lindt, A.J. Uzcatequi, M.E. Lewis
Date: 2004
Doc ID/URL: *Transportation Research Record 1892*, 2004: 14-23.
Description: 10 pp.
Contents: Recent developments in fatigue analysis and design of overhead sign support structures prompted AASHTO to update the "Standard Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals" in 2001. An earlier version of the specification was published in 1994 and, according to recent studies, did not adequately address the issue of fatigue. Updating existing sign support structures to comply with the AASHTO 2001 sign specification may result in a substantial expense to the state departments of transportation nationwide. A method was developed to analyze and evaluate overhead sign support structures for comparison based on cost and performance. The method was then applied to sign support structures across the United States to determine the best performing and most economical designs currently in use. To determine the estimated fatigue life of critical connection details, the evaluation of overhead sign support structure performance was based on dynamic analyses of finite element analysis models. Cost evaluation was based on structure weight and its relative constructability. Performance and cost metrics were combined to establish an optimization parameter, providing a quantitative measure of comparison between overhead sign support structure designs. It is therefore a representation of both effectiveness and economy and, because the performance measure is based on fatigue, it is consistent with

current trends in overhead sign support structure design. The method may be used by all state departments of transportation and for all different types of sign support structures.

Title: Performance-based approach for selection of overhead cantilever sign support structures
Author(s): J.W. Van de Lindt, T.M. Ahlborn, M.E. Lewis
Date: 2004
Doc ID/URL: *Proceedings of the 2004 Structures Congress, Building on the Past: Securing the Future*, 2004: 319-326.
Description: 8 pp.
Contents: Overhead sign support structures number in the tens of thousands throughout the trunk-line roadways in the U.S. A recent two-phase study sponsored by the National Cooperative Highway Research Program resulted in the most significant changes to the AASHTO design specifications for sign support structures to date. The driving factor for these substantial changes was fatigue related cracks and some recent failures. This paper presents the results of a subsequent study sponsored by the Michigan Department of Transportation (MDOT) to develop a performance-based procedure to rank overhead sign support structures around the country based on their expected fatigue life and an approximate measure of cost. This was accomplished by combining a random vibrations approach with six degree-of-freedom linear dynamic models for fatigue life estimation. Then, expert opinion of a panel formed especially for this project was used to determine the importance, i.e. weighting, of cost and an optimization function was developed. The optimization function was used to rank selected sign support structures from around the country with the goal of maximizing the optimization function, thus selecting the structures most likely to meet the new AASHTO design criteria. Sixteen possible candidates were considered from around the country.

Title: Wind-induced fatigue of VMS sign structures
Author(s): Jong S. Park, Wes McLean, J. Michael Stallings
Date: 2004
Doc ID/URL: *Proceedings of the 2004 Structures Congress, Building on the Past: Securing the Future*, 2004: 407-411.
Description: 5 pp.
Contents: Variable Message Sign (VMS) panels are becoming increasingly popular. Wind loading on these signs sometimes results in significant cyclic loading of the support structure. The wind loading can result from gusts from the passing of trucks or from natural wind. An analytical and experimental investigation of the cyclic loading and resulting fatigue stress ranges produced by wind in a VMS sign structure are discussed in this paper. Comparisons of analytical and experimental results are presented. A summary of the relative effects of wind gusts due to passing trucks and due to natural wind are presented. Comparisons of fatigue stress ranges and fatigue limits are presented.

Title: Fatigue Evaluation of a Variable Message Sign Bridge Type Support Structure by Analytical and Experimental Methods
Author(s): Troy Weston McLean
Date: 2004
Doc ID/URL: M.S. Thesis, Auburn University, 2004.
Description: 211 pp.
Contents: n/a

Title: A fix for aluminum overheads
Author(s): P. Mooney
Date: November 2003
Doc ID/URL: *Public Roads*, Vol. 67 (3), November 2003: 25-27. http://www.tfhrc.gov/pubrds/03nov/06.htm
Description: 3 pp.
Contents: In the early 1960s, state departments of transportation (DOTs) began using aluminum trichord overhead structures to support signs along U.S. highways. Aluminum is lightweight, costs less than steel, and is inherently resistant to rusting, but is also prone to fatigue as a design factor. Over time, wind forces can create stresses on aluminum structures, eventually causing cracks to appear in the welded joints of the truss diagonals. If these cracks are not discovered and repaired, a welded joint could fail and cause an aluminum diagonal to fall onto the roadway. This article describes an inexpensive way to repair problematic structures, developed by the New York State DOT working with private industry and the University of Utah, to increase their safe and useful lives by employing a fiber-reinforced polymer composite to wrap cracked joints. By this means, workers can restore the structural integrity of a cracked joint to virtually the same strength as the original aluminum weld. The cost of the material is minimal and the repair can be conducted in the field.

Title: Endurance testing of composite reinforced welded aluminum structures
Author(s): Larry Cercone, Franz Worth, Justin Nadauld, Chris Pantelides, Harry White
Date: 2003
Doc ID/URL: *Proceedings of the International SAMPE Symposium and Exhibition*, Vol. 48 II, 2003: 2424-2431.
Description: 8 pp.
Contents: Several states utilize welded aluminum structures to support freeway and throughway signage. In some cases the welds at the joints of these structures have either partially or fully cracked. The exact failure mechanism has not been isolated but the need to reinforce them is urgent. Air Logistics Corporation has developed and tested a field applied FRP repair system, which is currently in use to repair the cracked joint welds. Several joints with cracked welds were cut from dismantled sign structures and repaired with the FRP repair system. These samples were tested at the University of Utah in a series of tension tests and proved to be as strong as sound aluminum welds. A second series of endurance tests was also conducted. In this series, two test specimens were set up and subjected to long term cyclical loads. The first included a composite reinforcement over a failed weld. The second specimen was a sound weld with no defects. The final results were compared and it was determined that the composite reinforced welds performed as well as, or better than, a sound weld with no defects under a cyclical load.

Title: Field monitoring and evaluation for sign support structures subject to dynamic loads
Author(s): Michael DelGrego, John T. DeWolf
Date: 2003
Doc ID/URL: JHR 03-291
http://www.ct.gov/dot/LIB/dot/documents/dresearch/CT-JHR%5F03-291%5FJH%5F00-5.pdf
Description: 42 pp.
Contents: Recent changes in the sign support specification have resulted in an increase in design wind pressures. As a result, some existing overhead bridge highway sign structures supported by two vertical trusses are no longer adequate, even though they have performed acceptably over the years. As a result of the new design provisions, a program was begun to reinforce the sign supports, which involved adding stiffeners to the vertical truss chords. An initial review of the, then, current design procedures, using estimated effective length factors, indicated that use of a more rigorous stability analysis could show that many of the existing vertical trusses had sufficient strength to meet the new wind loading without the expensive field modifications. This could be achieved through more accurate calculations of the effective lengths for the vertical truss chords. The study reported herein was undertaken to use the new stability software to study existing sign supports, review alternative approaches for strengthening the trusses when the improved stability analysis is not sufficient, and revise the overall design approach and design software used by ConnDOT. The results presented in this study can be used in both the review of existing sign structures and the design of new sign structures.

Title: Fatigue Performance of Full-Span Sign Support Structures Considering Truck-Induced Gust and Natural Wind Pressures
Author(s): Scott Ginal
Date: 2003
Doc ID/URL: M.S. Thesis, Marquette University, 2003.
Description: 378 pp.
Contents: n/a

Title: Smart sign support
Author(s): R.J. Dexter, K. Johns, R. DiBartolo
Date: September 2000
Doc ID/URL: *Civil Engineering*, Vol. 17 (9), September 2000: 62-65.
Description: 4 pp.
Contents: The Route 80-MAGIC (Metropolitan Area Guidance, Information and Control) project is considered to be the showcase Intelligent Transportation System (ITS) project for the state of New Jersey. The project consists of a total of 72 miles (116 km) of intelligent highway starting at the George Washington Bridge near New York City and continuing westerly, and including parts of the New Jersey Turnpike and some of the most congested traffic areas within the state. There are 35 variable message signs, used to post traffic information for drivers, located in advance of interchanges and along selected diversion routes throughout this project. Supporting these large structures safely over the roadway presents special challenges not covered by existing design specifications. The New Jersey Department of Transportation engaged Lehigh University to instrument a cantilever sign structure and to help develop a design criteria that would address the fatigue design from loads imposed by truck and natural wind, including wind buffeting.

Title: Fatigue Resistant Design of Non-Cantilevered Sign Support Structures
Author(s): Ramy S. Abdalla
Date: 2000
Doc ID/URL: M.S. Thesis, University of Alabama, Birmingham, 2000.
Description: 110 pp.
Contents: n/a