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Project Title:
Optimized Adhesive Performance in Electronic Transportation Sign Construction

University:
South Dakota State University

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Research Needs:
To reliably utilize Dynamic Message Signs (DMSs) with adhesive bonding in the US transportation system, comprehensive knowledge of structural behavior of DMSs subjected to ultimate and fatigue loads is needed.

DMSs are used in Intelligent Transportation System (ITS) applications along road networks to improve traffic control and mobility. These signs consist of cabinet sheet metal skin, internal structure frame, sign controller, inter-connect cable, and traffic cabinet enclosure. Typically, welded connections that meet the requirements of the strength and fatigue design specifications are used in the DMS system.

In spite of the ubiquity of welded connections in the system, adhesive connections between the cabinet sheet metal skin and internal structure frame have gained popularity in many fields due to their cost-effectiveness and fabrication efficiency (e.g., the automotive industry) (Mclean et al., 2004; Močibob and Crisinel 2008). Unlike welded connections which see residual stresses and distortion that develop during welding process, adhesive bonding can facilitate a more uniform load transfer mechanism between cabinet skin-frames that may reduce these problems. Adhesive-based connections also provide a better water seal than welded connections. For these reasons, some transportation sign manufacturing companies are pursuing adhesive connections in DMSs.

Although some studies (Constantinescu et al. 2007; Huckelbridges and Metzger 2007) have assessed structural integrity of welded connected DMS supporting structures, very limited substantiated test data exists to investigate structural performance of DMSs with adhesive bonding. Specifically, there is a lack of detailed ultimate and fatigue load testing data on cabinet skin-frame joints made with adhesive bonding.

Research Objectives:

1. Study the effects of adhesive and environmental characteristics on joint performance of adhesive-based specimens
2. Examine the structural performance of DMSs with chemical adhesive joints
3. Determine optimized adhesive performance in terms of fatigue life and strength

The goal of this project is to provide comprehensive knowledge of structural behavior of DMSs with adhesive bonding subjected to ultimate and fatigue loads. The aforementioned measurable objectives are designed to achieve this goal.

Research Methods:

To accomplish the objectives, three research methods are detailed as follows:

Objective 1: Structural tests will be performed, including uniaxial shear tests of several adhesive-based specimens (focusing on LORD Acrylic Adhesives, which are commonly used for chemical adhesive bonding in DMSs) with variation in adhesive and environmental characteristics for their failure investigation. Several welded specimens will serve as benchmarks and be tested in comparison with the adhesive-based specimens. Relationships between force and deformation (including stress-to-strain curves) for each specimen will be discovered. Each pair of adhesive and welded joint specimens, under the same conditions, will be graphically compared to determine joint performance. All testing data will be analyzed using statistical analysis to determine the effects of adhesive and environmental characteristics on joint performance in an efficient manner. At least three samples per specimen will be tested to obtain reliable data.

Objective 2: Ultimate load testing will be carried out on one full-scale DMS system with LORD adhesive joints; one DMS with typical welding connections will be used as the reference test. Loading will be applied to each specimen by a hydraulic actuator and monotonic under the displacement-based control until structural failure. Fatigue testing will be also conducted of one full-scale DMS system with LORD adhesive joints and one with welding connection. For the fatigue evaluation of each specimen, the applied load will be determined as an equivalent static wind load, according to the AASHTO LRFD Specification (AASHTO 2015). Each test specimen will be evaluated by applying AASHTO Fatigue load cycles using single point load applied to the center of the cabinet panel to maximize the magnitude of load effect. During each testing, strain and deflection data along with visual inspection imagery will be collected to gain better understanding of structural behaviors and failure modes. The results of the tests in this project will be used to determine the structural adequacy of the adhesive-based joints and compare the failure mechanisms and thresholds to welding joints.

For objectives 1 and 2, the required tests will be performed using Universal Testing Machine (UTM), hydraulic actuators, and supporting steel frames at the Lohr Structures Laboratory at South Dakota State University. All testing materials will be provided by a private sector partner (i.e., Daktronics) in this project.

Objective 3: A high-fidelity computational modeling approach to predict structural response of DMS systems will be developed using commercially-available finite element software. The modeling approach will be applied to one full-scale DMS specimen with adhesive joints and to one with welding connection, and then the approach will be calibrated with testing data to replicate each of their actual structural behavior. The calibrated models will be used to perform parametric studies for the determination of each DMS system with optimized structural performance.

Expected Outcomes:
Two key anticipated outcomes will be obtained through this project:

1. This project will provide a big testing database of the mechanical characteristics and structural performance data focused on ultimate strength and fatigue life of DMSs with chemical adhesive bonding and those with welding connection.
2. This project will produce validated high-fidelity computational models enabling the structural response prediction associated with variable connection geometric and environmental factors.

Outcomes will aid transportation engineers and agencies in taking advantage of adhesive joints in future DMSs and the associated reasonable cost of production and high water permeability resistance at the joints.

Relevance to Strategic Goals:

- State of Good Repair
- Safety

State of Good Repair – Many DMSs are in need of repair or replacement due to wind-induced fatigue damage. It is anticipated that adhesive bonding-based DMSs may be a good alternative to the conventional welded connected DMSs.

Safety – To determine structural performance of DMSs with adhesive bonding subjected to ultimate and fatigue loads will be critical to the safety of the DMSs used in Intelligent Transportation System (ITS) applications.

Educational Benefits:
One graduate student will be involved in this project. The student will secure fundamental and practical research experience and knowledge on load testing and computational simulation. Resulting findings through the project, especially testing data and computational modeling technology, will be integrated in SDSU engineering courses, CEE 455: Steel Design and CEE 754: Advanced Design of Steel Structures, led by PI Seo.

Tech Transfer:
The researchers will ensure the findings from testing and simulation can be transferred to transportation engineers. As the project progresses, researchers will share findings with the project's technical panel consisting of engineering staff and transportation engineers in the research private sector and conclude with a closeout presentation. Close collaboration will inform local and regional transportation agencies of this project's ongoing findings. The research team expects local and regional transportation agencies to capitalize on findings and recommendations and efficiently use adhesive-joint-based DMSs on transportation sign structure markets. Furthermore, all findings will be disseminated through publication in technical journals

and conference proceedings. Technology transfer activities will also be reported in the Program Progress Performance Reports (PPPR).

Work Plan:

1. Literature review of the state of the art and practice on adhesive joints
2. Adhesive and welding joint specimen selection and testing
3. Specimen testing data investigation and discussion with technical panel
4. Full-scale sign system selection and ultimate load and fatigue testing
5. Testing data analysis and discussion with technical panel
6. Develop and calibrate a computational model to simulate anticipated behaviors of the tested full-scale sign systems
7. Final report and closeout presentation

Task 1: Conduct a comprehensive literature review on the design and performance of adhesive joint-based DMS system. This task is expected to be done by the end of the 2nd month.

Task 2: Consult with transportation engineers to determine adhesive and welding joint specimens for shear tests to investigate joint performance considering variability in joint geometric and environmental factors. This task is expected to be done by the end of the 4th month.

Task 3: Analyze shear testing data and discuss the findings with project's technical panel. This task is expected to be done by the end of the 5th month.

Task 4: Consult with transportation engineers to determine four full-scale DMSs for ultimate load and fatigue testing. The ultimate load testing for one adhesive-joint-based and one welding connection-based DMSs will be conducted. The loading will be applied to the center of each specimen by a hydraulic actuator and monotonic under the displacement-based control until structural failure. The fatigue testing of the same full-scale DMS specimens as used in the ultimate load testing will be carried out. This task is expected to be done by the end of the 10th month.

Task 5: Analyze all testing data obtained from Task 4 using statistical analysis to examine structural performance in terms of ultimate strength and fatigue life. The PIs will discuss the testing findings with the technical panel. This task is expected to be done by the end of the 12th month.

Task 6: Develop and calibrate a computational modeling approach to predict actual behavior of tested full-scale DMSs using commercially available finite element software. A small number of parametric studies with various factors affecting structural performance will be carried out. This task is expected to be done by the end of the 15th month.

Task 7: Prepare a final report summarizing the research findings, conclusions, and recommendations. This task is expected to be done by the end of the 18th month.

Project Cost:

Total Project Costs:	$176,872.33
MPC Funds Requested:	$74,153
Matching Funds:	$102,719.33
Source of Matching Funds:	Daktronics and SDSU Faculty Time and Effort

References:

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Močibob, D. and Crisinel, M. (2008). "Linear connection system for structural application of glass panels in fully-transparent pavilions." Proceedings of Challenging Glass 1, Delft, Netherlands, 2008.

Constantinescu, S.G., Bhatti, M.A., and Tokyay, T. (2007). Improved method for determining wind loads on highway sign and traffic signal structures. Final Report TR-559, Iowa Highway Research Board, Iowa DOT, IA.