MPC-484
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Project Title:
Effect of Service Temperature on Joint Removal in Steel Bridges

University:
Colorado State University

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Research Needs:
With the deterioration of US infrastructure systems, bridge maintenance, performance and the necessity of deck joints and bearings has gained the attention of states, municipalities, engineers, researchers, and practitioners alike. Deck joints are designed to accommodate translational and rotational movements between two adjacent bridge spans while bearings are used in bridges to transfer vertical, translational and rotational loads from the superstructure to the abutments or piers. It is commonly recognized that deck joints and bearings are costly and complicated to install (Tsiatas and Boardman 2002; Wasserman 1987). In addition to greater complexity of construction, deck joints and bearings require maintenance throughout their life cycles to remain functional and to prevent damage to the superstructure (Hawk 2003). Water seepage through deck joints can cause significant corrosion to the superstructure and substructures below (Lam et al. 2008; Loveall 1985). The American Association of State Highway and Transportation Officials (AASHTO) also recognizes this problem in the commentary section of Chapter 2.5 of the current AASHTO LRFD Bridge Design Specifications, which states:
“Other than the deterioration of the concrete deck itself, the single most prevalent bridge maintenance problem is the disintegration of beam ends, bearings, pedestals, piers, and abutments due to percolation of waterborne road salts through the deck joints. Experience appears to indicate that a structurally continuous deck provides the best protection for components below the deck.”

The current abundance of deck joints originated from the straightforwardness of simply supported bridge span design. During the time that simple span bridge construction was prevalent, the infrastructure system in the US rapidly grew into its current state and a large quantity of bridges and roadways were constructed. Without information available regarding the necessary maintenance and repair costs of deck joints, a multitude of bridges were constructed as multiple simple spans and separated at each pier with deck joints (Tsiatas and Boardman 2002). Recently, the use of structural analysis software programs by practicing engineers has become commonplace and, therefore, continuous span bridges can now be designed with less effort than in the past. However, a substantial amount of older bridges with numerous deck joints still exist and pose maintenance and performance challenges to state transportation agencies. Bridge retrofits to eliminate deck joints and bearings have been proposed and implemented in many cases to alleviate the substandard performance of the deck joints (Burke Jr. 1990; Tsiatas and Boardman 2002; Wasserman 1987). However, the removal of deck joints in order to improve bridge performance and increase longevity raises questions about the thermal movement bridges must be able to accommodate.

In the current AASHTO LFRD Bridge Design Specifications discussion of thermal effects and discussion of joints and bearings are found in Sections 3 and 14, respectively. Multiple requirements for the performance of deck joints and bearings are listed, but the number of each should be minimized for a given bridge. The definition of setting temperature is provided and processes for estimating thermal movements of bridges are explained (AASHTO LRFD Bridge Design Specifications 2014). Current AASHTO provisions only require consideration of the total longitudinal thermal movement based on the average bridge temperature. A vertical thermal gradient is defined in Section 3, but consideration of this gradient is not required if past experience indicates that it is not necessary to maintain the functionality of the bridge. No mention of gradient in temperature is mentioned along the transverse or longitudinal axes. This over-simplified approach may result in a minimized design and analysis time since a uniform cross-sectional temperature can be assumed, but could potentially lead to inaccurate estimation of the demand resulting from the thermal loads and subsequent poor bridge performance.

Research Objectives:
This study will provide departments of transportations and consultant engineers with the insight needed to effectively consider the influence of temperature changes on steel bridges. This will be realized through numerical finite element modeling of prototype bridges in Colorado. Contingent upon the approval of CDOT, the bridges will be instrumented with strain gauges, scratch sensors, and thermocouples to monitor the actual bridge movements and the corresponding thermal temperatures and strains. The models will be constructed using SAP2000 and will include sufficient level of details such that all complex phenomena are captured. The results of the study will give engineers an insight on possible details that can be considered as a substitute for aged or damaged expansion joints. This enhanced understanding will also allow for the design of new bridges with fewer joints for higher long term performance lower maintenance cost.

The objectives of this study are:

1- Measurement of the thermal loads and the associated strains, displacements, and movement real bridges experience in service.
2- Development of analysis guidelines for joint reduction or elimination in bridges; and
3- Development of design and rehabilitation guidelines for joint reduction or elimination in bridges.

There is currently a pending CDOT proposal that is focused on analysis, design, and rehabilitation of bridges in relation to joint removal with consideration to thermal stresses. The CDOT proposal includes data collection of thermal-induced bridge movement using scratch gauges. The objective of this companion MPC proposal is to allow for enhanced data collection and better matching of the numerical finite element models. The enhanced data collection will include measurements of temperatures, strains, and displacements.

This proposed MPC project is to complement a CDOT study on analysis, design, and rehabilitation of bridges for joint removal

Research Methods:
The research approach will consist of seven (5) major tasks, each of which is detailed below:

Task 1: Conduct extensive literature review and multi-state survey

This initial task will consist of (1) a literature review encompassing NCHRP reports, TRB papers, journal papers, and state department of transportation reports to determine the existing state-of-knowledge on thermal analysis, design, and joint detailing for eliminating bridge joints; and (2) a short survey to determine state-of-practice for states around the country and the associated advantages and disadvantages resulting from joint elimination. The results of both the extensive literature review and survey will be included in the first quarterly report. The survey may include (but is not limited to) 1) procedures or guidelines used for conducting thermal analysis including the need for 2D versus 3D analysis and requirements for introducing thermal gradients in the models; 2) considerations for field measurement and data collection to capture the behavior of bridges under thermal loads; and 3) the corresponding major changes required to a typical design of new bridges or retrofit of existing bridges; The survey will be nation-wide and will include states with varying weather/temperature profiles.

Task 2: Identify the representative bridges (*Expanded beyond what is proposed for CDOT*)

A collection of 15-20 bridges will be identified for the field data collection with the aid of CDOT's Staff Bridge office. These representative bridges should (1) represent the overall inventory of bridges in Colorado and other states; (2) cover different span length; (3) be located in areas with seasonal weather changes; (4) be easily accessible to the research team if field testing is approved by CDOT; and (5) can be appropriately modeled with reasonable level of complexity. This full set of bridges will serve as the basis for selecting various steel bridges to be evaluated. This will include straight bridges, skewed bridges, and curved bridges to be modeled in SAP2000. The models will include different level of skewedness and curvature to evaluate the level of modeling detailed required to capture complex behavior including torsional effects. It is worth noting that this task is expanded beyond what was proposed for CDOT since the CDOT proposal was limited to only straight bridges and did not include the evaluation of skewed and curved bridges.

Task 3: Development of instrumentation plan and data collection (*Expanded beyond what is proposed for CDOT*)

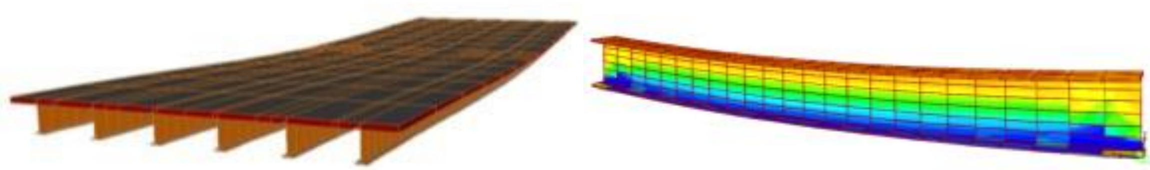
Fig. 1 One of the six CR1000 available at the structural laboratory at CSU

There is currently a CDOT proposal that is being evaluated and includes field data collection of bridge movement to assess bridge behavior under thermal loads and propose details for joint removal. If the CDOT proposal is approved, the development and implementation of the instrumentation plan will be conducted in collaboration with CDOT. In the pending CDOT proposal, scratch gauges will be fabricated at the Engineering Research Center shop and installed on the selected bridges to monitor the bridge movement. Timing of installation will be coordinated with CDOT maintenance and inspection crews. The requested MPC funds will be utilized for additional instrumentation on four selected bridges. Instrumentation arrays will be utilized to capture the localized joint behavior. The parameters quantified during field measurements will include temperature-induced displacement, rotations, and strains. In addition thermocouples will be installed so that proper correlation between the measured deformations and the thermal load can be made. This will allow for the proper development of the proposed parametric finite element models in Task 4. The data will be collected using portable DAQ Campbell Scientific CR1000 systems available at CSU. The PI, Dr. Mahmoud has extensive experience with field testing and monitoring and have led and conducted in-service evaluation of major bridges around the country.

Task 4: Develop three-dimensional finite element models of the selected bridges and model calibration against collected field data (*Expanded beyond what is proposed for CDOT*)

The finite element models will be developed using SAP2000 or CSI Bridge to allow DOT Staff Bridge engineers to use the same modeling approach. Both software are readily available for use at CSU. It is known that the major advantage of SAP2000 is that many nonlinear-link elements are already available which can be used to model bearings, gaps, plastic elements, and isolators. Various models will be developed for prototype steel bridges. The models will be representative of the existing condition of the selected bridges and will be developed such that all relevant behavioral aspects are captured. In addition the modeling approach will allow for the ease of evaluation of alternative joint details as per Task 5.

Dr. Mahmoud is near finishing a CDOT study on the seismic performance of bridges in Colorado in which SAP2000 was used for the study. In addition, Dr. Mahmoud has had extensive experience using SAP2000 for bridge and frame analysis in other studies. Moreover, Dr. Mahmoud has conducted a large number of analyses considering thermal loads on structural systems. It is envisioned that the developed models will be constructed using shell elements to allow for inclusion of thermal stress gradients across the depth of the girders. Line element models will also be used only if the uniform temperature is to be specified. This task is extended beyond the proposed CDOT study to include the evaluation of thermal demands in curved and skewed steel bridges.



(a) (b)

Fig. 2 SAP2000-based finite element models (a) bridge model and (b) thermal analysis on a beam using shell elements.

Task 5: Investigate design detailing for joint elimination

Based on the knowledge gained from all previous tasks, the SAP2000 models will be used to predict the forces and displacements experienced under traffic and thermal loads for bridges with and without joint removal. The investigated details will include both welded and bolted splices and will consider adequate performance, ease of construction, and proper inspection. Details where the steel girders are embedded in concrete encasing will also be considered.

Task 6: Final Report

A final report will be produced describing the results of the research. The results will also be disseminated through publication in scholarly journals such as the Transportation Research Record and Journals of Bridge Engineering. In addition, Dr. Mahmoud will present the findings to various committees on which he serves including AASHTO T-14 on steel bridges, TRB FH-70 on fabrication and inspection of metal structures.

Expected Outcomes:

This primary outcome of this project will be field data on bridge response to in-service thermal demands. In addition, numerical finite element models with the appropriate modeling techniques will be developed and will add to the existing knowledge on numerical assessment of bridges under the corresponding loads. The field data and numerical models can be used by designers to make more educated design decisions and will serve as the basis for further research. In addition, the PI can see possible extension of this work to include multiple load effects where the bridges are subjected to wind loads, traffic loads, and thermal loads.

Relevance to Strategic Goals:

The proposed study is developed with the vision to provide transportation personnel with numerical tools to assess the practicality of eliminating joints in steel bridges. Background information will provide a state-of-the-practice assessment of joint removal relevant to Colorado, and modeling strategies for assessment of thermal load effects. The knowledge and the proposed modeling tools to be developed, in relation to joint removal, directly relate to enhancing the **state-of-good repairs** of transportation bridges in mountain states, with particular emphasis on site-specific conditions in Colorado. Potential elimination of expansion joints can reduce maintenance and repair costs. The PI believes that implementation of effective joint elimination details mitigation structures will provide long-term benefits to reduce damage of transportation infrastructure. Thus, broader impacts of the proposed research are assessments of economic competitiveness of joint elimination in relation to life-cycle cost.

Educational Benefits:

The proposed project will support a Graduate Research Assistant (GRA) at Colorado State University (CSU) in pursuit of an MS degree in Civil Engineering. This GRA will lead the proposed research, and successful implementation of the project plan will allow the graduate student to prepare and defend an MS thesis. The GRA will gain invaluable knowledge and experience related to relevant and practical field testing and modeling tools for a future career as a Structural Engineer. In particular, the GRA will have an understanding of current and future steel bridge maintenance and design issues related to joint elimination.

The proposed project will provide an opportunity for the PIs to expand and enhance their understanding of steel bridge design and behavior. This knowledge will be used in both undergraduate and graduate courses. Dr. Mahmoud will integrate the results of the study in his CIVE 466 course on “Design and Behavior of Steel Structures” and CIVE 561 on “Advanced Steel Behavior and Design”. Specifically, in CIVE 466 review of service thermal loads will be provided and simple approaches for determining the demands, using simplified equations, will be considered. In CIVE 561, the group project typically given on composite systems will include the evaluation of the response of composite steel bridges under the thermal loads. The students will be given the developed SAP2000 models and will be expected to alter various parameters to assess the response of the bridges based on project requirements.

Work Plan:

The proposed project duration is 24 months. Table 1 below shows the schedule for the seven tasks previously outlined. The end of each horizontal bar is the time at which each of the tasks will be completed and submitted to the CDOT study panel for approval.

Table 1: Schedule of Tasks

	Months																							
Task	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Task 1: Literature review and survey	■	■	■																					
Task 2: Identification of representative bridges			■	■																				
Task 3: Development and collection of field data			■	■	■	■	■	■	■	■	■													
Task 4: 3-D SAP2000 analytical models of bridges					■	■	■	■	■	■	■	■	■	■	■	■	■	■						
Task 5: Design Detailing for joint elimination														■	■	■	■	■	■	■	■	■		
Task 6: Final report																						■	■	■

Project Cost:
Total Project Costs: $99,956
MPC Funds Requested: $49,000
Matching Funds: $ 50,956
Source of Matching Funds: CSU in-kind and a Colorado Department of Transportation project.

TRB Keywords: Joint removal, inspection, TRB, flow, infrastructure, modeling, soil-structure

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