Investigation of Prefabricated Steel-Truss Bridge Deck Systems

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PROBLEM STATEMENT

The Montana Department of Transportation has recently explored different accelerated bridge construction (ABC) systems and recognizes the advantages of these systems for certain bridge replacement and new construction projects in the state. In particular, a steel-truss girder system with an integrated concrete deck has the potential to increase the applicability of ABC projects for longer spans of 100 ft or more through a reduction in weight with more reliable deflection estimations, when compared to more conventional precast/prestressed concrete integrated deck systems. Results of this research would enable MDT to determine if a steel truss/integrated concrete deck bridge system is a viable bridge construction option for the state of Montana. Further, if deemed to be a viable option, this investigation will identify future research directions required to fully develop this new ABC methodology.

BACKGROUND AND SUMMARY

Accelerated bridge construction (ABC) techniques have been successful in their ability to reduce construction times and economic impact from construction-related traveler delays. The accelerated construction time reduces traveler and construction worker exposure to temporary travel environments, resulting in increased safety. The Montana Department of Transportation (MDT) commonly uses precast/prestressed concrete girder/deck systems for bridge construction throughout the state, and these systems have exhibited good overall performance. However, the low strength-to-weight ratio for this type of system and the difficulty in predicting long-term deflections limit the use of this system for longer spans. Steel systems with integrated concrete decks, and in particular steel truss systems, do not suffer these same limitations and may be more suitable for longer spans.

The initial evaluation of a steel-truss prefabricated bridge system is favorable, based on results of an assessment of new and innovative prefabricated steel bridge systems (SDR Engineering Consultants 2005). This report identified a prefabricated steel-supported system as the most promising in terms of configuration, construction, design, and maintenance categories. Based on these criteria, a steel truss system with an integrated concrete deck would rank well in comparison with the other bridge types included in the report by SDR Engineering (2005).

In recognition of the economic impact ABC provides and to further advance the state of knowledge, Departments of Transportation are currently supporting research funded by the FHWA to improve their performance. Such studies include connections (Iowa, Virginia, Nebraska), deck performance and cracking (Wisconsin), feasibility of standardized plans (Colorado), durability (Maryland), in-service performance (Virginia), and construction (Michigan).

In addition to these current efforts, several studies have been completed on the performance of different components of accelerated bridge girder/deck systems. For example, U-bars used in longitudinal bridge joints were found to outperform headed stud and deformed wire reinforcement alternatives (Ma et al. 2012). Live load shear connection tests concluded that non-composite behavior of a steel I-girder bridge with a precast deck system reduced the shear capacity by 8% (Brackus et al. 2013). Finally, challenges and lessons learned from a full-depth deck-panel ABC project were reported in Michigan that apply to a wide spectrum of prefabricated bridge elements and systems (Attanayake et al. 2014).

The proposed research will expand on this existing research and assist in the development of a new ABC system suitable for longer spans. This research will be accomplished in three phases, with the work on each successive phase contingent upon the outcome of the previous phase. Specifically, these phases will be:

Phase I. Review of the state of the practice in prefabricated steel bridge systems, followed by proof-of-concept analysis/evaluation of a prefabricated steel truss system with integrated concrete deck. Of particular importance in this evaluation will be the fatigue behavior of the welded connections, where bolted connections may be reviewed as an alternate.

Phase II. Further research and testing of the proposed system as necessary to finalize its design. Such testing could include both sub-component and full element testing to evaluate local (e.g. fatigue) and global (e.g. stiffness) performance.

Phase III. Construction and monitoring of a field demonstration project.

The research proposed herein is for the Phase I effort.

BENEFITS AND BUSINESS CASE

While MDT already employs precast concrete based ABC systems, this project will investigate a steel based alternative to these concrete systems. Such an alternative would allow for better optimization of system selection in any given situation, as each system has unique advantages and disadvantages. In particular, the proposed steel truss prefabricated bridge system would extend the benefits of ABC to longer spans with more reliable performance in terms of expected long- and short-term displacements. If this system is deemed feasible through the proposed work and refined through future phases of research, the benefits of ABC systems will be extended to a larger pool of bridge projects. The benefits of ABC include:

1) **Improved safety**. The time of exposure of the travelling public to work-zone related driving risks is reduced. Similarly, the exposure time of construction workers to highway work zone hazards is reduced, and a greater proportion of the work is done in the relatively safer environment of a fabrication facility.
2) **Reduced economic impacts**. Delays and detours associated with bridge construction has direct cost impacts on highway users through increased transportation costs associated with increased travel time/distances.
3) **Reduced environmental impacts.** The amount of additional energy consumed by the travelling public as a result of construction delays and detours, and any associated environmental impacts, are minimized. Further, the level of disturbance of the environment at the construction site is reduced, as a greater proportion of the work is done offsite.
4) **Reduced construction times.** This is particularly important in areas with short constructions seasons, as is the case in many areas in Montana.

OBJECTIVES

The overall objective of this proposed research is to investigate, and develop, as appropriate, a prefabricated steel truss/deck system as an alternative to other accelerated bridge construction (ABC) systems available to MDT. Specific objectives consist of (a) reviewing the state-of-practice and recent advancements in accelerated bridge construction, (b) extending this information to a proof-of-concept analytical evaluation of a prototype steel truss/integrated bridge deck system, and (c) recommending future research in the form of analytical and/or structural testing to fully develop this system.

RESEARCH PLAN

The research program described in this proposal will evaluate the potential of a proposed ABC system consisting of a prefabricated steel truss with integrated bridge deck. This evaluation will include a review of the state-of-the-practice in prefabricated bridge panels, an analytical assessment of the proposed system, and recommendations for future research required to fully develop this system. The specific work tasks include:

0) Project management
1) Literature review
2) Analytical evaluation
3) Analysis of results
4) Final report and dissemination of results.

Task 0: Project Management

The Principal Investigator on this project will be Dr. Damon Fick, serving as the primary point of contact between the Montana State University (MSU) research team and the Montana Department of Transportation (MDT) Project Manager. The project will begin with a kick-off meeting with the researchers and MDT to ensure everyone is informed of the contractual obligations and to clarify any technical issues and concerns. During the course of the project, the research team will submit quarterly progress reports to describe the status of the project with respect to timeline and budget. The project team will also submit task reports upon completion of specific tasks, and a project summary report and a final report upon completion of the project.

Task 1: Literature Review

As this research moves ahead, it is essential to be aware and take advantage of any work completed to date by other investigators/organizations. A comprehensive literature will be conducted to evaluate the state-of-the-practice and recent advances in ABC bridge panel systems. This review will include sources from the Transportation Research Board, State Departments of Transportation, Universities, and national and international journals. This task will also include a survey of state and national fabricators to evaluate the feasibility/constructability of and their interest in the proposed system.

Task 2: Analytical Evaluation

The prefabricated steel truss/integrated bridge deck system will be evaluated with a parametric analytical study. Linear-elastic finite element models of the proposed system with varying design parameters (e.g., truss spacing and depth, concrete deck thickness, span length, truss geometry) will be subjected to design loads, and critical response characteristics will be monitored (e.g., stiffness, max element/weld stresses and ranges). The maximum stresses and ranges will be used to assess the fatigue response of the connections.

Task 3: Analysis of Results

The results of the research program will be thoroughly analyzed in this task. This analysis will be used to identify the most efficient design parameters for this system, potential trouble areas, and possible design improvements such as the use of concentrically welded connections or bolted connections in place of eccentric fatigue prone welding. This analysis will include recent findings from a study conducted by Battistini et al. (2014), which included an evaluation of fatigue-sensitive steel connections. This analysis will also assess potential issues associated with constructability, and will result in preliminary design concept drawings. Future research needs to fully develop this system will also be identified.

Task 4: Final Report and Dissemination of Results

The dissemination of results will be achieved through a final report documenting the findings of this investigation. A final presentation will also made to MDT in Helena, followed by an implementation meeting where the potential and future direction of steel truss prefabricated bridge systems will be discussed. The research team will also prepare journal and conference manuscripts for publication and presentation at engineering venues such as the Transportation Research Board's Annual Meeting, American Society of Civil Engineers and Structural Engineering Institute's (ASCE/SEI) Structures Congress, and the American Concrete Institute's (ACI) semiannual conventions. These manuscripts and presentations will be submitted to the technical panel for approval if they are submitted/presented prior to the end of the project. Related expenses for the dissemination of the findings will be covered by Montana State University, and are not included in the proposed project budget.

MDT INVOLVEMENT

MDT will be involved in the beginning of the project by providing information on the Department's experience with ABC projects. This input will be used to focus Task 1 activities to meet the needs of their existing prefabricated bridge systems, while extending them to the proposed steel truss system. Task 2 of the project will include MDT's input on the model that will be used to evaluate the proposed steel truss pre-fabricated system. In particular, information on the design loads and design parameters of the model will be discussed with MDT prior to beginning this task.

PRODUCTS

The following products will be produced as a result of the proposed research:

1) Task 1 report – literature review
2) Task 2 report – analytical evaluation
3) Final report
4) Project summary report
5) Implementation meeting and report
6) Journal and/or conference publications and presentations

IMPLEMENTATION

The proposed research will provide MDT with the information and preliminary results to make an assessment of the application of a steel truss prefabricated bridge system for bridges in Montana. Depending on the results and recommendations of this project, MDT may decide to pursue additional phases of research to further develop this system. These additional phases may include laboratory testing on different components of the bridge system, laboratory testing on a fully assembled scaled panel, and field monitoring of a demonstration project.

SCHEDULE

This project will take approximately 12 months to complete. The project schedule by task is presented in Table 1. The anticipated start date is September 1, 2014 with an estimated completion date of September 1, 2015.

Table 1: Schedule of Tasks

Task / Activity	Quarter							
	1		2		3		4	
Task 0: Project Management	X	X	X	X	X	X	X	X
Task 1: Literature Review	X	X						
Task 2: Analytical Evaluation			X	X	X			
Task 3: Analysis of Results						X	X	
Task 4: Final report and desimination of results							X	X
MDT review of final report								X

BUDGET

This project is supported by MDT funding as shown in the project budget in Table 2. The in-state travel expenses include funding for the research team to travel to and from Helena four times to meet with the technical panel for project-related meetings, including trips for the kickoff meeting, two coordination meetings, and the final presentation and implementation meeting. The pay rates and benefit rates of the investigators is provided in Table 3. Project expenditures by task are shown in Table 4. Project expenditures by task during state and federal fiscal years are shown in Table 5.

Table 2: Project Budget by Item

Item	Total
Salaries	$24,373
Benefits	$5,104
In-State Travel	$400
Expendable Supplies and Materials	$0
Participant Support	$5,000
Total Direct Costs	$34,877
Overhead - 25%	$8,719
Total Project Cost	**$43,596**

Table 3: Pay Rate and Benefits

Name of Principal, Professional, Employee, or Support Classification	Hourly Rate	Benefit Rate
Damon Fick	$46.24	30%
Michael Berry	$46.24	30%
Jerry Stephens	$63.14	26%
Graduate Student	$14.00	10%
Business Mgr.	$41.77	33%
Admin Staff	$26.00	33%

Table 4: Project Budget by Task

Task	Budget
0 - Project Management	$7,617
1 - Literature Review	$9,024
2 - Model Development and Analysis	$8,061
3 - Results and Recommendations	$9,546
4 - Final Report and Desimination of Results	$9,348
Total	**$43,596**

Table 5: Project Budget by State and Fiscal Year

Item	State Fiscal Year		Federal Fiscal Year	
	2014	2015	2014	2015
Salaries	$20,311	$4,062	$2,031	$22,342
Benefits	$4,253	$851	$425	$4,679
In-State Travel	$333	$67	$33	$367
Participant Costs	$4,167	$833	$417	$4,583
Total Direct Costs	$29,064	$5,813	$2,906	$31,971
Overhead	$7,266	$1,453	$727	$7,993
Total Project Cost	$36,330	$7,266	$3,633	$39,963

STAFFING

The primary research team is composed of three faculty members and a graduate student researcher from the MSU Department of Civil Engineering. Collectively, the research team has extensive research experience in the analysis and design of reinforced concrete structures and alternative construction materials. With respect to bridge structures, the team's work has included bridge monitoring and materials characterization for prestressed and steel truss members.

Damon Fick will serve as PI on this project. Dr. Fick started in January 2014 as an Assistant Professor in the Civil Engineering department at MSU. His research experience includes instrumentation and testing of full and small-scale metallic and concrete structures and components. He serves as secretary of the joint ACI-ASCE Committee 352 - Joints and Connections in Monolithic Concrete Structures.

Michael Berry will serve as a Co-PI on this project. Dr. Berry is an Assistant Professor in the Civil Engineering Department at MSU and has a research background in reinforced concrete structures and the behavior of these structures subjected to earthquake excitations. More recently his work has focused on alternative materials and their use in structural elements. He currently serves on several ACI committees including Committee 341A - Earthquake-Resistant Bridge Columns, and Committee 555 - Recycled Materials in Concrete.

Jerry Stephens will serve as a Senior Personnel on this project. Dr. Stephens is the Department Head and a professor in the Civil Engineering Department at MSU. Dr. Stephens, a registered Professional Engineer, has extensive teaching experience in the areas of structural mechanics, structural engineering, and civil engineering materials. Dr. Stephens has over 30 years of experience in experimental and analytical research in the fields of structural performance, transportation infrastructure performance, and materials development and testing. Dr. Stephens has served on several national technical committees and project review panels.

The project will also employ a graduate student to assist in identifying and reviewing relevant research documents, creating models of the prototype structure, and analyzing results for the selected parameters of the investigation.

The projected level of effort by project personnel is summarized in Table 6. These personnel can commit the time necessary to complete this work in a timely and deliberate manner. Professional members of the research team will not be changed without written consent of MDT.

Table 6: Schedule of Staffing

Name of Principal, Professional, Employee, or Support Classification	Role in Study	Task					
		0	1	2	3	4	Total
Damon Fick	Principal Investigator	40	20	20	40	40	160
Michael Berry	Co-Principal Investigator	20	10	10	20	20	80
Jerry Stephens	Senior Personnel	5	5	5	5	5	25
Graduate Student	Literature review, analytical modeling, results summary	0	250	200	160	173	783
Business Mgr.	Report Preparation	8	0	0	0	0	8
Admin Staff	Report Preparation	8	0	0	0	20	28
Total		73	285	235	225	238	1084

FACILITIES

The proposed research does not include laboratory equipment or testing. MSU will provide access to published journal materials for review and computing resources and software for the analysis portion.

REFERENCES

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