Project Work Plan

for

IMAGING TOOLS FOR EVALUATION OF GUSSET PLATE CONNECTIONS IN STEEL TRUSS BRIDGES

Pooled Fund TPF 5(259)

Submitted by

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1.0 Identification

1.1 Organizations Sponsoring Research

Federal Highway Administration
Idaho Transportation Department
New York Department of Transportation
North Carolina Department of Transportation
Oregon Department of Transportation (lead agency)
Texas Department of Transportation
Wisconsin Department of Transportation
California Department of Transportation

1.2 Principal Investigator(s)

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1.3 Technical Advisory Committee (TAC) Members

Bernie Carrasco, Texas DOT
Darshan Bansal, New York DOT
Greg Perfetti, North Carolina DOT
Joshua Dietsche, Wisconsin DOT
Matt Farrar, Idaho DOT
Michael Johnson, CalTrans
Jon Rooper, Oregon DOT
Jeff Swanstrom, Oregon DOT
Justin Ocel, FHWA

1.4 Project Coordinator

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2.0 Problem Statement

The recent collapse of the I-35W Bridge in Minnesota has resulted in considerable interest in steel truss and gusset plate connection performance. The load paths in many truss bridges are non-redundant and thus failure of a truss member or connection may cause collapse of the structure. Periodic inspections and structural evaluations are crucial for these types of bridges.

The most common method of evaluation that has been used to assess the safety of highway bridges is load rating, an approach used to estimate the available strength and allowable load on a bridge. Although sophisticated bridge load rating computer programs are available, these programs do not explicitly consider the gusset plates connecting the truss members. Hence, after the initial design calculations are completed and checked, it is unlikely that recalculations for load rating purposes have been made for gusset plates. As an outcome of the investigation into the collapse of the I-35W Bridge, steel truss bridge connections are required to undergo review. This additional scrutiny requires development of new tools to efficiently and effectively evaluate the large numbers of steel truss bridge connections in the inventory.

Digital imaging techniques have been developed at Oregon State University to enable rapid collection of field geometric data from in-service gusset plates. These tools are implemented in software that allows extraction of gusset plate dimensional information to facilitate ratings. The present tools provide a basic set of functionality such as image rectification and scaling and allow geometric data extraction such as length, perimeter, and angles. These basic functions need enhancement to take full advantage of the advancements available to bridge inspection and management with digital imaging. Enhancements such as automation of rectification tasks and identification of features within the images are proposed that will enable transportation agencies to efficiently and effectively collect geometric and condition data and use this data to evaluate and rate gusset plate connections.

3.0 Objectives of the Study

There are four (4) main objectives of the proposed research:

1. Develop methods to collect dimensional gusset plate connection information including surface geometry and out-of-plane deformations on in-service gusset plates. The information to be collected includes the geometry of the connectors, members, and overall plate dimensions. It also includes out-of-plane distortions of the gusset plate.
2. Develop methods to automate identification and optimization of reference target points, and to automate identification and extraction of the gusset plate edges, fastener locations and their corresponding member affiliations, as well as member orientations. These dimensional data feed directly into the connection rating tasks.
3. Develop finite element modeling and analysis techniques to directly rate gusset plates using extracted digital image data as the input source.
4. Develop software tools to manage and organize images and image data to enhance bridge management and allow identification of condition changes over time.

3.1 Benefits

Evaluation of steel truss bridge gusset plates is a complex and time consuming task. Enhanced tools, such as those proposed in this work plan, provide an effective means of data collection for as-built, condition-based geometric properties for analysis inputs, and enables more rapid connection rating with greater fidelity than the current state-of-the-practice.

The techniques are also applicable to shop fabrication inspection and documentation of other field conditions. They can be used for identifying and remedying construction errors or for improving accuracy of rehabilitation designs that must interface with existing features.

4.0 Implementation

Software and manuals will be developed and distributed to pooled fund project participants. Meetings and workshops will be held with pooled fund participants to present in-progress as well as summary research findings. Presentations will be made to the bridge inspection and management community as well as to technical committees such as AASHTO and TRB. Background information and findings will be described in reports, papers, and peer-reviewed journals. Explicit examples will be provided to illustrate the developed methods. Project participants that provide a minimum of $25k will be provided with a set of image targets and an on-site workshop and demonstration will be held with their personnel.

5.0 Research Tasks

Task 1: **Literature Review**
Review technical literature on image analysis, machine vision, and finite element analysis applicable to steel gusset plate connection evaluation.

Time Frame: 1 month
Responsible Party: OSU
Cost: $10,000
Deliverable: Pertinent references and background information included in future research reports.
TAC Decision/Action: None.

Task 2: **Software Development and Data Collection**
Develop enhanced procedures for field inspectors to collect high fidelity three-dimensional geometric information of gusset plates.
These techniques include the following:

- Develop methods to capture out-of-plane plate distortions (in the direction orthogonal to the plate surface, defined here as the z-direction). This will allow inspectors to quantify the amplitude and shape of out-of-plane distortions. These distortions can be important in analysis of gusset plates for compression loaded members. This approach will rely on a single camera to take 2 images that can be combined into stereo images.
- Develop methods to combine multiple 2-D digital metric orthographs to produce three-dimensional representations of gusset plate connections. The images will be processed and embedded into plan and profile CAD drawings.
- Develop algorithms to automate (with user override capability) image rectification and data extraction. This will allow rapid image processing. These software methods will identify the

image target within the original image and optimize target locations to minimize measurement errors. Then the image will be rectified and other algorithms will identify the edges of the gusset plate, identify fastener locations and attribute the fasteners to the truss members, find member orientations and identify work point. The identified parameters will be verifiable and correctable by the user. Then the data will be exported for finite element analysis.

These procedures must be applicable to commonly encountered truss joint configurations. Execution of the procedures will involve the use of image editing software that will be developed through this research to allow for correction of out-of-plane distortion, image resizing and scale calibration, and extraction of dimensional measurements from the images. Practical experience from field use will be incorporated into manuals where appropriate.

Time Frame: 6 months
Responsible Party: OSU
Cost: $100,000
Deliverable: Executable software programs with manuals and report and/or draft paper detailing the image processing methods and results for example connections.
TAC Decision/Action: Review paper/report

Task 3: **Gusset Plate Analysis**

Develop software that can directly use the geometric information collected from the processed images to rate the connections according to the FHWA Guidelines for gusset plate connection evaluation. In addition, software scripts will be developed that can generate finite element analysis models that can directly rate gusset plate connections for allowable stress rating, load factor rating, or load and resistance factored rating from the processed digital image geometric information. Alternatively, inputs can be provided by the user from available drawings or other sources. The proposed analysis engine is Abaqus. The finite element method will use free-meshing to generate the gusset plate model and a nonlinear triangular plate formulation. Up to 100 load cases (20 permit trucks with 5 member loading combinations) will be batch analyzed. The member forces will be user specified (these will be input by the user for the possible loading scenarios of coincident member forces). The analyses will deploy rigid fasteners. Fastener loads will be transferred as equivalent forces at nodal locations. Compression dominated responses will be performed using the actual plate distortions collected from the field, or by performing an eigenvalue analysis and considering the lowest buckling mode with the mode amplitude set to the plate thickness. Analysis outputs will include von Mises stresses, spread of plasticity, and member force-deformation curves for controlling load cases. The final output will be the rating factor for each permit truck given the prescribed member loading cases.

Time Frame: 8 months
Responsible Party: OSU
Cost: $100,000
Deliverable: A draft paper detailing the analysis methods and a software package that can perform the analysis as well as display and report results. A user's manual will be provided.
TAC Decision/Action: Review paper.

Task 4: **Implementation Example**

Develop example gusset plate analyses using field and laboratory data. The examples will demonstrate the data collection methods. The plate analyses will be benchmarked with Abaqus and also compared with the FHWA Guidelines for gusset plate connection evaluation.

Time Frame: 1 months
Responsible Party: OSU
Cost: $25,000
Deliverable: Spreadsheet templates and draft report detailing the analysis and comparisons between methods.
TAC Decision/Action: Review analysis findings and report.

Task 5: **Imaging Data Informatics for Bridge Management**

Develop methods to manage, categorize, organize, and query digital orthographs to enable mapping correspondences with bridge inspection records and enhance long-term bridge management. Database structures will be developed that will enable image comparisons to be made between inspection intervals. Multi-scale imaging methods will enable coarse and fine metric features to be mapped and referenced to each other. A set of truss bridge metric images will be collected, rectified, categorized, mapped, and linked to available drawings and inspection notes. Requirements of the imaging system will be developed and implementation protocols developed.

Time Frame: 12 months
Responsible Party: OSU
Cost: $100,000
Deliverable: Executable software with manuals and report and/or draft paper detailing the methods and results for an example bridge.
TAC Decision/Action: Review spreadsheets and report.

Task 6: **Analysis Software**

Develop an analysis software package using OpenSees that will perform the same function as ABAQUS in Task 3. The OpenSees finite element software framework will provide a custom, targeted software tool “widget” for gusset plate analysis. The scripting capabilities of OpenSees are superior to those (if any) of many available FEA packages. The software will automatically create the finite element mesh from identified edges and fasteners from gusset plate image data. Analysis will allow checking of multiple limit states (allowable stress, LFR, and/or LRFR) under various load combinations and results will be processed to provide rating factors. Three-dimensional graphics libraries have already been incorporated with OpenSees so that visualization of model input and analysis output will be straightforward. The proposed software will be programmed directly in the OpenSees scripting language, Tcl/Tk, and this will alleviate the need for awkward middleware between the analysis and graphics engines. The inputs for the model will be provided through an excel spreadsheet interface. Analysis reports will be generated that describe the inputs and analysis results. This type of approach has already been implemented in analysis software developed by the project team members for Alaska DOT and is adaptable to gusset plate analysis. Because OpenSees is open source and free to download, no licensing costs are involved. Training and verification examples will be provided.

The OpenSees module would be available free to transportation agencies.

Time Frame: 12 months and concurrent with other tasks
Responsible Party: OSU
Cost: $80,000
Deliverable: Software with manuals.
TAC Decision/Action: Provide feedback about software.

6.0 Time Schedule

The time line for completion of the project tasks is shown below.

	OR FY12				OR FY13			
	Qtr 1	Qtr 2	Qtr 3	Qtr 4	Qtr 1	Qtr 2	Qtr 3	Qtr 4
Project Tasks	Jul-Sep	Oct-Dec	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec	Jan-Mar	Apr-Jun
Task 1: Literature Review								
Deliverable: Background for later reports								
Task 2: Software Development and Data Collection								
Deliverable: Software and draft report					*			
Task 3: Gusset Plate Analysis								
Deliverable: Software and draft report								*
Task 4: Implementation Example								
Deliverable: Draft paper/report.								*

	OR FY13				OR FY14			
	Qtr 1	Qtr 2	Qtr 3	Qtr 4	Qtr 1	Qtr 2	Qtr 3	Qtr 4
	Jul-Sep	Oct-Dec	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec	Jan-Mar	Apr-Jun
Task 5: Imaging Data for Bridge Management								
Deliverable: Draft paper/report								*
Task 6: Analysis Software								
Deliverable: Software with manuals				*				

*Deliverables

7.0 Budget

Task	FY12	FY13	FY14	Total
1. Literature search	10,000			10,000
2. Software Devel. and Data Collection	75,000	25,000		100,000
3. Gusset Plate Analysis	75,000	25,000		100,000
4. Implementation Example		25,000		25,000
5. Imaging Data for Bridge Manage.		50,000	50,000	100,000
6. Analysis Software		80,000		
Task costs	**160,000**	**205,000**	**50,000**	**415,000**
TAC Travel		25,000		25,000
Total project costs (contract amount)	**160,000**	**230,000**	**50,000**	**440,000**

Budget explanation: Funds will be used to support students; faculty time; fringe benefits; materials, minor equipment (such as digital cameras and lenses), supplies, services, and software; publications; travel to meetings and workshops; as well as University indirect costs.

Contributing Organizations:

Agency	Year	Commitments
California Department of Transportation	2011	$12,500.00
California Department of Transportation	2012	$25,000.00
California Department of Transportation	2013	$12,500.00
Federal Highway Administration	2011	$150,000.00
Idaho Department of Transportation	2012	$10,000.00
New York State Department of Transportation	2012	$25,000.00
New York State Department of Transportation	2013	$35,000.00
North Carolina Department of Transportation	2012	$20,000.00
North Carolina Department of Transportation	2013	$10,000.00
Oregon Department of Transportation	2011	$30,000.00
Oregon Department of Transportation	2012	$30,000.00
Oregon Department of Transportation	2013	$30,000.00
Texas Department of Transportation	2012	$35,000.00
Wisconsin Department of Transportation	2012	$25,000.00