Pooled Fund Project Work Plan

for

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

Submitted by

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1.0 Identification

1.1 Pooled Fund Lead State

Oregon Department of Transportation (ODOT)
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1.2 Principal Investigator(s)

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1.3 Technical Advisory Committee (TAC) Members

Bert Hartman, ODOT
Jon Rooper, ODOT
Jeff Swanstrom, ODOT

1.4 Project Coordinator

Steve Soltesz

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. According to The Federal Highway Administration, there are approximately 37 steel deck truss bridges in the National Bridge Inventory (NTSB Recommendations, 2008) within Oregon. Further, approximately 191 other types of truss bridges exist in the national inventory within Oregon. The load paths in many of these 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 including rectification, metrification, and selected 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. Such enhancements are proposed to 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 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.
2. Develop methods to automate identification and optimization of reference target points. Develop methods to automate extraction of gusset plate edge locations, fastener locations and their corresponding member affiliations, and member orientations.
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 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 loading. 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. Images will be wrapped around wireframe models to provide visual record of the connection state.
- Develop algorithms to automate image rectification and data extraction. This will allow rapid image processing. These methods will identify the image targets, optimize target locations to minimize measurement errors, identify gusset plate edges, identify work point, identify fastener locations, and attribute fasteners to members. 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.

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

Task 3: **Gusset Plate Finite Element Analysis**

Develop a finite element analysis modeling and analysis protocol that can directly rate gusset plate connections for allowable stress rating, load factor rating, or load and resistance factored rating from the metric digital orthographs. Alternatively, inputs can be provided by the user from available drawings or other sources. The 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 initially use 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: 6 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 an example gusset plate analysis demonstrating the field data collection methods. The plate analysis will be benchmarked with ABAQUS and also compared with traditional design methods and 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 full 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 example bridge.
TAC Decision/Action: Review spreadsheets and report.

6.0 Time Schedule

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

	FY11				FY12			
	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 Devel. and Data Collection Deliverable: Software and draft report						*		
Task 3: Finite Element Analysis Deliverable: Software and draft report.							*	
Task 4: Implementation Example Deliverable: Draft paper/report.								*

	FY12				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 5: Imaging Data for Bridge Management Deliverable: Draft paper/report.								*

*Deliverables

7.0 Budget Estimate

Task	FY11	FY12	FY13	Total
1. Literature search	10,000	0		10,000
2. Software Devel. and Data Collection	75,000	25,000		100,000
3. Finite Element 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
Total OSU costs	**160,000**	**125,000**	**50,000**	**335,000**
TAC travel costs (2 meetings in OR)		5,000	5,000	10,000
ODOT project management	2,000	2,000	5,000	9,000
Total project costs	**162,000**	**132,000**	**60,000**	**354,000**

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.