FY 16-17 Research Initial Scope of Work Guidelines

I. Project Title:

LFD and LRFD Capacity of Steel Pin and Hanger Assembly

II. Project Problem Statement:

Pinned steel hinges are a vital component of multi-span steel bridges, especially in older, fracture critical bridges. A pin & hanger hinge assembly in a steel girder bridge typically consists of staggered coped girder webs on the supported and supporting sides of the hinge, a pair of hanger bars straddling the coped webs, a pair of pin plates, and a pair of pins connecting the hanger bars to the webs (See Figure 1). In transmitting the loads, the adjoining surfaces of the pins, hanger bars, pin plates, and girder webs are all subjected to bearing stresses.

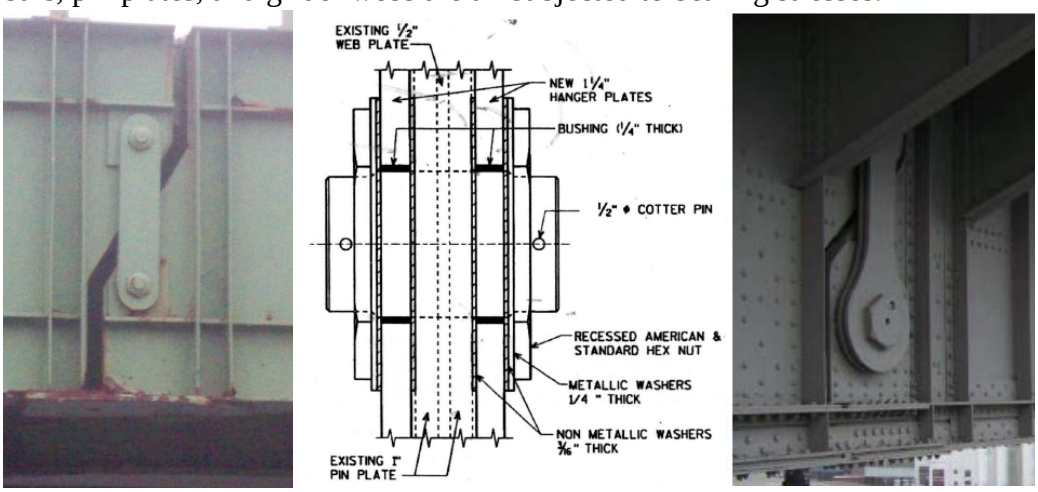


Figure 1: Standard Pin and Hanger Assembly on Plate and Built-up Girders

These pin and hanger assemblies have been determined to be too costly to maintain and ineffective at preventing catastrophic failure. For this reason, new bridges are not typically built using this type of connection. However, the determination of the capacities of the various elements of these hinges is a necessary part of the process of both the load rating of existing hinges and the design of new hinges.

Many of the existing hinge assemblies were designed using Working Stress Design Method (WSD). Unfortunately, FHWA does not allow the WSD method to design or load rate steel bridges and mandates bridge owners to use either the Load Factor Design (LFD) Method or Load and Resistance Factor Design (LRFD) Method only. The methodologies given within the LFD and LRFD specifications are inconsistent with the WSD methodology and provide inconsistent load capacities for these assemblies.

Behavior of the pins under bearing load appears to be dependent on the type of material used for the pin and the type of loading the pin is exposed to. Materials used in the past appear to have low galling resistance; as a result, it appears that the WSD method of past specifications provided much lower allowable bearing stresses for pins that are subjected to rotation. However, LFD and LRFD specifications do not differentiate between static pin and pins subjected to rotation when establishing bearing capacity, probably because these specifications are addressing the materials that are currently used for pins that have higher galling resistance.

There is a need for information related to the capacities of the "existing" pinned steel hinge elements which extends beyond the direction given in the current AASHTO LFD and LRFD Bridge Design Specifications, and the AASHTO Manual for Bridge Evaluation. To be of practical use, the end results of the research must be based on routine analysis of the hinge elements and provide straightforward illustrative examples.

III. Problem Statement Background/Context:

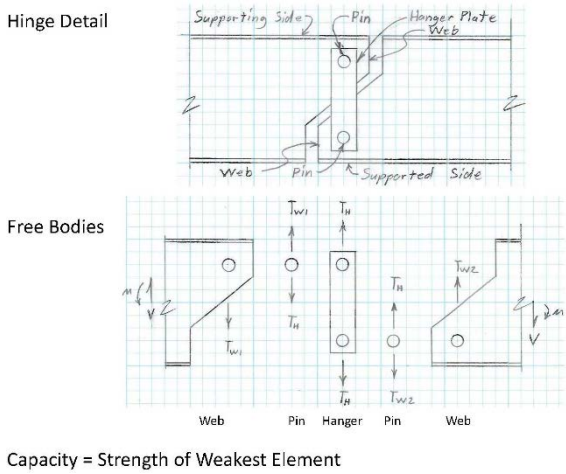
Caltrans has been rating pinned steel hinges as a part of the current effort to comply with the FHWA mandate to rate all bridges using either the LFR method or the LRFR method. Most existing bridges were designed by either the WSD method or the LFD method. Furthermore, many of these steel bridges consist of widely spaced or two girder systems and as a result are fracture critical.

As the rating of steel structures has progressed, the need to address the inconsistencies between the methodologies given within WSD, LFD and LRFD to establish the capacity of the pin and hanger assembly has been recognized. Furthermore, clear guidance is not available as to how each component should be evaluated.

A few of the issues noted during hinge evaluation are:

- A need for distinction between static pins and pins subject to rotation and how each method handles this distinction.
- While block shear is addressed in the bridge specifications, direct shear is not.
- Due to lack of guidance, beam web shear guidelines are being used and net area is taken after deducting for bolt holes in excess of 15% of the web area.
- Guidance is not available on how web shear at Pin Plates should be evaluated.
- Specification does not state whether full tension field action is considered for the stiffened panel adjacent to the coped web at hinge or not.
- Specification does not state whether to consider shear and bending stresses in Pins when evaluating pins. Pin connected elements typically have very high shear and a very short lever arm for bending. Analyzing these by simple static methods may be too conservative, while ignoring bending due to close coupling may be unconservative. The simple bending and shear equations may not apply.

There is a need to determine if more appropriate equations apply without requiring sophisticated analysis.



Over half of California's steel hinges currently being rated are governed by bearing. The WSD specification gave specific allowable stresses for bearing on pins and adjoining materials. There was a distinction between static pins and pins subject to rotation. This specification however is no longer accepted by the Code of Federal Regulations as a basis for load rating analysis. The LFD specification has no such specific guidance. The LRFD specification does not comprehensively address this analysis.

Section 10 of the 2004 California Bridge Design Specifications (BDS) addresses both the WSD and LFD requirements for steel bridges. Article 6 of the AASHTO LRFD Bridge Design Specifications address the LRFD requirements for steel bridges. The bearing stresses allowed on the contact surfaces between pins and webs or pins and hanger bars are inconsistent among the WSD, LFD, and LRFD design codes.

The ASD code, in Table 10.32.1A, allows 0.80 F_y for "Bearing on milled stiffeners and other steel parts in contact (rivets and bolts excluded)." It allows 0.80 F_y for "Bearing on pins not subject to rotation," with a footnote explaining, "This shall apply to pins used primarily in axially loaded members, such as truss members and cable adjusting links. It shall not apply to pins used on members having rotation caused by expansion or deflection." For "Bearing on pins subject to rotation (such as used in rockers and hinges)" the allowable stress is 0.40 F_y.

The LFD code says nothing specific about bearing on hinge pins and the adjoining materials. Therefore a bearing stress equal to the design stress of F_y per Section 10.46 is currently being assumed to apply to pins and the adjoining web or hanger bar materials. The load capacity is $B = A_b F_y$ where A_b is the bearing area and a capacity factor of 1.00 is assumed.

The LRFD code addresses bearing on pin-connected plates in Article 6.8.7.2. The bearing resistance is $Pr = \phi_b A_b F_y$ where the resistance factor ϕ_b is1.0 for bearing per Article 6.5.4.2, A_b is the bearing area, and F_y is the yield strength of the plate.

The LRFD code addresses bearing on pins in Article 6.7.6.2.2. The bearing resistance is $(R_{pB})_r = \phi_b(1.5\ t\ D\ F_y)$ where the resistance factor ϕ_b is1.0 for bearing per Article 6.5.4.2, "t" is the thickness of the adjoining plate, D is the diameter of the pin, and F_y is the yield strength of the plate. In the 2007 code there was no commentary on this subject. In the 2012 Commentary it is noted that the 1.5 coefficient may be halved at the discretion of the Engineer. But it also says the 1.5 coefficient should not be halved for evaluation of existing pins.

The inconsistencies noted within the different methods make it difficult to correctly establish the load carrying capacity of the bridges, especially knowing that any incorrect assumptions could lead to catastrophic failure and the safety of travelling public will be affected. Clear guidance for the design of the hinge elements needs to be provided in the LRFD code, and extended back to the LFD code.

As the rating of various types of structures has progressed, the need to address the specific issues as noted above has been recognized. Implementation of the results of the proposed research will help enable SM&I to complete the rating of our bridges as required by the FHWA mandate in a timely manner.

This knowledge will result in the cost effective preservation of our existing bridge inventory while allowing bridge raters and designers to maximize transportation system performance and accessibility with regards to permit routing of our state's extensive port and trucking industry.

IV. Research Objectives:

- To develop comprehensive but simple guidelines and specifications to be used to establish the capacity of pin and hanger assemblies of existing bridges.
- To develop a few examples using the guidance developed as part of this research to illustrate its application.
- To develop future research that needs to be performed to insure the safe load capacity of the pin and hanger assembly.

V. Support California Bridges & Structure Strategic Direction
(http://onramp.dot.ca.gov/hq/des/spi/docs/Final_California_Bridges_Structures_Strategic_Direction_9-11-14.pdf)

This research will improve the design specifications on pin and hanger assemblies and will provide better and consistent methodology for evaluating existing steel bridges.

Establishing the accurate capacity of steel pin and hanger assembly will

- insure greater public safety,
- reduce un-necessary detour of legal trucks and permit trucks thereby improving the mobility of goods across California,
- minimize the need for retrofitting of these hinges, and
- establish the best strengthening strategies and thereby improve the efficiency in managing our assets.

VI. Description of Work:

1. Literature review on various types of pin and hanger assemblies.
2. Literature review of materials used for the pins and hangers over the years and their behavior that influences their performance when subjected to bearing and rotation.
3. Literature review of existing nondestructive test methods to ascertain the material strength of pin and hanger assemblies, since cutting samples of the existing materials for testing is usually not possible or practical.
4. Review of past and present AASHTO (or AASHO) Specifications and guidelines used to design and build bridges using working stress, load factor and load and resistance factor methods.
5. Summarize the differences between the methodologies listed within these design methods and provide possible explanations for the requirements specified in these specifications.
6. Propose changes or improvements to the methods listed within LFD and LFRD Specifications if needed.
7. Apply the proposed improvements utilizing a few existing hinges built over several decades and illustrate the proposed method will be consistent and provide reliable capacity.
8. Recommend a method to establish the steel strength of pins whenever the steel strength is not listed in the as-built (or design) plans; and tabulate the material properties used over the years.
9. Develop an interim report on pin and hangers, evaluation methods, illustrative examples.

10. Develop recommended California Amendments to the AASHTO *LRFD Bridge Design Specifications.*
11. Develop recommended changes to the AASHTO Manual for Bridge Evaluation along with illustrative examples.
12. Develop recommendations for future research that needs to be carried on to establish the adequacy of pins whenever distress or deterioration is noted.
13. Final Report

VII. Related Research:

American Association of State Highway and Transportation Officials (AASHTO), Standard Specification for Highway Bridges, AASHTO, Washington D. C., 1st to 17 Editions.

David Houcque, *Structural Integrity Assessment of Pin and Hanger Connection of Aging Highway Bridges using Finite Element Analysis,* A PhD Dissertation, Northwestern University, June 2008.

David Juntunen, *Michigan's Link Plate and Pin Assemblies,* Michigan Technological University, Research Board, Issue Number 92, July 2001.

H. M. Westergaard, *Bearing Pressures and Cracks,* In Transactions, ASME, Journal of Applied Mechanics, 1939.

Jeffrey M. South, Christopher Hahin, Richard O. Telford, *Analysis, Inspection, and Repair Methods for Pin Connections of Illinois Bridges,* Illinois Department of Transportation, Report No. FHWA/IL/PR-107.

James R. Bellenoit, Ben T. Yen, and John W. Fisher, *Stresses in Hanger Plates of Suspended Bridge Girders,* Transportation research Record 950, Second Bridge Engineering Conference Volume 2.

John H. Magee, *Two Galling Resistant Stainless Steels used for Bridge Hinge Pins,* https://www.cartech.com/techarticles.aspx?id=1666, December 1996.

T. Kuennen, *Stainless Steel hinge Pins anchor bridge retrofit,* Road and Bridges, Dec. 1993.

VIII. Deliverables/Deployment Potential:

The deployable product will be (1) California Amendments to the AASHTO *LRFD Bridge Design Specifications* (2) Amendments to the Caltrans Bridge Design Specification (or AASHTO Standard Specification) (3) Recommended methodology to establish the steel strength for materials used for the assembly using the details given on the as-built plans (3) and A Memo to Designer or Load Rating Engineer may also be needed to explain implementation of the research.

This is a relatively small project that calls for extensive literature survey and review of past practices. However, if researchers require confirmation of any of their finding by testing in the laboratory, this study may need to be extended or expanded.

IX. Sponsor: Structure Maintenance and Investigation, Division of Maintenance.
Date: 01/07/2016