Preface

An important function of the Transportation Research Board (TRB) is to stimulate research that addresses problems facing the transportation community. In support of this function, TRB technical committees identify problems, and develop and disseminate research problem statements for use by practitioners, researchers, and others. The problem statements listed below were developed by the TRB committee noted above. These problem statements should not be considered comprehensive; they may only represent a portion of overall research problems identified by committee members.

Statements

<table>
<thead>
<tr>
<th>Statement Number</th>
<th>Priority</th>
<th>Problem Statement</th>
<th>Date Posted</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4</td>
<td>Fatigue Testing for Cantilever Traffic Signal and Sign Structure Connection Details</td>
<td>01/04</td>
</tr>
<tr>
<td>2</td>
<td>5</td>
<td>New Design Manual for Steel Orthotropic Deck Bridges</td>
<td>01/04</td>
</tr>
<tr>
<td>3</td>
<td>6</td>
<td>Stringer-to-Floor Beam Connection Design</td>
<td>01/04</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>Guidelines for the Design and Construction of Steel Orthotropic Deck Bridges</td>
<td>08/05</td>
</tr>
<tr>
<td>5</td>
<td>2</td>
<td>Development of Design and Construction Guidelines for the effect on performance of steel I-girders being out of plumb.</td>
<td>08/05</td>
</tr>
<tr>
<td>6</td>
<td>3</td>
<td>Pin Plate Variable Amplitude Fatigue Limit (VAFL)</td>
<td>08/05</td>
</tr>
</tbody>
</table>

I. Problem 1: Fatigue Testing for Cantilever Traffic Signal and Sign Structure Connection Details

II. Research Problem Statement

The new AASHTO Standard Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals, 4th Edition, incorporates a new design chapter for fatigue (chapter 11). Many traffic signal poles in the national inventory are deficient under the new fatigue provisions. Designing to the more stringent fatigue category I, Table 11-1, may be difficult or costly. Appearance could also suffer without efficient connection details. Although much research and testing has been accomplished to date, there is still only limited fatigue resistance data for many alternative details. Research should be pursued until cost effective, attractive solutions are available for all fatigue categories. Simple enhancements or repairs should be developed to extend the service life of existing
support structures. Effects of hot dip galvanizing on fatigue performance should be evaluated.

III. Research Proposed

Task 1 Review the latest and ongoing testing relating to traffic signal and sign support structure connections.
Identify number, type, and sizes of test specimens needed to adequately assign fatigue categories, building on available test data.
Survey researchers and manufacturers for most promising connection details.

Task 2 Develop a fatigue testing program that incorporates mast arm and base connection details found in the current inventory of cantilever traffic signal and sign supports.
Test specimens should be full size. Methods for lengthening the service life of existing structures, such as dampers and fatigue improvement techniques described above should be compared.
A second phase testing program should be anticipated so that connections that are not adequate under the new code can be redesigned and tested.
The effect of hot dip galvanizing on fatigue performance needs to be determined.

Task 3 Conduct the test program, including second phase tests.
Test specimens for second phase testing should be fabricated in accordance with Task 2 recommendations.
Some specimens should be suitable for extended mast arm spans designed to fatigue category I.

Task 4 Prepare findings of the tests and conclusions in a NCHRP report.
Recommendations for the existing inventory should be made.
Results should be in a format suitable for inclusion in chapters 5 and 11 of the Standard Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals.
Simple details adequate for designing extended spans to fatigue category I (Table 11-1) should be demonstrated.

IV. Estimate of Problem Funding and Research Period

The estimated funding for this proposal is $800,000. The research project will require approximately 36 months.

V. Urgency, Payoff Potential, and Implementation

The structural adequacy of the national inventory of cantilever traffic signal and sign supports needs to be evaluated in light of the new design code. Also, new designs must be economical and visually unobtrusive. Validating or modifying the fatigue stress categories is urgent for states that are requiring designs in accordance to the new code. Many states are not adopting the new provisions since cost of implementation is high. The cost of overhead structure failures is potentially high. The benefits of testing may be safer, economical traffic signal and sign structures.

VI. Literature Search Summary
Texas DOT has been testing connection details through the University of Texas at Austin. 55 full-size mast arm connection detail specimens were tested for fatigue performance. The research report is due to be published. A preliminary copy of the report was used to update this research proposal. Promising methods to test are identified in the report.

Lehigh University has tested a number of socketed mast arm connection details. These tests established the low fatigue category listed in the current design code. Further testing has confirmed those results. Lehigh is presently investigating the effect of base plate flexibility on the fatigue resistance of socket joint connections.

The University of Minnesota is testing traffic signal structure details commonly used in that state.

Valmont Industries tested some of their own products. The results of this testing are not generally accepted by the research community. Their efforts have pointed out how labor and skill intensive the stiffener approach is in practice.

The Tokyo Institute of Technology performed fatigue testing on stiffener details, including a proprietary U-rib stiffener detail. The U-rib stiffener was also tested at the University of Texas. The U-rib stiffener appears to be troublesome as a moisture and debris collector. It is also labor and skill intensive to fabricate.

Recent testing was also conducted at the University of Missouri – Columbia. Only a small number of full-scale specimens were tested.

TRB Research in Progress projects:
- Revision of AASHTO Fatigue Design Loadings for Signs, Luminaires, and Traffic Signal Structures, for Use in Texas
- Structural Fatigue Details (sponsored by Texas DOT, listed above)
- Traffic Signal Pole Research (sponsored by Wyoming DOT)
- Field Monitoring and Evaluation for Sign Support Structures Subject to Dynamic Loads (sponsored by Connecticut DOT)
- Structural Analysis of Sign and Luminaire Support Structures (sponsored by Wisconsin DOT)

A number of NCHRP projects are related to this proposal:
- NCHRP Report 412, Fatigue Resistant Design of Cantilevered Signal, Sign and Light Supports
- NCHRP Report 469, Fatigue Resistant Design of Cantilevered Signal, Sign and Light Supports
- NCHRP Report 494, Structural Supports for Highway Signs, Luminaires, and Traffic Signals
- NCHRP Project 17-10, 17-10(02) Structural Supports for Highway Signs, Luminaires, and Traffic Signals
- NCHRP Project 10-38, 10-38(02) Fatigue Resistant Design of Cantilevered Signal, Sign, and Light Supports

From a cursory review of related research:
• There can be a significant improvement in fatigue performance with ultrasonic impact treatment (UIT) and hammer peening, after galvanizing. The potential exists for increasing the socketed joint fatigue category from E’ to B’. These approaches have definite benefits for existing and future structures. The economics of these techniques should be examined and compared to other solutions. Hammer peened details and UIT treated details should be assigned a fatigue category, based on adequate testing.

• Additional testing of the socketed base connection only seems warranted if the use of thicker base plates is anticipated.

• Various stiffener solutions should be left out of testing based on detail expense. The external collar connection seems to offer a more practical solution by reducing stresses, and warrants the additional testing to assign a fatigue category.

• The post connections for the mast arm still need testing.

• Hot dip galvanizing appears to have a detrimental effect on fatigue performance and that needs to be reflected in the fatigue design table.

The literature search does not reveal any fatigue testing for cantilever traffic signal and sign structure connection details for assigning fatigue categories. In fact, NCHRP Report 469 notes that the largest remaining area of uncertainty is the fatigue resistance of the diverse details used for sign structures. NCHRP Report 469 further recommends that full-scale fatigue tests be conducted on the most common fatigue-critical connection details. The proposed research is needed and has merits in providing durable and cost-effective connection details.

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I. Problem 2: New Design Manual for Steel Orthotropic Deck Bridges

II. Research Problem Statement

Since the early 1900s, considerable effort has been put forth in order to develop analytical models that could reasonably predict the stresses, deflections, and overall behavior of orthotropic bridge decks. The basic “Design Manual for Orthotropic Steel Plate Deck Bridges” prepared by Roman Wolchuk published in 1963 by the AISC, although out of print, is an excellent example of earlier design procedures. This indispensable handbook proposed a design method for such decks using charts for the AASHTO loadings governing at that time and recommendations for details and surfacing, in accordance with the 1960’s state-of-art. While the theory and the design method presented in the Manual provided reasonable design solutions for global behavior, the methods were not capable of providing accurate estimates the stresses (or displacements) at critical details, like at the rib-to-diaphragm connection. However, nearly all documented performance failure of an orthotropic deck has been the result of localized stresses and not global response. High local stress ranges resulting in fatigue cracking or excessive local deflections resulting in failure of the wearing surface are by far most common. Clearly, the existing simplified methods discussed above provide no guidance in accurately estimating the local stresses or displacements at critical details, like at the rib to floorbeam connection.

The results of recent full-scale laboratory and field research programs have confirmed the complexity of the behavior and importance of accurately characterizing the stresses at critical details. For example, experimental and analytical studies have demonstrated that the rib-to-diaphragm detail is subjected to a complex stress cycle comprised of in-plane and out-of-plane components. In addition, the fatigue resistance of the rib-to-diaphragm welded details specified in the AASHTO LRFD Bridge Design Specifications, were established through laboratory testing of full-scale specimens using strain gage measurements. It is clear that in order to use the fatigue resistance specified in the AASHTO LRFD Bridge Design Specifications for future designs, the stress ranges must determined consistently with the approach used to establish the fatigue resistance in the laboratory. Hence, a rational procedure to calculate (or experimentally measure) stresses at the rib-to-diaphragm connection, which is consistent with the fatigue resistance published in the AASHTO LRFD Bridge Design Specifications, is required.

Recent field monitoring of orthotropic decks in the Eastern US has suggested that the fatigue limit-state load for some elements of orthotropic decks is larger than assumed in the current AASHTO LRFD (i.e., $S_{\text{max}} > 2\times S_{\text{reff}}$). Additional field testing and monitoring should also be conducted on orthotropic deck(s) in other locations in the Central or Western US, in order to confirm this finding. This will ensure the development of design specifications which result in fatigue resistant decks that are also economical.

A thorough review of performance of newer wearing surfaces, performance history, and appropriate applications has not been conducted. The Manual would collect, report, and
summarize the performance of various wearing surfaces in a single comprehensive document.

In light of the above, a new, thoroughly revised and updated guideline for the design of orthotropic bridge decks is urgently needed.

I. **Research Objective**

The objective of this research is to develop a new set of Design Guidelines for Orthotropic Deck Bridges. The Manual should contain at least the followings:

- Introductory chapter on structural behavior, applications of orthotropic decks and economy, with examples of steel deck bridges (box girders, tied arches, suspension and cable-stayed bridges, movable bridges).

- A short chapter summarizing the existing hand methods, such as the basic Pelikan-Esslinger method will be presented. However, the primary focus will be on the Finite Element Method of analysis. Guidance on modeling, boundary conditions, mesh generation, element type and size, and loading would be presented.

- Discussion regarding the importance of using a “system” approach, with emphasis on the serviceability- and fatigue-limit states will be discussed in detail (i.e., limiting flexibility for reliable surfacing performance, fatigue issues, etc.)

- Discussion of details of closed and open-rib systems from the viewpoint of economy and fabrication cost saving. Optimization of orthotropic deck framing.

- Fatigue design based on 2003 revisions of the AASHTO LRFD orthotropic deck provisions. Discussion of fatigue failures, causes, and retrofit schemes. The results of recent research related fatigue resistant details would be included with commentary.

- Practical design procedures, with examples based on actual U.S. structures (*decks with open and closed ribs, with a focus on FE investigation of rib/floorbeam intersections*).

- Surfacing design criteria and recommendations; review of past performance of various wearing surfaces will be presented.

- Guidance on fatigue testing of orthotropic decks systems, in order to establish the fatigue resistance of future details, will be included.

- Updated literature references

II. **Funding and Time**

Recommended Funding: $375,000
Research Period: Approximately 36 months.

III. **Urgency, Payoff Potential, and Implementation**
Orthotropic decks, unlike conventional concrete bridge decks, are immune to the salts and moisture and offer practically unlimited service life. Further advantages are: extremely light weight, large carrying capacity, jointless bridges, and expedient prefabrication and installation. Orthotropic decks are especially attractive for redecking existing bridges and indispensable where minimizing dead load is crucial (long-span cable supported bridges, movable bridges). Considering the aging infrastructure of the US and the benefits of orthotropic bridge decks in rehabilitation strategies, the immediate needs are apparent. Lack of an up-to-date reference manual limits the use of this system and severely hampers proper applications of orthotropic decks.

The product of this research addresses the thrust area of structural systems that improve performance and reliability and meets the business need of structural systems that reduce life-cycle costs, extend useful life, and improve the constructability of bridges.

IV. Literature Search Summary

A literature search was performed and included below. A list of reference is provided below. Although there is a considerable amount of research on orthotropic bridge decks, there is no single source which has compiled all of this information. In fact, the most recent laboratory, field testing, and analytical studies have not been summarized and brought together to form a single concise document. There is much new information related to wearing surfaces, fatigue, loading, overall behavior, and fabrication for example, which needs to be synthesized into a new design manual.


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I. Problem 3: Stringer-to-Floor Beam Connection Design

II. Problem Statement

Stringer-to-floorbeam connections in steel bridges are typically riveted or bolted angle connections designed as flexible connections that transfer stringer end shear only. These connection angles experience fatigue cracking because there is little capacity for end rotation and considerable flexural stress is present in the angle. A preliminary review of the literature indicates considerable research on flexible beam-to-column connections for building applications has been made, but that limited research on typical bridge stringer-to-floorbeam connections subject to stringer live loads has been performed.

Current bridge design codes make some recommendations for fastener geometry to allow sufficient flexibility of the connection to preclude fatigue cracking of the angles (Yen, Zhou and Fisher, Lehigh University, 1990-1991). That research developed moment-rotation relationships based on finite element analyses and examined fatigue behavior based on a limited number of tests.

It is recommended that a series of tests be carried out on stringer-to-floor beam connections to understand the load versus deformation behavior of the connection and the moment resistance of the connection under stringer live loads. The tests should measure...
the effect of fastener gage on fatigue stress ranges, angle geometry (thickness, length), and effect of stringer/floorbeam stiffness.

It is also recommended that S-N testing be conducted on stringer-to-floorbeam connections to develop an appropriate fatigue category for these connections.

III. Research Objective

The main objective of this proposed research is to conduct a series of load-deformation (moment-rotation) and fatigue tests on stringer-to-floorbeam connections to establish appropriate connection design and fatigue category criteria for the AASHTO and AREMA design specifications. The proposed research is expected to include at least the following tasks:

1. Perform a literature search on pertinent test data on stringer-to-floorbeam connections and pertinent related research on beam-to-column connections.
2. Evaluate the findings from Task 1 and identify additional information that is needed to establish appropriate connection design recommendations and fatigue category.
3. Prepare a “Work Plan” for carrying out a series of tests on stringer-to-floorbeam connections to establish appropriate load-deformation characteristics and fatigue category. The “Work Plan” should include the effects of size, thickness, and length of angles, gaps, and fastener gage and end distance. Floorbeam web thickness should reflect typical thicknesses encountered in the field.
5. Conduct fatigue tests.
6. Prepare design criteria for adoption by AASHTO and AREMA.
7. Prepare final report.

IV. Funding and Time

The estimated funding for this proposal is $350,000. The research project will require approximately 30 months.

V. Urgency, Payoff Potential, and Implementation

Currently, there are no end moment design recommendations for stringer-to-floorbeam angle connections. These connections are designed to be flexible and there is no category of fatigue detail for these connections. Tests are needed to develop AASHTO and AREMA design criteria to properly account for end moment transfer and fatigue behavior of these common stringer-to-floorbeam connections.

This research meets many of the Business Needs in three major areas: Enhanced Materials, Structural Systems, and Technologies; Enhanced Specifications for Improved Structural Performance; and Efficient Maintenance, Rehabilitation, and Construction.

VI. Literature Search Summary
A literature search was conducted using TRIS online (http://ntl.bts.gov/tris) and the Research In Progress database (http://rip.trb.org/search). Twenty-five records were reported. Three were of interest.

(1) Cousins and Stallings. “Laboratory testing of Bolted Diaphragm-Girder Connections,” ASCE Bridge Engineering, ASCE Bridge Engineering, May 1998, Vol. 3, No. 2, pp. 56-63, tested single-angle connections for intermediate channel sections. Fatigue cracking was a result of distortion-induced fatigue, not direct loading from roadway stringers proposed in this research. Other differences are the angles were on one side only, not on both sides as normally used on older highway bridges and there was a gap between the outstanding leg of the angle and the face of the girder web. The researchers suggest AASHTO Fatigue Category A for the single angle.

(2) Roeder, et al. “Fatigue Cracking of Riveted, Coped, Stringer-to-Floorbeam Connections,” Washington State Transportation Center, University of Washington, WA-RD 494.1, 2001, pp. 104. This research focused on determining the fatigue category of the stringer cope and not the angle connections. The researchers suggest the cope be AASHTO Fatigue Category D.

(3) Abouelmaaty, et al. “Fatigue Testing of Double-Angle Connections of Steel Railroad Bridges,” Transportation Research Record 1688, TRB, 1999, pp. 46-52. This research involved the fatigue testing of two full-scale double-angle connections for longitudinal stringer to transverse floorbeams for a steel thru-plate girder railroad bridge. This research comes closest to the research proposed herein. Normally, there is a gap equal to the thickness of the connecting angle between the end of the stringers and the floorbeam web. Unfortunately, the researchers placed the stringer against the floorbeam web so when testing began the stringer flanges “punched” against the web of the floorbeam causing fatigue cracking in the floorbeam web.

A further literature search and review was conducted from various text and journal publication reference indexes and the AISC Archive. The following six references are related to the presently proposed, or similar research.

(4) Wilson, W.M., “Design of Connection Angles for Stringers of Railway Bridges”, AREA Proceedings Vol. 41, 1940, pp. 889-903. This research was directed at riveted steel railway stringer to floorbeam connections and proposed design rules for connection angle detailing to ensure the required flexibility to enable connection design for stringer end shear only. The analysis of this research is valid for connection angle flexural stresses and deflections corresponding to loads below the loads established from some simple axial fatigue tests of riveted connections. These design rules for connection angle flexibility remain in use by many highway and railway bridge designers; and the proposed research is directed at design recommendations based on improved fatigue testing, moment-rotation testing and finite element analysis.

(5) Yen B.T. et al. “Fatigue Behavior of Stringer-Floorbeam Connections”, Proceedings of the International Bridge Conference, 1991. This research is similar to that being
proposed. The moment-rotation relationship of typical stringer to floorbeam connections was investigated by finite element modeling. Under HS-20 truck loading, large tensile stresses in the connection angles were calculated. Even larger stress ranges were noted due to existence of negative bending moments at the connections. Also, a limited number of fatigue tests were conducted which indicated data above the AASHTO and AREMA Category A curves. The research suggested that to alleviate fatigue problems at these connections, connection angle geometry control to attain flexibility is required. An empirical method of establishing adequate flexibility (similar to the method developed by Wilson in 1940) was proposed by the research. This research provided useful information for the design of typical stringer to floorbeam connections but further moment-rotation and fatigue testing is considered required to establish design rules under the heavier modern axle design loads for highway and railway bridges. Also, in order to establish a statistically valid fatigue category for this detail, further testing is required.

(6) Munse W.H., et al. “Behavior of Riveted and Bolted Beam to Column Connections”, Journal of Structural Division, ASCE, Vol. 85, 1959. As suggested by the title, this research was directed at beam-to-column connections. It concluded that the majority of connection flexibility is derived from deformation of the angles with only a minor influence from fastener deformations. This research did not consider beam (stringer) connections to thinner plate members (floorbeam and girder webs).

(7) Richard R.M., et al. “The Analysis and Design of Single Plate Framing Connections”, Engineering Journal, AISC, 1980. This research considered both beam connections to columns and supporting beam webs. The research was, however conducted on single plate rather than double-angle connections. The research indicated that, in some cases, the common practice of designing connections for a moment corresponding to an eccentric vertical shear might be nonconservative for end plate connections. The design of double-angle stringer to floorbeam connections with relatively large end shear eccentricity distances is sometimes done using a similar approach, but was not studied in the static load moment-rotation testing and finite element models of this research.

(8) Kennedy, D.J.L., “Moment-Rotation Characteristics of Shear Connections”, Engineering Journal, AISC, 1969. This research performed moment-rotation tests on double angle and end plate connections. The results provide valuable information concerning shear connection design but were performed under static load conditions only and did not simulate typical bridge member geometry.

(9) Rauscher, T., et al., “Reliability of Rotational Behavior of Framing Connections”, Engineering Journal, AISC, 1992. This research included a statistical analysis of moment-rotation test data on “partially-restrained” double-angle beam-column connections. The research concluded that slip resistant double angle connections exhibit nonlinear rotational behavior primarily due to yielding of the connection angles. The research also revealed a greater statistical variance in rotational behavior for more flexible joints (typically those designed for shear only). The research did not include fatigue testing as it focused on typical building framing angle connections.
The research proposed herein is to test highway stringer-to-floorbeam double-angle connections, which will simulate actual field conditions and typical bridge element geometry (i.e. the stringers are offset and do not bear against the floorbeam web).

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I. Problem 4: Guidelines for the Design and Construction of Steel Orthotropic Deck Bridges

II. Research Problem Statement

The orthotropic bridge deck industry in the USA is not adequately served by specifications published by AASHTO. Current USA design is partly based on interpretation of 1950’s German technical papers that were used by AISC to develop guidelines in 1963. The AISC manual is out of print and is considered obsolete. Design is based on testing and analysis to suit individual applications, often expensive retrofits. While appropriate for the particular bridge configuration, these projects leave no legacy to benefit applications that have different geometries. There has been a history of successes and problems. Surfacing, vital to distribution of wheel loads, has failed on the Throgs Neck and Champlain Bridges, and is starting to delaminate on the Williamsburg Bridge. Much effort is devoted to develop details that are resistant to fatigue cracking. On the other hand, many structures, including the Freemont Bridge in Portland and the San Mateo-Hayward crossing in San Francisco, have trouble free history.

At the August 2004 conference on orthotropic decks in Sacramento, 63 papers from the US and around the world pointed to the potential opportunities. It is possible to achieve a 100-year service life with these decks, vastly changing maintenance requirements. Lower deck loads enhance rehabilitation strategies, and significantly benefit cable structures. Panelized construction quickly gets traffic flowing again. The same conference also highlighted
differences in opinions about fatigue resistant details and spacing of floor beams. Research is needed to provide full implementation of LRFD to orthotropic decks. Even with all their experience with over a thousand bridges, overseas conference attendees indicated that they do not have all the answers. Several expressed a willingness to collaborate on a research program. It is vital to understand why some projects are more successful than others, so that proven techniques can be shared within the bridge community.

The need is there. Independent studies have shown that the lighter bridge decks are competitive for spans above 500m for new cable supported structures where significant savings in cable size are made. Similarly, orthotropic decks benefit retrofit of cable supported structures by reducing demand on the cables. Overseas practice indicates that spans as low as 100m can be economic with orthotropic decks. The weight savings for movable structures makes these decks very competitive. If standardized deck panels could be prefabricated with pre-approved details, then the likelihood is that orthotropic decks could be competitive at shorter spans in the US, especially for deck replacement under traffic. FHWA records show that over one third of major bridges in the USA will need rehabilitation over the next 20 years. Individually, these projects cannot support the research efforts needed. There are also ten new major bridges in planning and design, and more retrofits, that will use orthotropic decks in the US. For shorter spans, the bridge industry needs guidelines that can be used without specialist design effort and custom research to produce satisfactory results. For retrofits of longer spans and new cable structures, guidelines on design approach and methodology are needed to ensure best practices are employed.

III. Research Objective

The objective of the research is to develop new guidelines for orthotropic bridge decks that would be accepted by AASHTO. The initial task will be to investigate and quantify what has worked and what has not. The investigation will include surfacing as well as steel details. Special study will be given to recent retrofit details and testing. Overseas experience will be included. The work will be divided into four tasks.

1. Investigate constructed and operational orthotropic decks:
   - Identify structural system – rib types, rib span lengths, deck plate thickness, cut outs, diaphragms, surfacing.
   - Obtain truck loading and volumes data.
   - Evaluate performance of systems by literature search and interviews.
   - Compare actual performance with any physical testing done at time of design.
   - Compare actual performance with finite element analysis.
   - Interview fabricators and inspectors on practicality of existing details.
   - Measure recently constructed bridges (prototypes) for stresses and traffic.

2. Define potential systems using results of investigation task:
   - Systems with proven performance record.
   - Hybrid systems drawing from best practice and best results.
   - Systems modified to conform to fabricators’ preferences.

3. Define preferred systems:
   - Perform finite element analyses to identify stress behaviors of potential systems.
   - Compare stress behavior of potential systems with measured prototype systems.
   - Perform comparative costing to identify best fabrication practice.
   - Reduce potential systems to three preferred systems.

The report will take the form of a draft guideline pending adoption by AASHTO.

- There will be an introductory section on the applications and economy of orthotropic decks. A discussion of failures, including causes and retrofits, will be given.
- The next section will stress the importance of using a “system” approach. Closed and open-rib stringers will be compared from the viewpoint of weight and fabrication costs. Optimization of orthotropic deck framing will be discussed in detail.
- The third section will have fatigue design recommendations and data review.
- A section on finite element modeling, boundary conditions, mesh generation, element type and size, and loading will be included.
- Practical design procedures, including surfacing design, will be given.
- Guidance on fatigue testing of orthotropic decks systems will be included.

IV. Estimate of Problem Funding and Research Period

Recommended Funding: $450,000
Research Period: Approximately: 33 months.

V. Urgency, Payoff Potential, and Implementation

The bridge industry is using a forty year old document that has never been revised. There are many applications that could benefit from lighter weight and rapid installation of bridge decks, especially under traffic. New guidelines would introduce orthotropic decks to many bridge owners who presently pass them up as being too difficult to implement. Extensive testing has been done for retrofit of the Williamsburg and Bronx Whitestone Bridges, giving an opportunity to use research already carried out. Sacramento conference attendees from around the world have also promised to share information to assist this effort.

The product of this research addresses the thrust area of structural systems that improve performance and reliability and meets the business need of structural systems that reduce life-cycle costs, extend useful life, and improve the constructability of bridges.

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VII. Problem Monitor

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IX. Literature Search Summary

A literature search was performed and included below. A list of reference is provided below. Although there is a considerable amount of research on orthotropic bridge decks, there is no single source which has compiled all of this information. In fact, the most recent laboratory, field testing, and analytical studies have not been summarized and brought together to form a single concise document. There is much new information related to wearing surfaces, fatigue, loading, overall behavior, and fabrication for example, which needs to be synthesized into guidelines for design and construction.


I. **Problem 5: Development of Design and Construction Guidelines for the Effect on Performance of Steel I-Girders Being out of Plumb.**

II. **Research Problem Statement**

Girder vertical deflections under dead load (girder self weight, deck weight) for skewed and curved bridges do not necessarily align across the width of the bridge. For example, on skewed bridges, the maximum point of deflection for each girder in each span will be near mid-span for each girder. However, these mid-span deflection points of each girder do not align across the transverse width of the bridge. On curved bridges, the girder on the outside of the curve is longer than the girder on the inside of the curve, that, coupled with curvature effects, causes the girders to have different deflections combining curvature and skew exacerbates the phenomenon. It may be difficult to install cross frames at locations with significant differential deflection. Further, the installation of the cross frames may cause the girders to rotate or they may restrain additional deflections with the result that girders will rotate. These rotations of the girders will cause lateral stresses to be introduced into the flanges.

How should the designer, fabricator, and erector address issues related to differential deflection for skewed structures with and without horizontal curvature, especially, if there is a concern about the final out-of-plumb condition of the girders?

The following issues arise during design relative to differential deflections on skewed bridges:

- For skewed piers and abutments, should nearby cross frames be placed along the skew or normal to the girder?
- Should the intermediate cross frames be skewed parallel to the piers and abutments or placed normal to the girders and staggered, and at what angle should the change be made?
- If the differential deflection is significant, the webs of the girders will rotate in a transverse direction. The webs could either be erected in the vertical position and rotate
out-of-plumb after the dead load is applied, or be erected out of plumb and rotate to a
vertical position after the dead load is applied (Note that while one method may be easier
for the engineer to specify, it may not be the most economical to construct.). What is an
acceptable out-of-plumb tolerance if transverse rotation is taken into account? What
about permissible bearing rotations, especially for steel-on-steel conditions?
• Need guidance for the use of falsework during girder erection and perhaps during
concrete pour.

III. **Research Objective**

The objective of this research is to develop practical design and construction guidelines
and supporting commentary to help the bridge community in designing, detailing and
construction of skewed bridges of steel I girders with and without curvature. In
particular, determine the effects on performance of girders being out of plumb and to
develop an acceptable out of plumb tolerance for Steel I girders.

The proposed research is expected to include, at a minimum, the following tasks: Task 1
- Collect and review relevant domestic and foreign literature, research findings, and
current practices related to design of I steel girders to include effects on performance of
girders being out of plumb.
Task 2A - Develop analytical methods to quantify the effect on performance of girders
due to out of plumb.
Task 2B – Develop a computer model or small scale physical model using an appropriate
material to demonstrate that the deflections, rotations and movements are consistent with
the analytical methods developed in Task 2A.
Task 3 - Present the findings of Tasks 1 and 2 in an interim report. The report shall
include a discussion of the proposed procedure, emphasizing those areas where
experimental verification is needed. It shall also include a detailed research plan for the
experimental work needed to perform the verification. NCHRP approval of the interim
report and detailed research plan will be required before research on the remaining tasks
may commence.
Task 4 - Conduct field investigations, laboratory studies, or both, as appropriate in
accordance with the detailed research plan from Task 3. The purpose of these
experiments will be to calibrate and validate the analytical methods developed in Task 2.
Task 5 - Based on the experimental results, revise the analytical methods as required.
Develop practical design and construction guidelines and supporting commentary for
designing, detailing and construction of skewed bridges of steel I girders with and
without curvature. Determine the effects on performance of girders being out of plumb
and develop an acceptable out of plumb tolerance for steel I girders.
Task 6 - Prepare and submit a final report containing the research findings, the proposed
guidelines and commentary, and recommendations for further research.

IV. **Estimate of Problem Funding and Research Period**

Recommended Funding: $ 230,000
Research Period: 30 Months

V. **Urgency, Payoff Potential, and Implementation**

Without guidelines, the bridge community continues to stumble into design and
construction problems in dealing with girders supported on skewed piers or abutments.
Construction problems and remedial solutions are generally disruptive to schedule and
result in higher costs. Design and construction guidelines are urgently needed to give the bridge community needed tools to quantify and to account for the effect of out of plumb on girder performance and constructability.

There will be high payoff by eliminating or reducing delay of project work during construction. The research findings will support strategic goals for safety and mobility by helping in enhancing bridge design and construction, which will provide safer and more economical bridges.

This research will provide a tool to designers to estimate and to account for the effect on girder capacity due to out of plumb position of girders. The research findings will be used to improve guidelines for the design and construction of bridges. The resulting guidelines may be suitable for specifications would be submitted to AASHTO Highway Subcommittee on Bridges and Structures for adoption to include in the Bridge Design Specifications. Alternately, they would be included as commentary only to the proposed LRFD Specifications curved girder enhancements.

VI. Person(s) Developing the Problem

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VII. Problem Monitor

To be assigned

VIII. Date and Submitted by

I. Problem 6: Pin Plate Variable Amplitude Fatigue Limit (VAFL)

II. Research Problem Statement

Current AASHTO recommendations for cases where there are significant cycles above and below the Constant Amplitude Fatigue limit suggest extending the detail category with a –3 slope to a value of 0.5 the Constant Amplitude Fatigue limit.

Experimental data on rivets and on anchor rods suggest that there may be a variable amplitude fatigue limit of 6 ksi (at least to 100 million cycles) for these details.

Given that the material on pin plates is similar, non-welded, it is suspected that a similar phenomenon might occur for pin plates.
There are many (Costly to replace) truss spans in use today that still have pin-connected joints and saving these would not only further enhance the image of steel as a material of longevity, but would save the States considerable dollars if their rehabilitation or replacement could be significantly delayed.

For Category “E” pin Plates the difference in calculated life would be 17 times, if this phenomena were shown to be correct.

III. Literature Search Summary

Research has not been conducted on these phenomena with regard to Pin Plates.

IV. Research Objective

Long life testing of simulated full-scale pin plate connections, starting with Category “E” Pin plate details to establish behavior below 7 ksi.

V. Estimate of Problem Funding and Research Period

Recommended Funding:

$450,000 assuming relevant details would be donated by state agencies from bridges being replaced currently.

Research Period:

18 months of research effort, including three months for preparation of a draft final report.

VI. Urgency, Payoff Potential, and Implementation

At the successful conclusion of this research, the AASHTO requirements would change, potentially extending the lives of Category “E” Pin plates and thus their structures by a factor of 17 times.

A statement identifying the Thrust/Business Need that will be addressed by this research (ref to NCHRP 20/07, Task 121).

VII. Person(s) Developing the Problem


E Mail : rapsweeney@modjeski.com

VIII. Problem Monitor

A statement of the specifics (name, title, affiliation, address, telephone number, e-mail address) of the person who will be assigned by the Administrator or Committee submitting this problem to monitor the research, if programmed, from inception to completion. The monitor's final responsibility will entail recommendations to the Standing Committee on Research as to how the research results could be implemented.

IX. Date and Submitted by
Show date of submission and by whom problem is submitted (preferably co-submitted by a State Bridge Engineer).