December 31, 2008 Progress Report on Pooled Fund Study TPF-5(189)

Introduction

Transportation Pooled Fund study TPF-5(189), "***Enhancement of Welded Steel Bridge Girders Susceptible to Distortion-Induced Fatigue***," is underway. The design of a large steel test frame for use in loading the steel bridge girder specimens is complete. Specimens to be tested in distortion-induced fatigue loading are being sized and studied analytically to ensure that stresses are well-understood before experimental research is begun. Component-level studies are being performed to capture the behavior of fatigue specimens with the various enhancement techniques applied while the 3D test set-up is being constructed.

Test Frame

A one-bay by one-bay steel test frame has been designed to transmit actuator forces up to 250 kips. The steel frame is comprised of four columns, four girders around the upper perimeter, and one load beam, in addition to various stiffening elements. The frame includes eight post-tensioning bars aimed at reducing tensile stresses within connections. The 330-kip capacity actuator to be suspended from the test frame was ordered in September, 2008, and is expected to arrive in March, 2009.

Test Specimen Design

Design of the scaled bridge girders to be tested in distortion-induced fatigue has begun. A great deal of attention is being paid to adequately scaling the girders at this stage. Scaling of the girders' cross-section dimensions is practically constrained by force demand on the upper end of the scale, and constructability (primarily weldability) on the smaller end of the dimensional scale. A compromise in cross-section dimensions is being sought, and it is currently believed that a cross-section on the order of 3 ft deep will satisfy both practical constraints.

To better assess system behavior and more accurately scale the test bridge girders, a realistic bridge design is being examined and modeled. An example design of a single-span bridge published by the American Iron and Steel Institute (AISI) and the National Steel Bridge Alliance (NSBA) (1) is being referenced as a typical composite steel bridge design.

The example bridge system is currently being modeled using two software packages, SAP 2000 and ABAQUS, with the following goals:

1. Better understand system relationship between the girders when one girder is loaded separately from the other girders,
2. Distinguish between the load-sharing contributions of the deck and cross-frames,
3. Determine cross-frame forces,
4. Assess whether a cast-in-place concrete deck is necessary in physical experimentation (as opposed to using steel plates or another method to hold the top flanges rigid), and
5. Obtain realistic stress profiles for the steel cross-sections under distortional loading.

To this end, the AISI/NSBA bridge is being represented initially through grillage models, wherein the deck stiffness is approximated through a grid of transverse and longitudinal steel sections and the girders are constructed of shell elements. This effort is aimed at capturing the system response of the example bridge before more detailed analyses are performed. The current bridge as modeled in SAP2000 is shown in Figure 1. The analyses will become progressively more advanced as necessary, moving to a concrete deck comprised of shell elements, and to a model comprised entirely of 3D brick elements if that level of detail is required to obtain a more accurate system response.

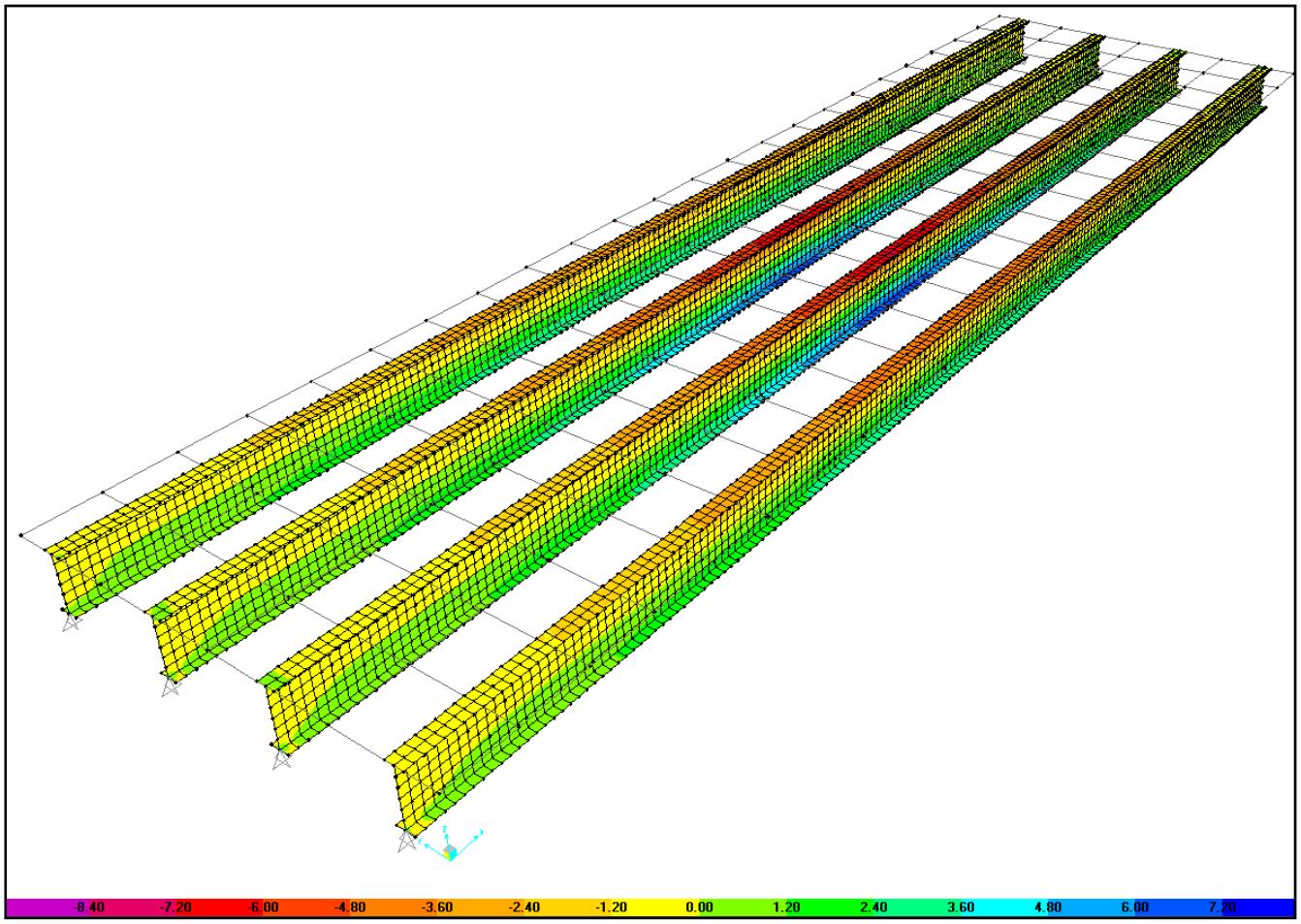

Figure 1: Grillage model of AISI-NSBA example bridge constructed using SAP 2000

Component-Level Studies

Two parallel studies are being performed concurrent to the outlined activities that will feed directly into the pooled fund study activities once 3D testing commences. These studies are:

1. Development and application of a PICK tool to treat the inside surface of undersized crack-stop holes,
2. Characterization of sprayed chopped carbon fiber composite on steel fatigue details, and

In addition, results from the use of molded carbon fiber reinforced polymer (CFRP) composites to improve steel fatigue detail performance can be found in references 2 and 3.

Chopped-Fiber Application

A commercial grade chopped-fiber spraying system has been purchased and utilized on component-level steel assemblages representative of a girder flange and welded coverplate. The chopper gun is shown in Figure 2. The chopped carbon fibers were sprayed on a steel assemblage by forming around the sensitive fatigue detail at the transverse welds to isolate the area to be sprayed with the composite, as shown in Figure 3. While the test frame is being constructed and the 3D test specimens are being finalized, component level tests will be performed on the steel assemblages to improve manufacturing processes of the chopped-fiber layup and to characterize its fatigue performance in a simple geometric configuration.

Figure 2: Chopped fiber spraying system at the University of Kansas Structural Testing Lab

Figure 3: Chopped fiber composite sprayed on cover plate detail

Treatment of Undersized Crack Stop Holes

The PICK tool has been developed, and is currently being characterized and tested for effectiveness. Sheet-type fatigue specimens with untreated drilled holes have been tested in fatigue in tension at high stress ranges (30 ksi). Similar specimens with treated drilled holes will be fatigue tested to determine the fatigue performance when treated using the PICK tool.

Upcoming Tasks

Given the current project activities, the following tasks are expected to occur in the next quarter:

1. Detailed modeling of the example bridge system,
2. Selection of test girder geometry,
3. Tentative selection and discussion of specific connection details susceptible to distortion-induced fatigue,
4. 3D finite element modeling of specific connection details under realistic longitudinal and brace forces,
5. Experimental testing and manufacturing refinement of the chopped-fiber laminate material,

6. Additional experimental testing of treated crack-stop hole on component-level specimens,
7. Fabrication of the test frame, and
8. Receipt of the 330-kip actuator.

Status and Completion Date

Percentage of work completed to date for total project: Project is approximately 5% Complete.

Project is __X__ on schedule ___ behind schedule, explain:

Expected Completion Date: __8/31/2011__

Conclusion

Project TPF-5(189) is underway and significant progress has been this quarter on multiple fronts. Specifically, the test frame has been designed, the test girders are being designed, and multiple component-level studies are being performed to refine and better understand fatigue enhancement techniques that will be applied to the scaled test girders.

Contact Information

Please contact Caroline Bennett at (785)864-3235 or crb@ku.edu with any questions or discussion items.

References

1. AISI, NSBA. (1997). "Four LRFD Design Examples of Steel Highway Bridges," American Iron and Steel Institute (AISI) and National Steel Bridge Alliance (NSBA), Chicago, IL.

2. Kaan, B.,‡ Barrett, R., Bennett, C., Matamoros, A., and Rolfe, S. (2008). "Fatigue enhancement of welded coverplates using carbon-fiber composites," Proceedings of the 2008 ASCE / SEI Structures Congress, Vancouver, BC, April 24 – 26, 2008.

3. Kaan, B. (2008). "Fatigue enhancement of category E' details in steel bridge girders using CFRP materials," thesis, presented to the University of Kansas, Lawrence, KS in partial fulfillment of the requirements for the degree of Masters of Science.