letters

Details of Bridge Erection Program Questioned

The June 2010 issue of *Modern Steel Construction* included the article, "An Analytical Monitoring Tool for Bridge Construction," by Jason Stith et al. It is not clear how a number of issues are addressed.

If the program is to be used to accurately predict stresses and deflections during erection it would be anticipated that the program would track deflections and stresses from the as-erected position. As part of the fabrication process, steel girders are cambered for their dead load deflection. However, in order to be sure that the girders are in the correct final dead load condition the cross frames are not cambered. To add to the complexity, for curved steel girders, the girders are cambered for vertical deflection but, for practical reasons, are not cambered for horizontal deflection, i.e., the webs are cut to include dead load deflections but the horizontal geometry of the flanges is not cambered. As a result, when they are delivered to the field, the girders are erected in a cambered position. From the article it appears that it has been assumed that the girders are erected in their uncambered, i.e., final dead load position. For straight girders, the girders need to be forced to align with the cross frames only to the extent that they have camber differences due to fabrication. But for curved and skewed bridges there can be large differences between the uncambered geometry of the cross frames and the cambered position of the girders and as a result the girders need to be forced to align with the cross frames. (This can lead to issues in the field and requests to use oversized holes in the cross frame connections, which should not be allowed as (1) one loses control of the geometry, and (2) it is prohibited for curved girder bridges; see AASHTO Article 6.13.1.) Clearly the erection introduces forces and deformations into the girders and cross frames that are not accounted for in the normal design process that uses a stiffness analysis based on the final geometry. It is not clear how the effects of camber are addressed in the program.

The article discusses the program's ability to utilize a set of existing design plans to analyze an erection sequence but then goes on to indicate that the program can be used to determine cambering requirements. But typically the camber requirements are already part of a set of bridge plans, and would have been already incorporated in the analytic model being used for the erection analysis.

The article also indicates that deck pour sequences can be tracked, but it is not clear if the program includes the ability to include the installation of formwork and, if stay-in-place formwork is not used the subsequent removal of the formwork; the installation of the reinforcing, which together with the formwork installation precedes the deck pour; and finally temporary placement loads, such as the weight of the screed, that are associated with an active deck pour front. The AASHTO *Guide Specifications for Temporary Bridge Works*, Article 2.2.3.1, Construction Live Load, provides guidance on the loads associated with an active front.

The program's ability to include any eigenvalue buckling analysis appears to be a useful addition but it is not clear how the effects of the girder's fabrication tolerances, alignment, or residual stresses, all of which will affect the bucking capacity, have been included. Typically code provisions for buckling of steel members are based on tests so that the effects of fabrication tolerances and residual stresses are accounted for. A purely theoretical buckling analysis will tend to overestimate the buckling capacity.

In engineering one needs to temper any computer output with a heavy dose of reality. Merely relying on a detailed computer program fails to capture all of the engineering aspects, some of which I have listed above. Perhaps the authors can comment on these issues.

—Michael J. Abrahams
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The authors respond:

We would like to thank Mr. Abrahams for his questions regarding the UT Bridge program. Analyzing the behavior of the steel bridge systems during early stages of the erection and construction process poses many difficult modeling issues. The goal of the software is to provide a tool that allows the creation of a 3D finite element model of the bridge that can be used to evaluate the deformations and stability of partially erected systems as well as the behavior during casting of the concrete bridge deck. The authors are not aware of any other software that is available to create these models, nor carry out these analyses, without significant user training and experience. Even with substantial experience, most available finite element programs require significant time to construct the models. The software does not solve every problem that will come up during the construction and erection process, but the authors feel that the software is a useful program that fills a void created by a lack of computational tools for evaluating the behavior during the erection and construction process.

Some of the bridge analysis and detailing issues presented by Mr. Abrahams arose in discussions during the creation of the program. While these issues are not new they do present many challenges that were never intended to be solved with UT Bridge, but forums like this can provide a platform to discuss the issues further. First, we would like to clarify that UT Bridge is, strictly speaking, an analysis software capable of performing linear elastic and eigenvalue buckling analysis on curved and straight I-girder bridges with or without skew substructures. However, due to the ease of input and the quick analysis runs, design work can be accomplished as an iterative process.

Mr. Abrahams asked four questions that will be responded to.

1. Mr. Abrahams brings up several issues with this question including the effect of camber on the analysis. The program is a linear elastic small displacement analysis that assumes the geometric effects associated with a cambered girder are relatively small. To ease the input and development of the 3D finite element node location and meshing, the bridge is assumed to be located on a horizontal plane. Superelevation is not accounted for in the analysis. Previous research at the University of Texas has determined that neglecting the superelevation in the modeling of a 3D FEA bridge model usually results in relatively small effects in the overall behavior of the system. The detailing of the bridge cross frames for the no load, steel only dead load, or full dead load has been discussed previously in journals, but has proved difficult to resolve analytically. The author is correct in indicating that the stresses introduced by the

cambering of the girders or detailing of the cross frames is not considered in the analysis. Because UT Bridge creates a relatively robust model compared to many models that engineers may be using, the software is actually a good tool for predicting the amount of deformation that is likely to occur during erection and construction of the bridge so that the girder can be properly detailed and fabricated for the desired conditions. The authors believe that it is up to the engineer to specify whether the web should be plumb in the no-load, steel dead load, or full dead load condition. This is actually a difficult problem since the placement and curing of the concrete deck has a significant effect on the web plumbness in the final bridge. Since UT Bridge can model the time-dependent stiffening of the concrete, it provides a useful tool for estimating the deformations. UT Bridge estimates the displacements of the bridge under construction loads; however the modeling and tracking of locked-in stresses resulting from various detailing methods is not available from this software and the authors are aware of no other software that will provide such a feature. Tracking such stresses would require a great deal of knowledge about the state of stress from the fabrication process, which is complex and highly variable.

2. Our description of the software as using the information available from a set of design plans was mainly used to demonstrate that the required input is based upon information readily available to the designer or the erection engineer. While an engineer can easily use the software once the design plans are complete, there is nothing precluding an engineer from using the software during the design process. The software has been used to provide relatively accurate estimates of the camber on problematic bridges where commercially available grid-based software provided relatively poor estimates of the camber. These bridges had relatively unique geometry in which the 3D model provided better modeling of the girder stiffness compared to the simplified models that were used in the original designs. If UT Bridge had been used for camber prediction on these bridges, significant problems during construction could have been avoided.

3. The concrete deck placement analysis activates the deck elements associated with the placement of concrete and tracks the stiffening effects of the early age concrete providing the displacement and stresses. Point loads can be specified on the girders for each analysis to simulate the screed or other construction live loads. The subsequent removal of formwork is not thought to significantly impact the final displacement or stress and is not included in the program.

4. We have completed significant computational work to suggest that the capacity of a curved bridge is overestimated by an eigenvalue analysis. The curved girder capacity is governed by deformation rather than buckling. However, the eigenvalue works well for straight bridges. Mr. Abrahams is correct that the residual stresses, fabrication tolerances, and alignment will affect the buckling capacity of a curved bridge, but the researchers have found that the displacements will become excessive before a buckling failure occurs. This leads to serviceability failure that can be indicated by a linear elastic analysis.

—Jason Stith, Ph.D., Todd Helwig, P.E., Ph.D., Eric Williamson, P.E., Ph.D., Karl Frank, P.E., Ph.D., Brian Petruzzi, Hyeong Jun Kim, Ph.D.

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