Project Summary

Texas Department of Transportation

0-5574: Curved Plate Girder Design for Safe and Economical Construction

Background

Horizontally curved steel I-girder bridges are important components of the highway system that are commonly used for providing efficient transfer of traffic between major thoroughfares. The critical stage for the stability of these curved bridges generally occurs during early stages of erection and construction when little or no bracing may be present. The curved geometry of girders often necessitates temporary supports in the form of shoring towers or temporary holding cranes during erection. Design and erection engineers are typically faced with the difficult task of assessing the stability of the girders during these early stages; however, expressions for evaluating the capacity are not available. As a result, TxDOT has relied on simple rules of thumb in the proportioning of the girder cross-sections as well as the need for temporary supports. The Texas Steel Quality Council recommends a flange width to girder depth ratio of 1/3 in the *Preferred Practices for Steel Bridge Design, Fabrication, and Erection* (2009). While these rules of thumb have resulted in safe girder systems during erection, there is a lack of research justification for the proportioning, and the recommendation is twice the limit of 1/6 that is in the *AASHTO LRFD Bridge Construction Specifications* (2008). Therefore, the purpose of this research investigation was to study the behavior of straight and curved steel girders during early stages of erection and construction to determine their stability. The goal of the research was to provide guidance on girder proportioning as well as the need and placement of temporary supports, such as shoring towers or holding cranes.

What the Researchers Did

The research included field monitoring, a survey of erectors and contractors, finite element analytical studies, and the development of computer tools for predicting girder behavior during erection and early stages of construction. The field monitoring consisted of the instrumentation and monitoring of a continuous curved steel bridge during construction, as well as a series of lifting tests of curved girder segments in the fabrication yard. Data collected on the steel bridge provided information on the behavior of the bridge during early stages of construction through the placement of the concrete bridge deck. The lifting tests, conducted at Hirschfeld Industries, provided valuable data on the behavior of curved steel girder segments during lifting. Data from the field studies was used to validate the finite element model. This model was then used to conduct parametric finite element analyses to study the impact of geometrical proportions on the stability of curved steel girders. The researchers also developed and verified two computer programs that can be used by design and erection engineers to evaluate girder safety and behavior during early stages of construction.

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What They Found

Results from the field studies provided valuable insight into the behavior of the girders during lifting. During lifting the girders rotate about the top of the lifting clamps. The deformation of the girders consists of both a rigid body rotation about the beam clamps as well as flexural and torsional deformations that vary along the length of the girders. The survey of erection engineers and contractors provided valuable insight into the range of erection practices that are used. From this, the researchers identified important limitations that must be considered in evaluating the girder behavior during lifting and early stages of erection. For example, limiting the amount of rigid body rotation that the girder experiences is an important consideration to ensure that the segment can be spliced to previously erected girder segments. The finite element analytical studies demonstrated that girders with excessive flexibility often experienced very large rotations that violated these limits. For checking girder stability during lifting, the researchers developed moment gradient factors (C_b) for girder segments.

The commercial three-dimensional finite element software ANSYS was used to carry out the parametric analyses. These studies showed that the TxDOT preferred practice of limiting the flange width to girder depth ratio to 1/3 often leads to relatively stocky girders that were often stiffer than necessary. However, the researchers also found that girders close to the AASHTO flange width to girder depth ratio of 1/6 were likely to experience problems with stability during construction. A limit closer to 1/4 will generally provide better behavior from the points of both economy and ease of erection. To assist in evaluating the girder behavior during the critical stages, two computer programs were developed. The first program, UT Lift, is an Excel spreadsheet with embedded macros for evaluating the stability of curved girder segments during lifting. This program can be used to either identify the ideal location to position the crane lift points or to predict the girder deformations that will occur for general lift locations. The other computer program is a three-dimensional finite element program named UT Bridge. UT Bridge includes a graphical user interface to simplify geometrical and load input as well as viewing the results. This program carries out either an elastic first order structural analysis or an eigenvalue buckling analysis to determine critical loads. In UT Bridge, the engineer can define the girder erection sequence along with placing temporary supports, such as shore towers or holding cranes. It also allows the engineer to investigate the concrete casting sequence and will consider the contributions of early age concrete. Both programs are available for free download at the website: http://fsel.engr.utexas.edu/software/index.cfm

What This Means

The recommendation to reduce the limiting flange width to girder depth ratio to a value of approximately 1/4 should result in better efficiency of the steel section. In addition, the computer programs that were developed provide designers and erection engineers with the ability to evaluate the behavior of the steel girders during the most critical stages of construction. The ease of use of these programs, coupled with the computational abilities, provides engineers with a valuable resource for evaluating the erection sequence and concrete placement sequence. Engineers can employ these tools to make effective use of temporary supports, such as shoring towers and holding cranes, which will improve both the economy and safety of steel bridge systems during construction.

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