structural design

Hitting the Mark on Steel Girder Bridge Erection

By Robert H. Canham, P.E.

Many things can derail a bridge construction project; one is as seemingly minor as a bridge girder with an erected profile that is out of whack. Millimeters or fractions of inches may not seem like much, but out-of-tolerance girder profiles can result in poor serviceability or increased costs. If everything goes well, the girder elevations will hit the mark. If not, those involved scratch their heads and point fingers while project delays and claims start mounting.

Structural engineers are involved in many aspects of this issue. Acting on behalf of an owner, they design and inspect the bridge. Acting on behalf of a contractor, they develop procedures and details for fabricating and erecting the girders.

The problem is girders often don't behave exactly the way structural engineers assume they will. One should not forget that design codes and accepted engineering practices are often based on a certain amount of conservatism and simplification. This works well for design, but it doesn't always quite work when it comes to accurately predicting actual behavior. The key word here is accurate. Structural engineering is not nearly as accurate as it is precise. As a simple illustrative example, including an additional 10.0 percent allowance in dead load may work well for design, but isn't accurate.

Steel Multi-Girder Bridges

In many parts of the country, steel multi-girder bridges with composite concrete decks are the dominant form used for medium- and long-span bridges. Frequently, these bridges possess one or more features, such as skew, which complicate their actual behavior. If a construction inspector finds that a girder profile is out of tolerance, it then becomes the contractors problem to fix. Concrete deck haunches can make up for a certain amount of out-of-tolerance elevation, but this is not always enough.

Fabrication Challenges

Girders are cambered to account for deflections that will occur, and to provide a final girder profile that accommodates the roadway profile. Typically, the contractor's fabricator is responsible for providing cambers that match those shown in construction documents. To maintain project schedules, sometimes fabrication commences before all of the details of girder erection are worked out. This trend is exacerbated by the recent marked increase in steel prices and fluctuations in steel availability.

Girders often get fabricated using camber information provided by a bridge designer that had to assume a certain erection sequence. For example, one such assumption made, though probably rarely used and often infeasible during actual construction, is that the girders will be completely erected in the no-load position.

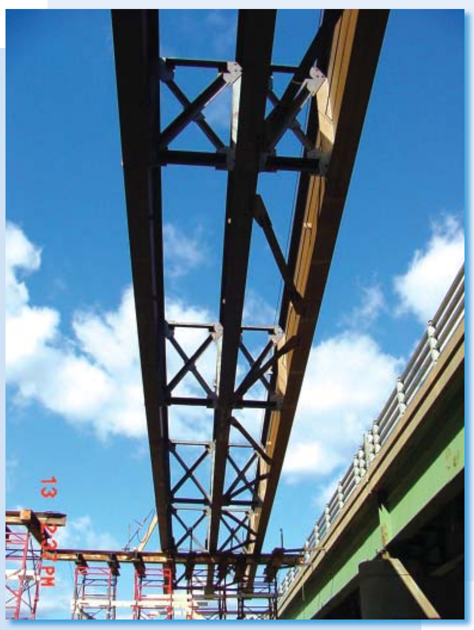

Figure 1

Solutions

One solution is to try to increase the accuracy of structural engineering computations by more accurately modeling real-world behavior. Another is to allow the mark to get bigger, which in effect means broadening the tolerance for camber by acknowledging the uncertainties between actual and theoretical deflections. In addition to providing the theoretical deflections, the design engineer should be ready to provide details of the methods and all parameters used in deriving deflections along with an assessment of the anticipated accuracies of those deflections.

Accuracy Considerations

Many factors affect the accuracy of calculated deflections. The publication *Guidelines for Design for Constructability*, developed by the Steel Bridge Collaboration of the American Association of State Highway and Transportation Officials (AASHTO) and the National Steel Bridge Alliance (NSBA), discusses several of them.

To illustrate, first consider the behavior of a relatively simple structure consisting of a horizontally-straight, non-skewed, constant-width, simple-span, plate-girder bridge built in one entire stage with all the individual girders being exactly the same size. Deflections are typically calculated using conventional beam theory, and by considering each girder individually. Assuming the analysis is correct, the theoretical deflections should hopefully be within perhaps 10 percent of the actual deflections. Reasons why they might not include:

- Simple beam theory is not quite correct because shear deformations also occur within the girders and plane sections do not always remain plane.
- Bridge bearings are not truly frictionless pins. Friction restricts rotation, and the bearings and substructures have some degree of compressibility.
- Actual plate thicknesses used for the flanges and webs are usually slightly larger than design documents because plates are often manufactured to be near the high end of thickness tolerances.
- Changes in flange size along the length

of a girder are common, and it is customary, though not entirely accurate, to assume that the corresponding changes in girder stiffness occur abruptly at the changes in size.

- Girder splices are often used, and the stiffness of girders within splice regions is different than in other areas.
- Slight variation in exact camber will often occur between adjacent girders due to camber tolerance, and cross-frames may not always exactly fit due to fabrication tolerance. Hence, the cross frames will pull up a bit on some girders while pushing down a bit on others.

Variation in Girder Sizes

All girders within a bridge are not always designed all the exact same size. Fascia girders are often different from interior girders. Each girder can be and customarily is modeled independently. However, as shown in *Figure 1*, the girders are interconnected by cross frames, and differential deflections start to have a significant effect on overall girder deflections because of the varying stiffness between adjacent girders.

Figure2

Multiple Spans

Multi-span continuous girders such as those shown in *Figure 2 and Figure 3*, introduce additional complexities which affect deflections.

- Girder splices are usually not located exactly at the inflection points of the bare steel girders.
- False work is often provided only near the splice areas to support the ends of the anchor segments of the girders until the drop-in segments are erected.
- Drop-in segments are perhaps fully spliced (e.g., all splice bolts are installed fully tight) to anchor segments before being released from a crane, but this is not always the case.
- Exact false work elevations are not always known, and do not always account for false work stiffness or deflections that will occur after false work is removed.

Superposition of the incremental deflections associated with the various erection steps can be used, but miscommunication of exact splice and false work locations can quickly consume allowable tolerances.

Horizontal Geometry

Complexities caused by horizontal geometry can have a large affect on deflections. Anything that creates differences in relative stiffness between adjacent girders, or causes loads to be transferred from one girder to the next through cross frames, is not accounted for in just a simple beam model of an individual girder and the loads directly on that girder. Horizontal curvature obviously affects girder interaction, and this is well recognized and usually accounted for by methods customarily used for curved girder design. Skewed supports also cause a greater interaction between girders, though this is not always recognized and accounted for. Variation in skew, where one bearing line is skewed differently than another, has an even greater effect.

Stage Construction

Stage construction introduces its own set of complexities. The first stage constructed is essentially an independent system that possesses the features described above. However, once the deck is placed, the first stage is no longer a simple set of discrete girders. Determining the exact deflections that will occur when connecting a second stage to the first stage is a challenge. Variation in the age or tributary width of concrete decks can cause significant variation in stiffness in adjacent composite girders. Closure pours and cross frames that are temporarily left loose are sometimes used to make the final connection between stages easier to predict. To add to the complexity, sometimes the break line between adjacent construction stages does not neatly fall between girders but ends up straddling one or more girders.

Analysis Methods

The factors above can all be accounted for, with varying degrees of accuracy, through theoretical engineering modeling. This usually involves a level of sophistication in engineering computations that is considerably

Figure 3

higher than is warranted for sizing the girders during design. Because of the effort required, it is probably rarely done, and the details of it are unlikely to get disseminated. It is a task that perhaps would best be completed after all other details of construction have been thoroughly thought out.

A three-dimensional analysis can generate deflections directly, and this is often used for horizontally-curved frameworks. But even this is not an exact replica of actual behavior. For example, modeling girders using two-node beam elements with six degrees of freedom at each node (i.e., translation and rotation about the global X, Y, and Z axes) does not accurately account for the additional torsional stiffness provided by warping resistance of the girders. This additional stiffness is usually far greater than the Saint Venants torsional stiffness for typical steel bridge girders. This means that such a model will not accurately predict the girder rotations and differential deflections that occur.

In summary, raising awareness of this issue with everyone involved can help avoid the pitfalls. Everyone should benefit from a greater understanding of how things really work and how things are really put together. When the girders hit the mark, there will be less head scratching and finger pointing and more satisfied contractors, owners, and structural engineers.▪

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