A Skewed Perspective

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Starting with girders out-of-plumb is the way to go for skewed bridge construction.

THE IDEA OF BEAMS BEING TWISTED DURING ERECTION might seem a bit alarming to the average person. But in the case of skewed bridges, beams, in fact, *should* be twisted out of shape during erection.

Specifically, steel girder webs on straight skewed bridges must be out-of-plumb during construction if they are to be plumb at the end of the construction. This is because the individual girders and overall bridge cross section twist, or displace torsionally, as the concrete deck is placed; if the girders are made plumb before erection, they will twist out-of-plumb as the deck is placed. In other words, the girders can be plumb in only one configuration. When this phenomenon is not understood, delays, rework, claims, or compromised performance can result. (This article is limited to straight bridges with intermediate cross-frames that are normal to the girders, as opposed to parallel to the skew angle.)

Deflections

Engineers generally understand that girders deflect under load and that this deflection varies along the length of the girders. For example, on a simply supported girder, the deflection is greatest near the mid-span and varies to zero at the supports.

During the bridge construction sequence, the girders deflect a certain amount under their own weight, then deflect further when the deck is placed. On a square (non-skewed) bridge, the deflections across any section of the bridge due to the deck weight are roughly the same; for example, at the mid-span on a square bridge, the girders all deflect approximately the same amount as the deck is placed.

By contrast, on a skewed bridge, the deflections are not the same across the width of the bridge since the girders are longitudinally offset from each other by the skew—i.e., there are differential deflections between the girders across any section of the bridge. However, the girders cannot realize these differential deflections without twisting because they are tied together by relatively rigid cross-frames. As the dead load is applied, the change in the shape of the cross-frames is relatively minor compared to the deflection of the girders. Prior to their connection to the cross-frames, steel I-girders are torsionally flexible; the skewed girders tied together with cross-frames twist due to differential deflections.

Girder Twist and Layover

For straight skewed bridges, it is recommended that the girders should be plumb (within a reasonable tolerance) when the construction is complete. Therefore, as stated above, the girders must be out-of-plumb so that as the deck is placed, they will deflect and untwist into the plumb condition. Detailing and fabricating the cross-frames such that the girders will be plumb under the application of the total dead load facilitates the alignment of the adjacent deck segments at expansion joints and avoids potentially visible layover of the girder webs relative to substructure components.

The natural question, then, is just how out-of-plumb the girders should be prior to the deck placement—i.e., what is the required layover prior to deck placement? This number is not difficult to calculate, but doing so is unnecessary.

Consider how girders and cross-frames change shape during erection: The girders begin in a twisted, out-of-plumb state before the deck placement, then twist to plumb as the concrete is added. However, the cross-frames stay effectively rigid (within their planes). Therefore, the simple way to set the girders to the proper web layover is to detail and fabricate the cross-frames to their final desired geometry and to fit the girders to the cross-frames in the field.

The AASHTO/NSBA Steel Bridge Collaboration Standard G12.1, *Design for Constructability*, Figure 1.6.1.B, describes an effective way to erect girders on a skewed bridge using this approach (note that this example is just one way of erecting a bridge):

- The girders are first set in place in a plumb condition, without intermediate cross-frames added (at this stage, the girders must be properly supported to ensure stability).
- As intermediate cross-frames are added, the girders are twisted—i.e., forced into position—to fit the frames. In the G12.1 example, this is accomplished by first suspending the frames from the top two corners and then pushing the girders as needed to fit the bottom two corners. The bolts are tightened (a must), and then the girder condition is set and ready for the deck placement; the girders have now been set to the proper layover by the attachment of the cross-frames to the connection plates.

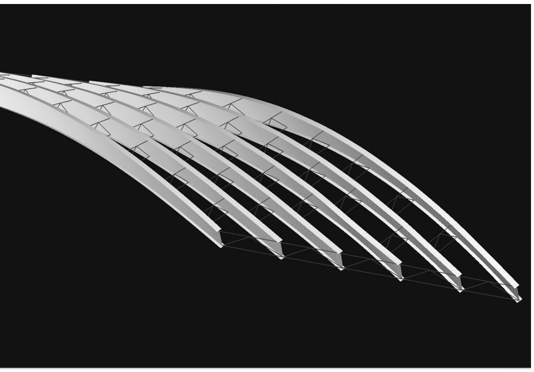
The erector chooses a girder and cross-frame erection sequence to align and twist each subsequent girder to fit the previously erected girder during construction.

Analysis

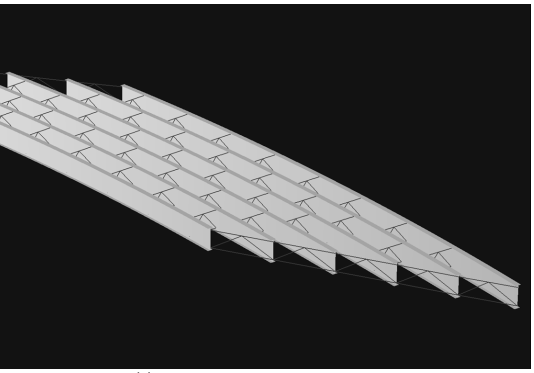
What twist forces must be accounted for in the design to accommodate the girder layover and rotation to plumb? For straight, skewed I-girder bridges, the answer is simple: none. The girders are twisted out of plumb during cross-frame installation (by use of come-alongs or other force), but then they "untwist" back into the plumb position once the deck is placed. Though the girders experience a certain amount of stress during the initial twisting, this stress is relatively small and is largely released when the girders untwist into their final and proper orientation during the deck placement.

Plumb before Placement?

It is certainly possible to set girders up plumb prior to casting the deck, though we don't recommended this practice for straight skewed bridges. To achieve this condition, the girders and cross-frames must be detailed and fabricated accordingly, and the fabricator must know this prior to de-



Skewed beam geometry, before deck pouring.



Final beam geometry.

tailing and, preferably, prior to bidding the job.

However, not only does setting girders up plumb prior to deck casting result in a final out-of-plumb condition, but also the final twisted shape will induce some additional stresses in the girders and cross-frames in the final condition. Again, using the recommended approach, the stresses due to the initial twisting of the girders during installation of the cross-frames largely offset the stresses due to the twisting of the girders in the opposite direction under the action of the dead load.

Curved Bridges

The behavior of curved bridges, especially skewed curved bridges, is similar but more complex than straight skewed bridges. Although the concepts discussed in this article also apply to a certain extent to curved bridges, other considerations not discussed here are necessary for these structure types.

Bearing Line Diaphragms or Cross-frames

Bearing line diaphragms or cross-frames, which tie the girders together at the bearing lines, are a special case and, depending on the framing arrangement, can be difficult to install, especially at abutments. The construction rotations must be accommodated in the bearing design.

Unlike intermediate cross-frames, abutment cross-frames always follow the skew of the bearing line. Since the vertical deflections are zero at the bearing line, differential deflection twist effects are avoided. However, the abutment cross-frames introduce a twist associated with longitudinal girder rotation. Since the abutment cross-frames or diaphragms are relatively stiff in their own plane compared to the stiffness of the girders, they force a twist into the girders such that compatibility with the girders is maintained. The AASHTO/NSBA Steel Bridge Collaboration Standard S10.1, *Steel Bridge Erection Guide Specification's* first sample of erection procedures illustrates one method of installing the abutment cross-frames such that the girders are initially rotated out-of-plane at the bearing lines but rotate back to plumb under the action of the dead load.

Fasteners

Fasteners that connect the girders to the cross-frames must be installed and tightened before the deck is placed. Otherwise, the cross-frames cannot maintain the proper girder orientation during deck placement. Local exceptions to this rule may be instituted in some cases at end cross-frames, where the interaction with adjacent intermediate cross-frames may make the installation of one of the frames difficult. Also, in parallel staged construction, where superstructures are built in separate longitudinal units with a longitudinal joint between them, exceptions to this rule are common at the longitudinal joint between the superstructures. However, in each of these cases, the girders and cross-frames are well connected within the individual units such that the deflected geometry can be reliably calculated and controlled.

One last consideration of fundamental importance: Successful skewed bridge erection, with the least impact of the skew on the design, requires an experienced bridge project team that understands—and applies—the principles addressed in this article. MSC

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