CONCRETE BRIDGE TECHNOLOGY

Detailing Segmental Concrete Box Girders for Constructability

by Jeremy Johannesen, McNary Bergeron & Associates

Figure 1. At the St. Croix Crossing in Oak Park Heights, Minn., a cast-in-place pier cross beam interfaces with a precast concrete segmental box-girder superstructure. In some cases, both the cast-in-place element and the precast concrete segment can satisfy their own dimensional tolerances but not match each other. All Photos: McNary Bergeron & Associates.

Bridge design and construction are an exercise in optimizing opposing forces. As part of this, structural detailing must balance design demands with practicality. The construction engineer's role, and specifically the detailing of integrated shop drawings, provides a unique perspective into the interface between design and construction. This experience allows us to explain why some things work "on paper" but prove to be problematic in the field. Constructability—how well things go together—is a subjective term, but there are some fundamental aspects to good detailing.

The foremost consideration should be tolerances. Just as design requires safety factors, construction also requires a margin for error. How great a margin depends on the nature of the details. Apart from the people who build them (who also require some tolerance), concrete segmental bridge construction has three key ingredients: concrete, post-tensioning, and reinforcement.

Concrete

When the design plans call for an 8-in.-thick slab, the end product is generally very close to that. Problems tend to occur when joining concrete elements from different forms. In segmental construction, wet joints are often used to connect precast concrete elements to cast-in-place (CIP) sections at substructure connections or where CIP construction is more practical (**Fig. 1**). From experience, we know that two elements can satisfy their own dimensional tolerances but not match each other. This can result in misaligned slabs and other features. There are two solutions for misaligned slabs. The first is to thicken the cross section on one side of the joint to ensure that the full design thickness is met across the joint. The other solution is to design a longer wet joint to smooth any kinks (**Fig. 2**).

Post-Tensioning

Construction specifications generally give post-tensioning (PT) ducts, anchors, and hardware the right of way when conflicts arise. In this hierarchy, PT can do no wrong unless it conflicts or does not align with itself. This can happen as in the previously mentioned case when joining tendons from two concrete elements cast in different forms are misaligned. Whenever possible, the best solution is to provide details with some free length of tendon duct to reduce or eliminate abrupt angle changes or kinks.

In the example shown in **Fig. 3**, precast concrete segments framing into a straddle beam were designed to sit high enough to allow the top-slab tendons to pass over the top of the beam. This avoided the need to precisely set ducts in the CIP straddle beam amid the heavy reinforcement at the top of the beam.

For tendons crossing through the straddle beam from the webs and bottom slab, other means were required to reckon with construction tolerances. In this case, blockouts were formed around the ducts in both the CIP straddle beam (**Fig. 4**) and in the adjoining face of the segment. The additional length of duct in the blockouts provided flexibility, allowing misalignments to be accommodated as smooth curves rather than sharp kinks.

A secondary consideration with PT is the actual size of the hardware. The corrugated plastic duct used in most systems has an outer diameter that is approximately 15% larger than the inside diameter. For example, a duct with a 4 in. inside diameter used for a

Figure 2. Example of a short wet-joint closure where location variations in duct layout between cast-in-place and precast concrete elements have resulted in post-tensioning duct misalignments. The use of a wet-joint closure provides space to accommodate such duct alignment variations.

19-strand tendon actually has a 4.6 in. outer diameter. Knowing the real size of the hardware is key to making it fit and avoiding conflicts in the field.

Reinforcement

There are numerous considerations for reinforcement tolerances. To begin, most reinforcing bars are approximately ¼ in. larger than their nominal diameter. While this added width sounds harmless, it can accumulate to make bad situations worse. It is always good practice to verify that the overall width of all crossing bars (and tendons) does not exceed the space available.

Figure 3. A precast concrete segment erected against a cast-in-place (CIP) straddle bent for the Hong Kong Mass Transit Railway's South Island Line. The precast concrete segments have been designed to sit high enough to allow top-slab tendons to pass over the CIP beam, avoiding the need to align these ducts between the CIP beam and precast segments. The deck above the top of the straddle beam is cast at the same time as the wet joint. Post-tensioning ducts near the top of the web (indicated with arrows) have been detailed slightly lower than other ducts in the top flange to accommodate reinforcing bar bend tolerances in the stirrups (see Fig. 5).

Figure 4. Formwork for the face of the CIP straddle beam where additional tolerance has been created by placing blockouts around post-tensioning ducts where they enter a wet joint (ducts will be installed in holes in blockout, indicated with arrows). The blockout increases the length of the ducts crossing the splice, adding flexibility to connect the ducts to the precast concrete segment.

Reinforcing bar fabrication also brings imperfections. Acceptance tolerances for bent bar dimensions are generally ±1 in. Tighter tolerances are only achieved by measuring each bar and rejecting nonconforming bars, which translates to added material and labor costs.

Where reinforcing bars are supported on chairs, the full length variation must be taken up at one end. In these instances, it makes sense to dimension bars slightly short and ensure that the details allow for the minus tolerance. An example for consideration is when PT is required near the top of a beam and "short" stirrups may conflict with the duct. In such cases, shifting the ducts down to provide a margin for tolerances avoids changes during construction (**Fig. 5**). For example, the ducts in the top slab shown in Fig. 3 have been lowered slightly near the web, compared to other ducts in the top flange, to allow for reinforcing bar tolerances in the stirrups.

In conjunction with length tolerances, reinforcing bar bends around the inside of reentrant corners should be avoided (**Fig. 6**). This detail is problematic primarily because it induces a "pop-out" force when the bar goes in tension. Even if restrained with ties, this detail is sensitive to reinforcing bar bend tolerances.

In addition to length tolerances, every reinforcing bar bend has acceptance tolerances for angular and out-of-plane deviations. This can be observed when reinforcing bars are being sorted for placement—bent bars often appear twisted and do not lay flat. Smaller-diameter bars can be tied into neat alignment during placement; however, fitting a twisted bar to other tightly spaced bars can require additional effort. For the record, sledgehammers should not be considered a standard reinforcing bar placing tool. Extensive use of "beaters" indicates a lack of consideration for tolerances or nonconforming reinforcement.

Accurate placement becomes more important as the amount of reinforcing steel increases. Bar placing tolerance represents a two-way street; it allows bars to be shifted to accommodate the previously described issues or when misplaced as initially set, either of which can result in a domino effect of unanticipated changes. While this point leads to a separate discussion of layout, the remedy is the same: provide reasonable gaps between bar sets—the definition of "reasonable" is subjective, but a good rule of thumb is to provide approximately 2 in. of clear space between sets for every 10 in. of nominal reinforcing bar width.

Conclusion

Detailed design for segmental bridge construction can be tedious, and consideration of details adds one more check on top of many others. But the reality is that tolerances must eventually be dealt with, either on paper or in the field. For that reason, it is in everyone's interest to consider what happens if things are not executed perfectly and how to mitigate the consequences. Addressing these questions early avoids problems and helps put any project on the road to success.

This article focusing on tolerances is the first of two articles on constructability in segmental box-girder bridges. The next article will outline strategies to standardize and integrate details with the goal of making these bridges less complex.

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Figure 5. Partial view of box-girder web showing web bar tolerances. When post-tensioning is required near the top of a beam, "short" stirrups may conflict with the duct. Shifting the ducts down provides a margin for tolerances.

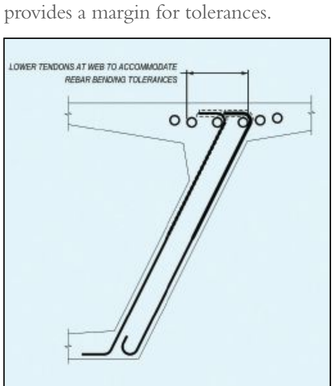

Figure 6. Partial view of box-girder web showing reentrant corner web bar details. Reinforcing bar bends around reentrant corners are problematic because they induce a "pop-out" force when the bar goes in tension (left). Reinforcement that crosses at the corner is a better detail (right).