Trusses Instead of Solid Webs?

When designing post-tensioned, concrete box girder bridges, the dead load of the structure has a tremendous impact on almost all major construction issues, such as the need for expensive construction equipment, the maximum span lengths, and box geometry selection. Reducing the dead load (the sum of the bottom slab, top deck, and web weights) is most important. The deck geometry generally can’t be reduced substantially, because the width is given in the project requirements, and the thickness is governed by transverse flexure stresses. Similarly, the bottom slab geometry usually can’t be significantly reduced. Therefore, the most logical place to look for weight reduction is the webs.

As a percentage of the overall concrete dead load, the web percentage increases as the span length increases, and the box shape deepens to resist the increased moment. In addition, if the box construction uses internal post-tensioning (tendons draped internally within the webs), the width of the web wall is usually thicker than needed to resist principal stresses. It is not uncommon for the webs to represent 30% of the dead load of the box.

Additionally, the webs are generally the most difficult box elements to fabricate, form, and cast in the field. To reduce field labor and optimize thickness, several bridges have been constructed using precast solid webs. Applying external post-tensioning techniques rather than internal post-tensioning, the webs can be thinner and lighter because they no longer serve as containment for the longitudinal post-tensioning ducts. Going one step further, designers can now look at other possibilities for creating a lighter concrete box girder bridge.

**Replace the web with a truss**

In recent years, a few progressive highway bridges have been designed and constructed using external post-tensioning, top and bottom flanges of reinforced concrete, and precast trusses connecting the flanges instead of solid concrete webs. What are the important differences between designing with trusses and designing with solid concrete webs? Globally, either the web or the precast truss must carry applied shear forces and restrain the top and bottom slab longitudinal movement associated with the axial prestressing forces, bending moments, thermal movements, and concrete creep and shrinkage over time. In a traditional box girder design, a solid concrete web results in a member with large shear and torsional stiffness, effectively resisting the above loads with negligible shear deformation. In a truss box girder, however, neither longitudinal nor torsional shear deformation can be neglected. Therefore, these effects need to be carefully analyzed.¹

A truss box girder without transverse stiffening elements or diaphragms (that is, only two parallel trusses connecting the top and bottom slabs) relies on frame action to handle eccentric loading, bridge curvature, or lateral loads. The vertical truss members have little flexural capacity, making a weak frame. Repeated diaphragms along the length of the span are almost always needed to laterally stabilize the cross section and resist transverse loads and torsion. In keeping with the precast truss solution, these diaphragms can also be precast trusses and share nodes with the longitudinal precast trusses (see Fig. 1). Alternately, several longitudinal trusses can be canted in such a manner to connect them across the section (see Fig. 2), creating a space truss along the full length of the bridge.
Fig. 1: The use of additional struts in the transverse plane permits control of distortion without affecting the truss scheme of the webs.

Fig. 2: The use of several cross-shaped trusses lightens the precast elements, increases their number, and reduces the cross-sectional deformation by means of the truss action in the transverse plane.

Fig. 3: Deformation of pinned node trusses subject to axial forces.

**Design of external post-tensioning**

The longitudinal tendons will either terminate or deviate at the truss nodal points and be designed to reduce or eliminate tension in the concrete slabs, truss diagonals, and verticals. Also, truss diagonals or verticals resisting significant tension can be individually prestressed with strands or bars to precompress the concrete in those members.

By locating the deviation points for the longitudinal tendons over many nodal points (pseudo-parabolic), the gravity force is counteracted almost uniformly; however, large angle deviation of a tendon is somewhat costly. It may be more practical to limit the tendon deviator points to the third or quarter points of the span. A finite-element model will help locate the optimum deviation points for harping the external post-tensioning.

The level of uplift provided by the post-tensioning impacts the shear force distribution between the truss and the top and bottom slabs and influences their final design. As an initial value, the post-tensioning force should be designed to resist the dead load and half of the live load, so the truss will resist only the shear.
fluctuations due to the presence or absence of the live load.

**Node design**

One method of node construction is to make them integral with the longitudinal precast truss members. A second possibility is to create either cast-in-place or precast nodes that act like three-dimensional gusset plates, connecting the slab with both the longitudinal and transverse truss members and acting as tendon deviators. Critical to the node design is the resolution of all force components acting at the node. Because of the physical geometry of the various members, it is not always possible to converge all centerlines to a single point, causing a geometric discontinuity. The node area will require careful analysis, especially near such discontinuities. Large shear and axial forces at discontinuities can generate significant local tension and local shear deformation in the top or bottom slabs.

**Truss geometry effects**

The selection of the truss panel geometry has an impact on the magnitude of the secondary moments and shears induced by post-tensioning and thermal movement. When both the top and bottom chords are compressed by post-tensioning, the deformation patterns for Pratt and Warren trusses are different, as shown in Fig. 3. Under compression, each repeating panel of the Pratt truss deforms as a parallelogram. An overall structure with Pratt trusses undergoes a shear-type deformation, which in turn causes secondary forces in the chords. The longitudinal components of the diagonal forces balance out in each repeating panel of the Warren truss, resulting in much less secondary force imparted to the chords.

When a truss girder structure is subjected to a thermal gradient, the top and bottom slab movements will cause secondary forces in the diagonals and verticals of both truss types.

In general, a geometrically more complicated truss uses a larger number of diagonals and verticals, which allows for greater redundancy and an increased number of possible tendon deviator points from which to choose.

Concrete box girder bridges constructed with trusses have the following advantages over traditional box girder bridge construction:
- A mass reduction of 25 to 35%, with proportional savings on materials and labor;
- An increased flexural efficiency versus mass, with the cross section’s mass concentrated at the flanges;
- Reduced dependency on concrete tensile strength as the shear forces are resisted through truss action;
- Replacing the difficult field operations associated with web construction with precast trusses; and
- Less-expensive construction equipment and falsework can be used due to overall reduced weight.

A number of bridges have now been constructed using variations of this concept (see Fig. 4 and 5). This higher efficiency of the truss box girder opens new perspectives in both precast segmental and cast-in-place box girder bridges.

**References**


Received and reviewed under Institute publication policies.

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