Box girder bridges

No. 1.08

Scope

This Guidance Note gives an overview of the main design issues for steel box girders in short and medium span bridge schemes. SCI-publication P140 (Ref 1) gives a more extensive treatment of steel box girder design.

Comments relate principally to the use of box girders as the main girders, acting compositely with a deck slab, but many of the considerations are also applicable where box sections are used as arch members.

Advice on the use of steel box girders in long span road bridge schemes, particularly those with orthotropic steel decks, is not covered by this Guidance Note.

Current use of steel box girders

Road bridges

Nowadays, in short and medium span road bridge construction, steel box girders acting compositely with a deck slab are usually only found in schemes where a high emphasis on aesthetics justifies their increased fabrication costs.

Tied arch bridge systems have recently been used effectively and economically for the upper end of the medium span range and box girders are often chosen for the arch members of such bridges.

Footbridges

Box girders are used for footbridges curved in plan, bridges with longer spans and cable-stayed bridges with a single plane of stays. All-steel construction is typically used, for lightness.

A single box girder as the main longitudinal spine of the bridge is an excellent solution for such situations. With deck cantilevers, a single box can carry the full width of deck.

Railway bridges

Network Rail continues to make use of the ‘Western Region’ standard box girder bridge system in many situations where construction depth is very tightly constrained. Indeed, the standard designs have recently been updated to conform to design to the Eurocodes.

Why choose steel box girders?

The selection, or otherwise, of a steel box girder always needs a consideration of the relative advantages and disadvantages of box girder elements compared to the more traditional **I** girder elements.

Advantages, compared to I girders

- High torsional stiffness and strength, giving greater suitability for horizontally curved bridges, greater aerodynamic stability and reduced susceptibility to lateral buckling of flanges (in lateral-torsional or distortional buckling modes).
- Reduced need for support points.
- Improved durability and reduced maintenance of protective coatings (less exposed surface, fewer edges, avoidance of exposed horizontal surfaces, no exposed bracing and stiffeners).
- The clean lines of a closed box girder are also often considered give a better appearance, particularly for footbridges where the visual impact is considered to be important.

Disadvantages

- Greater fabrication cost on account of the reduced scope for automated fabrication and greater difficulty of handling and rotating during fabrication and coating.
- Greater design input.
- Risks associated with working in enclosed spaces.

Design aspects that require particular consideration

The following aspects are reviewed below:

- Complexity of fabrication
- Internal access
- Stability during construction
- Longitudinal stiffening of plate panels
- Transverse stiffeners and beams
- Control of distortion
- Web/flange welds
- Internal corrosion protection

Complexity of fabrication

Once the decision has been made to opt for a steel box girder, it is strongly recommended that a fabricator is consulted as early on in the design process as possible. Boxes normally need a greater fabrication input, and so the success of a scheme can often depend on whether the design allows efficient fabrication.

It should also be appreciated that the design of a box girder is invariably more complex than that of an I-girder. A box girder needs greater consideration of local buckling, torsion and distortion effects – phenomena not common to I-girder design. Designers also need to establish an appropriate strategy for both the longitudinal and transverse elements of the box.

Internal access
Box girders deep enough to allow internal access will need to provide an access route through the box to enable routine internal inspection. Internal access is also needed by the fabricator to ensure that operatives working inside a closed box can be quickly removed from the box in the event of an emergency.

Previous designs have demonstrated that a minimum internal access hole provision of 600 mm x 600 mm is usually adequate for the needs of both fabricator and inspection authority. However, on account of continuing amendments to safety legislation, it is recommended that internal access provisions are always reviewed and agreed between all parties early in the design stage.

Stability during construction
Closed box girders are inherently very stable torsionally and checks during construction will usually be limited to checking the cross section resistance; lateral torsional buckling is unlikely to reduce the strength unless the box girders have an unusually high height/width aspect ratio.

Open top box girders can, however, be susceptible to torsional buckling during construction before the deck slab has hardened. This problem is identified in AD 331 (Ref 2). Where stability in the temporary condition is a problem, plan bracing will be required to the open top box

Longitudinal stiffening of plate panels
The slender steel plates forming the webs of box girders are often class 4 in bending and the bottom flanges are usually Class 4 in compression. Local buckling (and thus a reduced effective cross section) may be avoided by increasing the out-of-plane stiffness of the plate. This is achieved either by providing longitudinal stiffeners or by using thicker plates

Longitudinal stiffeners typically take the form of longitudinal flats, bulb flats, Tees or trough sections welded to the inner surface of the plate. Extensive use of longitudinal stiffeners typically enables the thickness of the plates forming the walls of the box to be minimised. Taken to the extreme, this strategy will result in a minimum weight box with high fabrication costs.

Figure 1 *Internal view of a steel box girder showing use of longitudinal stiffeners*

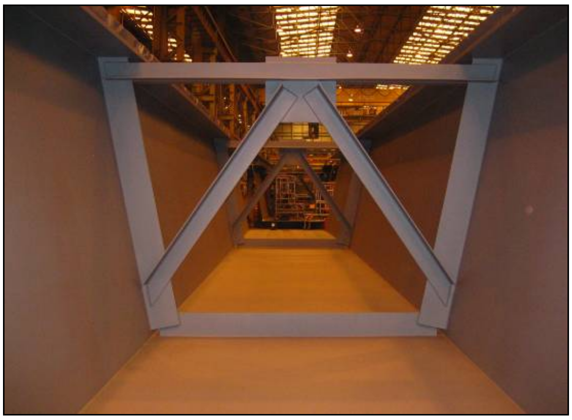

Figure 2 *Internal view of a steel box girder where longitudinal stiffeners were avoided by the use of thicker plates*

As an alternative, the number of longitudinal stiffeners can be minimised by providing thicker plates for the sides of the box. This strategy will result in heavier boxes but with minimum fabrication costs. The increased dead weight, usually not a problem over short spans, can become an issue as spans become longer. When considering the use of thicker plates, the reduced box fabrication costs need to be offset against the resulting increase in temporary works, transportation and substructure costs.

Current box girder designs in the UK have commonly adopted a strategy of minimising the number of longitudinal stiffeners through the use of thicker side wall plates, as current fabrication techniques still typically result in heavier, lightly stiffened boxes being more economical than heavily stiffened, lighter boxes. As this could change in the future with developments in stiffened plate fabrication technology and fluctuations in global steel prices, the preferred longitudinal stiffening strategy should always be discussed with a fabricator early in the design process. It is also noted that the design rules in BS EN 1993-1-5 typically lead to greater resistance from stiffened structures than the rules in BS 5400-3 and this will also encourage a return to thinner stiffened plates.

Transverse stiffeners and beams

Internal transverse stiffeners or beams will be needed for the following reasons:

a) *Enhancing the shear strength of webs*
   The webs of a box are typically very slender and require transverse stiffeners to provide the design shear resistance.
b) *Restraining longitudinal stiffeners*
   Buckling of longitudinal stiffeners in compression needs to be restrained by appropriate transverse elements of adequate stiffness.
c) *Providing paths for local loads*
   Concentrated local loads from components such as cable hangers and support bearings need to be distributed safely into the box sides via a load path provided by transverse beams.

Control of distortion

Where vertical loads are applied eccentrically (normally at top flange level), the torsional component of the loading is girder not a 'pure' (St Venant) torque and the cross section is subject to forces that tend to distort to shape of the cross-section. These distortional forces induce both longitudinal stresses from in-plane bending of the box walls (known as distortional warping stresses) and transverse bending stresses in the box walls (known as distortional transverse bending stresses). Both need careful consideration during design. Box distortion is controlled with the use of internal diaphragms or cross frames that limit the extent of the distortion. These internal diaphragms or frames can take many forms :

- Full depth unstiffened diaphragms.
- Full depth stiffened diaphragms.
- Triangulated cross frames (see Figure 2).
- Ring frames (see Figure 1).

The selection of an appropriate form of diaphragm or frame and the spacing will need to be considered in conjunction with any requirements for transverse stiffeners or beams; the diaphragms or frames will also provide transverse restraint to the flange and web panels and their stiffeners.

Distortional stiffening is also needed by the fabricator to control the shape of the box during construction. The ideal arrangement is where the chosen distortional stiffening design can meet the requirements of both service loads and fabrication.

Many box girder schemes meet all of these requirements via a transverse stiffening strategy of regularly spaced, plated diaphragms or cross frames. The ideal transverse stiffening strategy will meet all of the above demands in conjunction with being economic to fabricate and thus should be derived through close collaboration between designer and fabricator early on in the design phase.

Web/flange welds

The web/flange welds are subject to longitudinal shear and to transverse bending associated with distortional effects. Tee joints with double fillet welds are usually sufficient but over-design of the welds can result in an unnecessary increase in fabrication cost. Full penetration butt welds should only be specified where truly necessary. Designers are strongly recommended to ensure that their box corner weld details can be fabricated efficiently.

Fatigue needs to be considered carefully in all box girders, particularly in welded details which are susceptible to transverse distortional bending stresses or large fluctuations of live load stresses. The degree of fatigue stress fluctuation will vary from detail to detail and will need to be considered on a case-by-case basis by the designer. Designers need also to be aware that details that require specification of a Quantifiable Service Category greater than F56 (see PD 6705-2) may well have considerable financial implications for the fabricator as a consequence of the greater scope of non-destructive testing required. It is recommended that the use of such details is discussed with the fabricator before the design is finalized.

Internal Corrosion Protection

The inside of a box will usually require corrosion protection. Traditionally, as illustrated in Figure 1, the insides of steel boxes were protected by the application of an appropriate light-duty paint system designed to withstand the mild corrosion environment present inside the box.

Painting inside a steel box girder has many disadvantages:-

- Economic – The box girder element needs to be painted both inside and out.
- Health and Safety - The paint needs to be applied in a confined space.
- Application - The degree of stiffening inside a box makes the application of a uniform coating difficult.

To avoid these disadvantages, modern steel boxes such as the box illustrated in Figure 2, are now predominately fabricated from weathering steel, with a small allowance for corrosion of the internal surface. This avoids the need to paint inside the box, even if paint is still required on the outside of the box for aesthetic or other reasons.

Guidance on corrosion allowances, for weathering steel and structural steel, is given in Clause NA.2.14 of the National Annex to BS EN 1993-2 (Ref 3).

Adequate drainage should also be provided to allow any water ingress to drain out of the box void. General guidance on drainage is also given in NA.2.14.

For further details of designing with weathering steel, readers are also referred to a Corus publication (Ref 4).

Sealing boxes that are large enough to access is not recommended. It is very difficult to guarantee an airtight seal. If sealing is attempted, a pressure test should be undertaken to demonstrate the adequacy of sealing and the box must be designed for the pressure difference between internal and external environments.

References

1. Design guide for composite box girder bridges (P140), SCI, 2004.
2. Advisory Desk Note: AD331 Open top box girders for bridges, SCI, 2009 (available on www.steelbiz.org).
3. NA to BS EN 1993-2:2006, UK National Annex to Eurocode 3: Design of steel structures. Steel bridges.
4. Steel Bridges - Material matters, weathering steel (Section 8.4, Box Girders), Corus 2009.
5. PD 6705-2:2010+A1:2013 Structural use of steel and aluminium. Recommendations for the execution of steel bridges to BS EN 1090-2.