Bracing and cross girder connections

No. 2.03

Scope

This Guidance Note covers the attachment of bracing members and cross girders to main I girders, usually achieved by means of connections to stiffeners or cleats on the web of the girder. The details are representative of details that are used in practice, but are not the only details that are suitable in all cases. Some of the details described are also appropriate to box girders.

Additionally, the consequences of the use of the various connections are covered in the Note. The general considerations for design and detailing of web stiffeners are covered in GN 2.04 and GN 2.05.

For guidance on the design of bracing systems, see GN 1.03.

Intermediate triangulated bracing

Where the main I girders are deep enough, diagonal bracing is normally used, either with a single diagonal or crossed diagonals. See Figure 1.

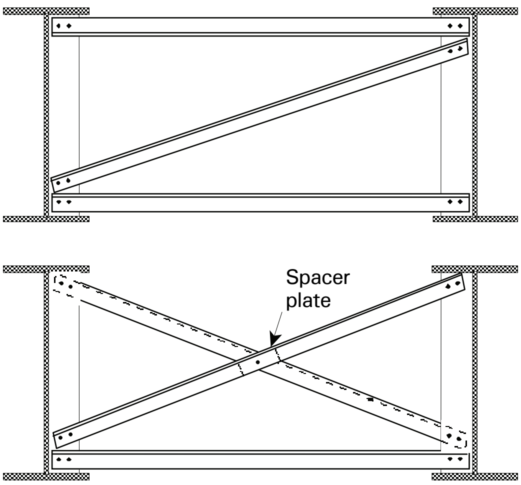

Figure 1 *Triangulated cross-bracing*

For shallower girders (typically less than 1.2 m deep) where diagonals would be at too shallow an angle to be efficient, either K-bracing (see Figure 2) or ‘channel bracing’ (see next page and Figure 5) is normally used.

If temporary formwork is used for slab construction, the bracing needs to be sufficiently below the top flange to provide clearance.

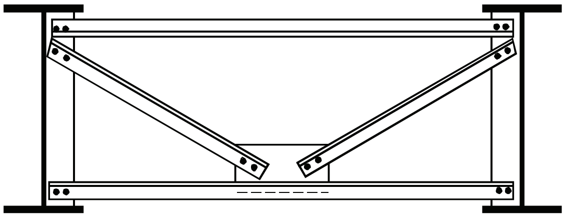

Figure 2 *K-bracing*

In detailing a connection, moments induced in the stiffeners and bracing members can be minimised by ensuring that:

- the centrelines of bracing and effective stiffener section meet as closely as is practical
- the distance between these intersections and the web flange junction is minimised (but sufficient clearance should be allowed for application of protective treatment, for access to tighten the bolts, or to provide space for slab formwork).

The ‘centreline’ of a bracing member is, strictly, along its centroid, although for triangulated bracing members the centrelines indicated on drawings are usually taken as the lines of the bolts.

Bracing members are usually attached by bolting. If the stiffener is made sufficiently wide the bracing can connect through a simple lap connection. Typical connections are shown in Figure 3. A 200 mm wide flat stiffener provides sufficient room for a two-bolt connection using M24 bolts. The ends of bracing members should be kept sufficiently clear of the face of the web to allow completion of protective treatment. Similarly, the horizontal leg of the bracing member should be sufficiently clear of the flange to allow access for painting.

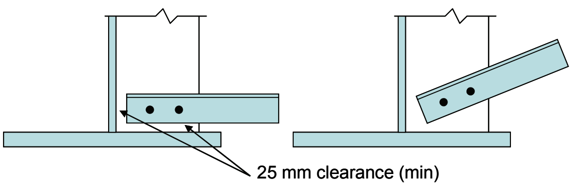

Figure 3 *Lapped connection of bracing member*

Where two bracing members are bolted to one end of a stiffener, the two members should generally be separately connected. It is not good practice to try to 'economize' by lapping two members on opposite faces of the stiffener using a common group of bolts, because it complicates erection.

If there is insufficient room for the required number of bolts within the width of the stiffener (as chosen for its function as a stiffener), the stiffener may be shaped and extended to facilitate the connection. However, it is advisable not to increase the width over the full height of the stiffener, just to facilitate connections at the ends, because an excessive outstand in the central region will reduce its effectiveness as a stiffener. See Figure 4.

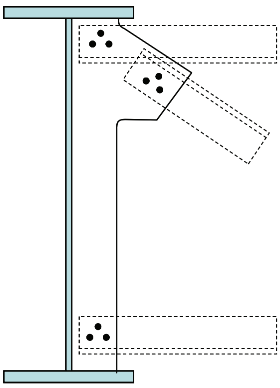

Figure 4 *Example of a shaped stiffener*

At the crossover of X-bracing it is usual to provide a packing piece (the same thickness as the web stiffener) and a single preloaded bolt through all three pieces. This avoids a narrow gap that is difficult to maintain and achieves a reduction in effective length in compression.

The designer should specify the geometry of the bracing system and the number of bolts at each connection. Either the designer or the fabricator can detail the exact location of bolt holes. Sufficient space should be allowed that the fabricator has some flexibility in detailing hole positions and accommodating tolerances without infringing minimum edge distances.

Where the triangulated bracing provides 'torsional' restraint to the main girders the web stiffeners to which the bracing is attached should be welded to both flanges (fillet welds are adequate). Note, however, that the stiffener with bracing may attract local load effects as the deck slab deflects under wheel loads giving rise to fatigue problems. The weld size may need to be increased.

Bracing can represent a greater maintenance liability than the main steelwork. This is particularly true of the top horizontal member, which is more difficult to maintain (because of the slab above), is a roosting spot for birds and is also a dirt trap because of the orientation of the angle. (Usually the horizontal leg is at the bottom, to avoid a significant width of plate close to the underside of the deck slab.) Because of this and the potential fatigue problem, horizontal top bracing members should either be avoided or, where used for construction purposes, removed afterwards.

In choosing the arrangement of the bracing itself, consideration should be given to the assembly of the bracing and the space needed for its attachment to the web stiffeners.

Gusset plates

Gusset plates should always be lapped and either fillet welded around the edges or bolted to bracing members, rather than, for example, butt welding a smaller plate onto the heel or toe of an angle. The latter detail is more expensive and requires grinding flush.

With K-bracing, the central gusset may be bolted or shop welded to the bottom tie, leaving the diagonals to be bolted to it during erection. The central gusset will normally be rectangular (the outstand corner may be sniped); there is no saving in shaping it to a V between the diagonals.

Channel bracing

An alternative to triangulated bracing is to use a stiff cross member, usually a channel, to provide torsional restraint to the main girders. A channel is usually chosen because, with flange outstands on one side only, it is easy to lap it onto the stiffener.

Channel bracing requires a moment resisting connection to the girder (see Figure 5). This is usually accomplished by providing a group of preloaded bolts. The web stiffener is normally a simple flat, though it will probably be wider than would be needed as an ordinary intermediate stiffener. If it is overwidth, it should be tapered back to the usual limiting width either side of the connection to the channel but such that no welding is required within about 25 mm of the flange edges.

If the channel bracing member is too shallow for an adequate group of bolts, a plate can be welded across the end of the member to provide room for further bolts. A simple full depth plate lapped onto the channel is much easier to fabricate than angle or flat cleats welded to top and bottom, and achieves a flat surface for bolting to the stiffener.

When detailing the extra plate, there should be space for fillet welds all round - the plate should therefore extend slightly beyond the end of the channel, not be flush with it. The outer end of the plate may be flush with the edge of the stiffener or project beyond it; it should not be set back from the edge of the stiffener.

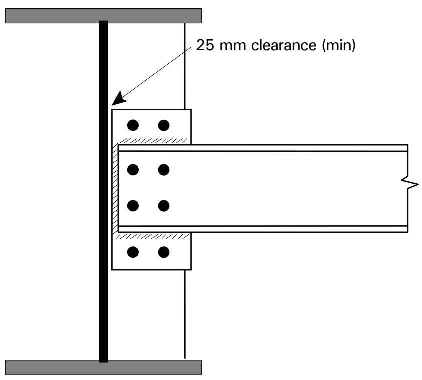

Figure 5 *Connection of channel bracing*

Plan bracing
Lateral restraint is sometimes provided by plan bracing. Angle sections are usually appropriate.

Plan bracing to the top flange, if provided, is usually required only before construction of the deck slab. It will preferably be connected sufficiently below top flange level that it does not interfere with formwork for the slab soffit.

Plan bracing within the depth of the slab is usually connected to the girders by means of cleats welded on the top flange, although this may complicate the positioning of shear connectors and the fixing of slab reinforcement. For these practical reasons, bracing within the depth of the slab is best avoided.

Connection of plan bracing below top flange level is best achieved through cleats welded into the corner between web and a transverse stiffener (Figure 6). Consideration should be given to balancing local moment effects at the connection by careful choice of orientation of bracing members. Such bracing is usually removed after the slab is cast, to avoid the need for future maintenance.

Plan bracing to the bottom flange is not normally needed unless overall torsional rigidity of the bridge is required to enhance aerodynamic stability or to form pseudo-box girders. If it is used, a detail similar to that in Figure 6 should be appropriate.

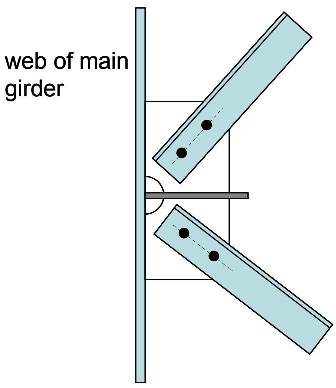

Figure 6 *Connection of plan bracing*

Support bracing
Bracing at supports may be triangulated or channel bracing. Similar considerations as for intermediate bracing generally apply, though the design loads and thus the member sizes are larger. Additionally, this bracing will often act as a trimmer beam at the end of the slab.

Where the supports are at a significant skew to the line of the bridge, the deflection of the girders and the bracing during construction must be considered carefully. Effectively, the bracing plane tends to rotate about a line through all the bearings, which results in a twist to the main girders. The designer must make it clear at which stage the webs are required to be truly vertical, as this will determine the geometry of the bracing. See GN 1.02.

In some designs, a reinforced concrete diaphragm is provided at end supports. This reduces the amount of exposed steelwork in an area where access for maintenance can be difficult, and where water penetration through deck joints can lead to corrosion - especially where unpainted weather resistant steel is used. With concrete diaphragms, light bracing may still be needed for construction. Holes in the webs of main girders for reinforcing bars should be large enough to allow plenty of room for fixing the reinforcement. Shear stud connectors are often provided on the webs of the main girders to ensure that the concrete does not shrink away from the face of the web. Consideration should be given to the use of weather flats at steel-concrete interfaces.

Where channel bracing acts as a trimmer, shear connectors are normally provided, to generate composite action of the trimmer beam.

High skews lead to difficulties for access (into the acute corner) for welding the bearing stiffeners unless they can be arranged square to the web. The size of the fillet weld in the obtuse corner needs to be considered carefully. See GN 2.04.

End connections in integral bridges

At the ends of integral bridges, the ends of the steel girders will normally be cast into the abutment (either capping beam or end-screen wall detail). As for reinforced concrete diaphragms for non-integral bridges, light bracing (which will probably get cast into the abutment) will usually be necessary for the construction condition. Holes are needed in the web for reinforcing bars to pass through, and shear connectors will be needed to assist in transmitting the moments and forces.

Connection of 'ladder deck' cross girders

The steelwork system in ladder decks generally comprises two main longitudinal girders and equally spaced cross girders arranged to span transversely between the main girders (like the rungs of a ladder). The cross girders are usually arranged orthogonal to the main girders, but for small skews ($<15°$) can be parallel to the line of the supports. The cross girders will usually be fabricated **I** sections, although in some instances it may be possible to use a rolled section. The concrete deck slab acts compositely with the main girders and the cross girders,. There are shear studs on the top flanges of the main girders and the cross girders.

With a deck slab of uniform thickness, the top flange of the cross girders will line up with the top flange of the main girders. If the slab is haunched over the main girders, the top flange of the cross girders will be set up higher than that of the main girders. This is often done to provide extra depth at the root of the slab's edge cantilever if the cantilever is long. Usually on ladder decks the cross girders are provided only between the main girders, however they may be extended as cantilevers on the outside face of the main girders. This means that, assuming a full width pour, the steelwork supports the entire deck slab in the wet concrete condition.

There are two methods in general use for connecting the cross girders to the main girders. With a lapped connection, the web of the cross girder is lapped on one side of a stiffener on the main girder as shown in Figure 7. With a splice plate connection, the web of the cross girder is aligned with a stiffener on the main girder and double cover plates are used as shown in Figure 8. Use of end plate connections where an end plate welded onto the cross girder is bolted to the web of the main girder is not recommended, because of the difficulty in fit-up.

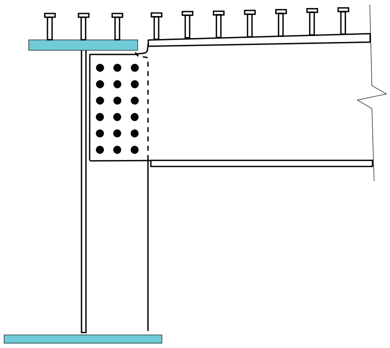

Figure 7 *Cross girder lapped connection*

The connections are more simply designed so that only a bolted connection to the cross girder web is required. This simplifies the steelwork erection. It is not necessary to make any connection between the cross girder top flange and the main girder top flange, or the cross girder bottom flange and the main girder web stiffener, although the addition of a top flange cover plate connection is sometimes useful to reduce the effective length of the cross girder. In the bare steel condition, the connection must have adequate capacity for the wet concrete loads, after which the composite top flange will provide additional capacity for subsequent stages of loading. If need be, the web of the cross girder can be strengthened by welding on additional plating in the region of the bolt group.

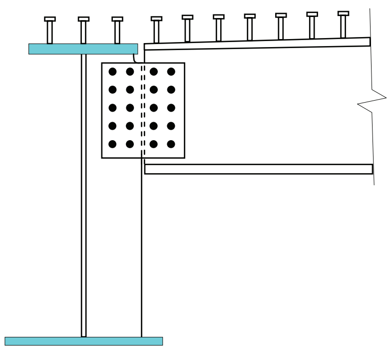

Figure 8 *Cross girder splice plate connection*

At internal supports of continuous multi-span bridges, the standard cross girder can be adapted to provide restraint to the main girder bottom flange at the support and, if needed, within the hogging moment region. This can be achieved by the introduction of bracing members or by increasing the depth of the cross girder (see Ref 1). Similar arrangements can be used at the abutments or end supports. At internal supports to skew decks, with judicious spacing of the cross girders, the bearings under the main girders can be arranged so that they are staggered by a multiple of the cross girder spacing. At a skew abutment the cross girders can be connected into a heavier end trimmer girder that is parallel to the line of the bearings. Where the skew is heavy, the trimmer to main girder connection may also be subjected to significant hogging moments and the design and details developed accordingly.

References

1. Composite highway bridge design (P356), The Steel Construction Institute, 2009

Further reading

Hayward and Weare, Steel detailers' manual, Second Edition (revised by Oakhill), Blackwell Science, 2002.

Hayward, Sadler and Tordoff, Steel bridges (34/02), BCSA, 2002.