Steel Bridge Group

Guidance Note

Bracing systems

No. 1.03

Scope

This Guidance Note gives advice on bracing systems for composite beam and slab bridges. The bracing described provides lateral or torsional restraint to the main beams and forms part of the load path in resisting lateral forces.

This brief note cannot provide a complete treatment of such a wide-ranging subject, and is intended purely as an introduction although the general principles are applicable to other configurations and forms of construction.

For further guidance on the restraint systems employed in half-through (or U-frame) bridges, see GN 1.10. For guidance on use of cross girders in ladder deck type bridges, see Ref 1.

General

Most steel beams of rolled or fabricated I-section are potentially susceptible to lateral torsional buckling at some stage during erection; composite beams are also potentially susceptible to buckling where the steel flange is in compression. Susceptibility to these forms of instability is influenced by a number of factors, not least of which is the degree of lateral and/or torsional restraint provided at support positions and at intermediate positions on spans. Beams that are erected in pairs, connected by torsional bracing, can also still be prone to buckling of the girder pair in a torsional mode where plan bracing is not provided during construction – see below.

Bracing systems in any structure are ‘secondary’ elements, but their function is nevertheless vital to the performance requirements of the primary elements, both in service and during construction.

Both the stiffness and strength characteristics of restraint systems are critical from the point of view of providing ‘adequate’ or fully effective restraint.

In single span composite bridges, with the slab on top of the beams, the bracing required for the service condition is solely necessary for providing torsional restraint at supports. Further bracing may be incorporated to stabilise top flanges in compression during construction, particularly during casting of the deck slab – see *Bracing for Construction* below. In the case of continuous composite spans some permanent bracing may also be required adjacent to intermediate supports to stabilise the bottom (compression) flange against lateral buckling.

Typical bracing arrangements in plan, for a bridge that has ‘almost square’ spans (i.e. skew less than about 20° are shown in Figure 1. The considerations for each type of bracing are discussed below.

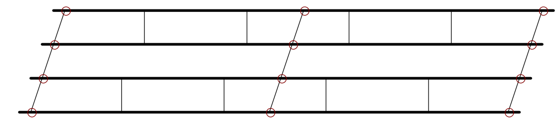

Figure 1 *Types of bracing to main beams of a composite beam and slab deck*

Bracing at supports

Bracing at intermediate and end supports is required to provide torsional restraint to the girders and to effect the transfer of lateral forces (e.g. collision loads) from deck level to the bearings. The bracing system may also offer vertical support to the end of the deck slab, for example by providing a trimmer, or transverse member below the end of the slab that gives it vertical support along its edge.

Where the bracing system also provides support to the slab, it should be continuous across all the girders. See Figure 2.

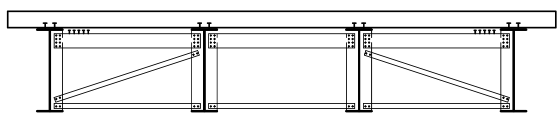

Figure 2 *Support bracing with trimmer beam*

Support bracing can be provided simply between paired girders (i.e. with no connection between adjacent pairs), provided that the bracing can transmit lateral forces to whichever of the girders is restrained laterally by a bearing (and that the deck is capable of transferring all transverse forces to these girders). However, it is common to provide at least a tie/strut at bottom flange level between adjacent pairs.

Intermediate bracing adjacent to supports

In continuous construction, the bottom flanges adjacent to intermediate supports are in compression. Lateral restraint may be needed to ensure that buckling does not significantly limit the bending strength of the girders. This can be achieved either by the use of triangulated bracing, or by a stiff cross-member or inverted U-frame. See Figure 3 for examples.

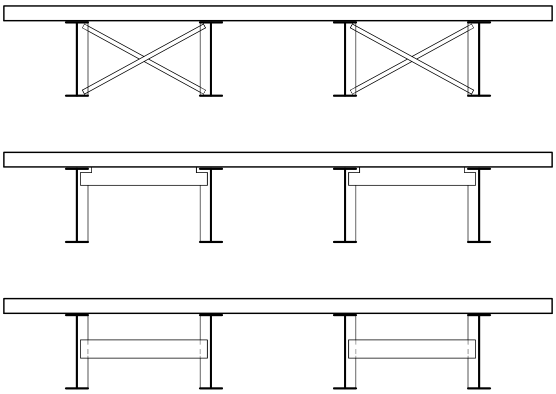

Figure 3 *Typical intermediate bracing adjacent to supports*

Note that, in Figure 3, if there is a tie with the X bracing, or if there is a bolted connection at the crossover, it may also act as torsional bracing during construction. Stiff transverse members require moment-resisting connections to the main girders.

When the skew is less than about 20°, intermediate bracing can be positioned on the skew, parallel to the lines of supports, or it can be square to the girders (in which case the 'panel lengths' of adjacent girders are slightly different - see Figure 1).

Girders should normally be braced in pairs (but without any bracing between adjacent girder pairs). Continuity is not necessary, as if the bracing were continuous it might lead to fatigue problems because of the transverse loads induced in the bracing members and connections.

Even with paired bracing, fatigue effects need to be checked at bracing positions; with such bracing the most critical areas are those at the tops of the stiffeners, where significant bending can be induced by wheel loads on the deck slab.

Bracing for construction

The staged construction of composite bridges usually demands more extensive bracing, to stabilise the primary members before the deck slab is complete, in addition to the bracing needed for the service condition.

The designers of the permanent bracing and the temporary works bracing both need to consider risks to health and safety, as required by the CDM regulations. In particular, the permanent works designer needs to check the overall structure for stability both in the in-service condition and during construction. The designer might, for example consider the use of larger top flanges to reduce the amount of temporary bracing, or to achieve stability of individual girders under their self weight (avoiding the need for temporary measures to stabilise them).

In mid-span regions, the steel top flanges are in compression. Without lateral restraint during construction, these flanges would often be too slender to carry any significant load (not even their own self weight in many cases). Restraint to flanges can be provided either by transverse ‘torsional restraints’ between paired girders or by triangulated plan bracing.

The most economic form of bracing is usually torsional bracing, as shown in Figure 4. This configuration can have the horizontal at bottom or top flange level, although the latter may restrict fixing of formwork (keep the tie at least 100 mm below the slab).

Where only torsional bracing is provided (i.e. bracing between adjacent beams in a vertical plane), calculation of the effective length, and hence slenderness, is not simple during construction when the deck slab is not present. A computer model is likely to be needed to calculate M_{cr} (the elastic critical buckling moment) and hence the slenderness in such cases. **The effective length is usually not the distance between torsional braces, but a greater length.**

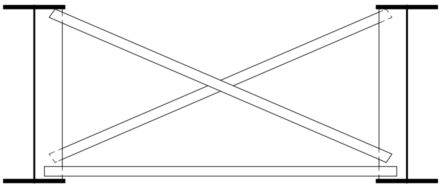

Figure 4 *Typical 'torsional bracing' between paired beams for erection*

Other common configurations are Z (two horizontals and one diagonal) and K. K bracing is effective only if the horizontal is very stiff or if it is tied by a second horizontal.

Bracing that is required only for construction purposes may be removed once construction is complete if it impedes maintenance operations or adversely affects the performance of the bridge in service. However, it is often safer and cheaper to leave the bracing in place; consideration then needs to be given to the implications on maintenance operations if left in place and the risks associated with removal. If left in place, the bracing members and their connections need to be designed for fatigue effects and the members should receive the same corrosion protection as the remainder of the steelwork.

Whenever bracing for construction is to remain as part of the permanent structure, it must be connected by means of preloaded slip-resistant bolts, as for any other part of the Permanent Works.

As an alternative, or more usually in addition to torsional bracing, plan bracing can be provided at top flange level. Such bracing can be positioned within the depth of the slab, so that is completely surrounded and protected by the slab when it is cast. Such positioning is very effective, but it complicates fixing of slab reinforcement and should normally be avoided. Plan bracing just below the slab can cause even more difficulties, as it interferes with falsework support and has either to be removed or to be protected and maintained. Removal is hazardous once the slab is in place as the bracing cannot be supported from above while the bolts are being undone.

If girders must be erected singly, temporary bowstrings can be used to provide the necessary compression flange restraint until the girder is connected to other restraints. (A bowstring is an arrangement of transverse struts and longitudinal tensioned wires that provides extra stiffness to transverse displacement.)

In longer spans, simple struts inserted transversely between girders (or between pairs of girders) are sometimes needed to share wind loads between the girders until such times as the deck slab is capable of performing this function. These struts may be removed after construction, to facilitate maintenance and to avoid creating transverse continuity and thus possibly attracting fatigue problems. The comments above concerning removal of bracing apply equally to these struts.

Sometimes on longer spans plan bracing may be required (forming with the main beams a truss in plan), to resist transverse bending effects, chiefly those due to wind loading during construction. It has also been used to create a pseudo box on longer spans to avoid classical flutter aerodynamic instability by increasing the deck's torsional stiffness. Plan bracing does, however, tend to be a nuisance, whether at top or bottom flange level and is therefore better avoided, if possible.

Skew bridges

Bridges where the support lines are skewed at more than about 20° from square call for special care when designing the bracing system. In such cases, intermediate bracing is best arranged square to the girders. Support bracing may also be best set square to the girders, as shown in Figure 5, but see further comment in GN 1.02.

Whether the support bracing is along the line of support or set square to the girders, there will be a consequent twist of the girders at the supports as the girders deflect under load. This is because the girders rotate in the planes of their webs; the effects are greater at end supports than at intermediate supports, because of the continuity at the latter. See more detailed discussion in GN 7.03.

Note that if bracing is set at a skew of more than 30°, the attachment of the web stiffeners at an acute angle to facilitate connection of bracing will complicate the welding detail, because of the acute/obtuse angles with the web (see further comment in GN 2.04).

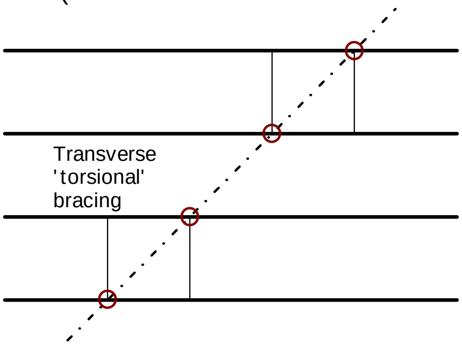

Figure 5 *Typical support bracing arrangements for skew bridges*

Reference

1. Composite Highway Bridge Design (P356), SCI, 2010.