Steel Bridge Group

Guidance Note

Skew bridges

No. 1.02

Scope
This Guidance Note relates principally to the design and construction of deck-type and half-through skew bridge decks. Deck-type bridges, which comprise steel girders supporting a composite concrete slab at the top flange, are most frequently used for highways, whilst half-through decks are commonly used for railway bridges.

For the purposes of this Note, a skew bridge is one where the longitudinal axis of the bridge deck is not square to the lines of its supporting piers and/or abutments. In the Note, the skew angle is taken as the angle between a line square to the supports and the longitudinal axis of the bridge. Thus the greater the skew angle, the higher (or more severe) the skew.

Curved skew bridges are not covered.

Main steelwork system
Deck-type construction is common for highway bridges and is used for some railway bridges. In continuous bridges of this type, the main girders are usually arranged parallel to the longitudinal axis of the bridge, even for high skews.

At the intermediate supports of continuous bridges, the girders can be supported either directly, by individual bearings beneath each girder, or indirectly, with the bearings providing support to integral crossheads that frame into the longitudinal girders. In 'ladder' decks, internal supports will usually be directly under the main girders.

Some typical arrangements for deck-type multiple spans are shown in Figure 1.

With continuous spans, variable depth or haunched girders are generally best avoided for skews over about 20°, because of the geometrical complexity of the bracing.

On single span deck-type bridges, the main girders are usually arranged parallel to the longitudinal axis of the bridge when either:

- the skew is less than 45°; or
- the deck is narrow in relation to its span.

On a narrow single span bridge with a pair of main girders spanning in the direction of the bridge axis, consideration should be given to squaring up the ends of the deck. This is particularly relevant for railway bridges, to avoid track twist.

However, when either:

- the skew is more than 45°; or
- the deck is wide in relation to its span,

the main girders are more often arranged to span square to the abutments. In the case of a wide deck, the main girders will span directly between the two abutments over the centre part of the deck. Edge girders are provided, generally parallel to the longitudinal axis of the bridge, to support the other main girders so

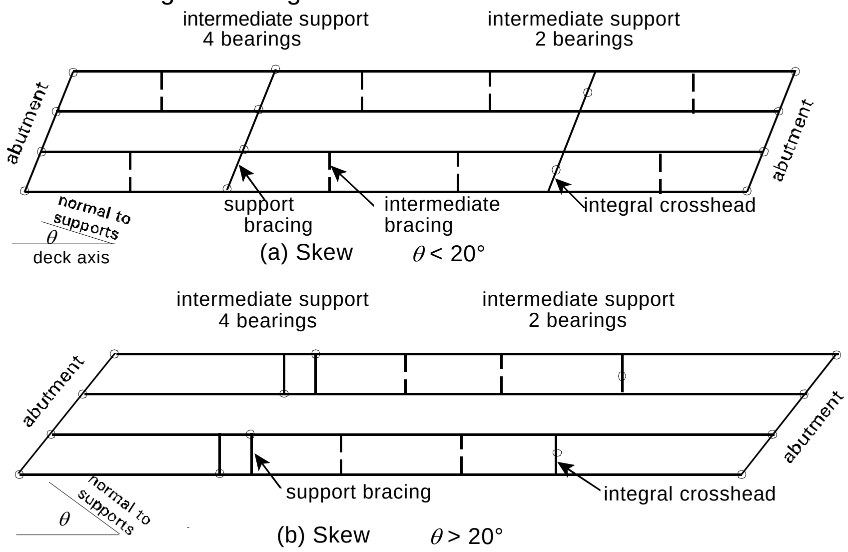

Figure 1 *Arrangement of girders for deck-type multiple skew spans*

that they span from the abutment to an edge girder. The main girders are usually framed into these edge girders with a rigid moment connection.

Typical arrangements for deck-type single spans are shown in Figure 2.

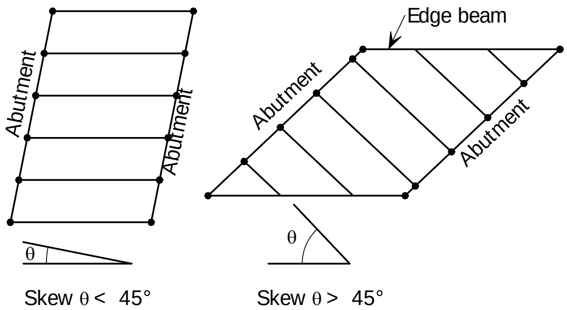

Figure 2 *Arrangement of girders for deck-type single spans*

Half-through bridges
For railway bridges in particular, the depth available for construction may dictate that half-through composite construction is used, with cross girders spanning between two main girders located at the edge of the deck. The cross girders may be partly or wholly encased in a concrete slab. When a steel deck plate is used, the transverse 'ribs' are arranged in the same manner as described below for cross girders.

For skews up to 20º, the cross girders can be either parallel to the abutment (termed skewed cross girders) or orthogonal to the main girders. When the cross girders in the centre part of the span are arranged orthogonal to the main girders, at the end of the span the cross girders nearest the abutment may be fanned to the trimmer beams (termed fanned cross girders).

For skews greater than 20º, the cross girders are better arranged orthogonal to the main girders, and skew trimmer girders spanning between the ends of the main girders are provided at the abutments to support the ends of the cross girders (an arrangement termed trimmed cross girders).

Typical arrangements for half-through railway bridges are shown in Figure 3.

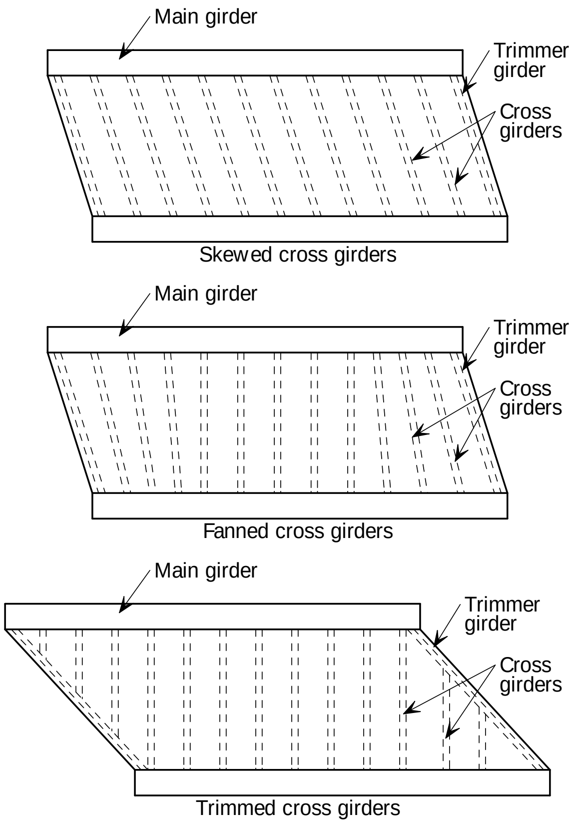

Figure 3 *Arrangement of girders for half-through railway bridges*

Bracing in deck-type construction
In deck type construction, for skews up to about 20º, intermediate bracing can be either parallel to the line of the abutment bearings (termed skew bracing), or orthogonal to the main girders. Intermediate bracing will usually only be needed to brace girders together in pairs rather than to provide a continuous line of bracing across the deck. Whilst continuous bracing across the deck can improve the transverse distribution between main beams, the more so with increasing skew, it will also attract large forces to the bracing system, which can be difficult to accommodate in design for fatigue and strength, particularly at connections. As the skew increases, cross girders of a size similar to that of the main longitudinal girders may be needed (see Reference 1). Continuous bracing is therefore usually best avoided, where possible.

Skew bracing requires that the stiffeners to which it is connected are welded to the webs of the main girders at a skew rather than square. There is no particular advantage in making the bracing skew, except for link bracing between two braced pairs of main girders, where the bracings would otherwise be staggered in plan. For skews over about 20º, intermediate bracing is almost always arranged orthogonally to the main girders.

Irrespective of skew, bracing at the abutment supports is usually best arranged parallel to the line through the bearings. This bracing will also act as a trimmer beam to the deck slab.
At the internal supports of continuous decks where the skew is small (typically less than 20º), the bracing is also usually arranged parallel to the line through the bearings. For higher skews (over 20º) there are no hard and fast rules, and the bracing for each individual bridge should be tailored to the particular circumstances. Geometry, erection method and deflections (including twist) must all be considered.

Plate girder integral crossheads are often used at internal supports. Integral crossheads are usually arranged orthogonal to, and frame into the longitudinal girders. They may either join the main girders in pairs, or be continuous between girders across the width of the deck. Where the main girders are joined in pairs over a single bearing at the internal support the integral crosshead effectively acts as a bearing support diaphragm. See GN 2.09 for guidance on integral crossheads.

Vertical profile

Particular attention should be paid to bridges with a vertical profile that has to follow a vertical curve, as a different geometry is required for each of the longitudinal girders. This, together with any crossfall, will also lead to differing geometry in the elements of the bracing system. For railway bridges there may also be a requirement to superimpose a live load precamber on the vertical profile of the girders.

Girder twist

At the abutments or end supports of bridges having high skews (typically 45º or more) where the main girders are interconnected by the deck or by intermediate bracings, the deck will tend to rotate about the line through the bearings. This mode of rotation will also occur during slab construction, once the main girders have been interconnected by bracing, and will cause the main girders to twist. This twist effect is explained in GN 7.03. The resulting out-of-verticality of the girders should be taken into account in the design. Note that whilst EN 1090-2 (Ref 2) Table D.1.1 requires that for I girders without bearing stiffeners, the out-of-verticality of the web at the supports is limited to depth/200 but not more than the web thickness, GN 7.03 recommends that the tolerance on verticality of main girders at supports is also specified at completion of erection and should be depth/300. This provides a small margin on the tolerance assumed in clause 10.2.4 of PD 6695-2:2008 (Ref 3) when calculating the force required to torsionally restrain a beam at support due to non-verticality.

A pre-set twist can be built into the girders so that after deck concreting, the verticality of the web will be within tolerance. The designer should determine the pre-set twist necessary to counteract the twist that will occur. When the bridge is constructed, this pre-set can be achieved on site either by designing the permanent bracings with appropriate geometry, or in unbraced girders by twisting them at the support during erection. On the drawings, the pre-set twist should be illustrated as a rotation angle of departure from vertical and given in tabular form if twist varies at different locations.

The tendency of the deck to rotate about the line of the abutment bearings must be taken into account in the choice of the type of bearings and their axes of rotation. With elastomeric or pot type bearings, which allow rotation about all axes, no special consideration is required. However if linear roller or rocker bearings are needed to provide restraint against lateral rotation of the girder, the alignment of the axis of the bearing is an important consideration.

With half-through railway bridges, the bearings at the obtuse corners may need to be set relative to those at the acute corners to facilitate the erection of the cross girders.

Twist also has implications for the temporary works. In particular it is necessary to consider restraint to the main girders to prevent lateral torsional buckling. Experience during erection has shown that the actual movement that takes place is frequently less than that predicted by the designer.

Designers should consider every bridge with a skew greater than 45º as a special case, and determine the most appropriate method of dealing with twist.

Deck slab

EN 1994-2 (Ref 4) 6.6.6 requires that the design of the transverse reinforcement in the deck slab of a composite bridge should be designed for the ultimate limit state so that premature longitudinal shear failure between the slab and the girder or longitudinal splitting shall be prevented. Note that EN 1994:2 6.6.5.5 states that the maximum longitudinal spacing of shear connectors should not exceed the lesser of 4 times the slab thickness or 800 mm.

In deck slabs of composite bridges the most efficient arrangement is generally for the longitudinal reinforcement to be parallel to the main girders, and the transverse reinforcement to be at right angles to the main girders. In skew decks and away from the edge of the deck at the abutment, the slab effectively spans square between girders, so the arrangement with the transverse reinforcement at right angles to the main girders is the most efficient. This does, however, lead to complicated detailing of the reinforcement at the edge of the deck parallel to the abutment. Hence at small skews (less than 15º) it may be preferable to place the transverse reinforcement parallel to the abutments. This will result in little loss in efficiency (see Reference 5).

It is important that the spacing and positioning of the shear studs on the girder top flanges and the detailing of the transverse reinforcement in the slab are coordinated so as to avoid unnecessary clashes with the studs. Shear studs are usually detailed in rows orthogonal to the axis of the girder, but if skewed reinforcement is preferred, the studs should be arranged on the skew to suit.

Where precast plank type permanent formwork is used for the slab, the planks are normally placed at right angles to the main girders. The spacing and positioning of the shear studs and the transverse reinforcement should be coordinated with that of the planks. The triangles of slab without planks left at the edge of the deck at the abutments are usually cast using conventional formwork supported from off the abutment. Alternatively, though less commonly, precast ‘specials’ may be made to close these gaps.

Detailing skew stiffeners

Care needs to be taken in specifying the size of welds between webs and skew stiffeners, as the dimension of the weld throat is dependent on the angle between the web and the stiffener. Reference should be made to EN 1011-2 (Ref 6):, Annex B, Table B.1. As skew increases, the ability of the welder to achieve root penetration on the acute side of the stiffener is impaired (see GN 2.05). Also with highly skewed stiffeners, access for bolting the bracing members needs to be considered in deriving the geometry of the stiffener.

References

1. Bridged in Steel 12, British Steel.
2. EN 1090-2:2008 Execution of steel structures and aluminium structures - Part 2: Technical requirements for steel structures.
3. PD 6695-2:2008, Recommendations for the design of bridges to BS EN 1993
4. EN 1994-2: 2005 Eurocode 4 –Design of composite steel and concrete structures – Part 2: General rules and rules for bridges.
5. Concrete, Feb 1968 and August 1968.
6. EN 1011-2:2001, Welding. Recommendations for welding of metallic materials. Arc welding of ferritic steels

