Verticality of webs at supports

No. 7.03

Scope

This Guidance Note explains the importance of web verticality at the supports of I-section beams, comments on the verticality limit in EN 1090-2 and discusses the verticality at the ends of skew decks.

The importance of web verticality

Bridge decks are usually arranged with a number of main beams (either beneath a compositely acting slab or at the edges of a half-through deck) that sit on bearings. The principal loading is vertical and the bearings are arranged to provide vertical reactions. Torsional restraint is provided at the ends of the beams, by means of bracing, by end trimmer beams, by U-frame action in half through bridges, or possibly by using linear rocker bearings.

If the web of a beam is not vertical over a support, the load transferred from the beam is inclined, because the shear in the web is in its plane. However, the reaction at the bearing is vertical and, in ordinary circumstances, there is no (external) horizontal reaction, other than through a small amount of friction on the bearing. Consequently, there is a horizontal resultant of these two forces at bottom flange level that must be balanced internally by some means; this is achieved by providing a couple at the top and bottom flanges, by reaction on the bracing (or other torsional restraint).

The magnitude of force that the bracing must sustain depends on the torsional restraint needed to stabilise the beam (according to the design rules) and the reactions needed to restrain the inclined web; the greater the inclination, the greater the required capacity of the bracing.

Verticality criteria

The only essential tolerance on verticality at bearings in EN1090-2 is in Table D.1.1 where a limit of D/200 on squareness is given at support positions of beams without web stiffeners. It could be inferred that this criterion applies only to the girder as fabricated, not as erected, because Annex D of EN 1090-2 relates to *manufacturing tolerances*, but it is more logical to assume that it applies to the completed structure, because it should be compatible with the design rules for restraints in EN 1993.

In the MPS [Ref 2] the limit on verticality of main girder webs at supports was specified as depth/300 or 3 mm, whichever is greater; this is consistent with the value of *D*/200 used in PD 6695-2 [Ref 3], after application of a partial factor of 1.5. This is more onerous than the Table D.1.1 tolerance. However, as noted in GN 5.03, the SHW 1811.3.2 [Ref 4] applies, as a functional tolerance, EN 1090 D.2.1(6), class 2 at bearing stiffeners; this limit is depth/500, which is tighter than either the Table D.1.1 or the MPS essential tolerances.

Note that the essential tolerance that is necessary for resistance and stability is on web verticality, and not on simply the squareness of the flanges to the web.

It is recommended that project specifications be written to make it clear when the web verticality criterion is to be met. Unless the designer has made special allowance (see below), this should be achieved for the beams under permanent load conditions (i.e. all dead and superimposed dead loads).

Web verticality at the ends of square decks

When the bridge deck is square (i.e. zero skew angle), the main beams are perpendicular to the line of supports; in a composite bridge, bracing will usually be provided along the line of supports.

When the beams are loaded, they deflect, and at the supports they rotate only in the planes of the webs. There are no twisting deformations (save possibly for minor secondary effects). Consequently, the verticality that is achieved when the beams are erected and the bracing connected should substantially be maintained as the deck loads and superimposed loads are added

Web verticality at the ends of skew decks

However, the situation on skew decks is very different. If the beams are interconnected by bracing, as they usually are (or by a concrete diaphragm, as is also common), then the deflection under load will cause a rotation about an axis defined by the straight line drawn through the centres of the bearings at that support. This rotation can be illustrated vectorially, as shown in Figure 1.

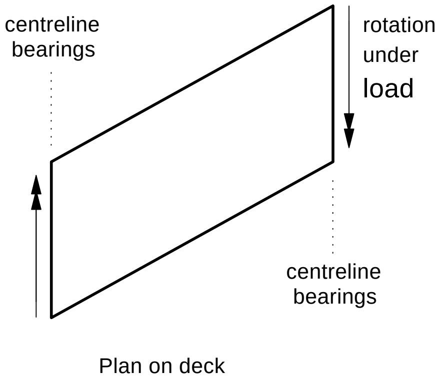

Figure 1 *Vectorial representation of end rotations on a skew deck*

The result is that there is a component of twist rotation applied to each beam as shown in Figure 2.

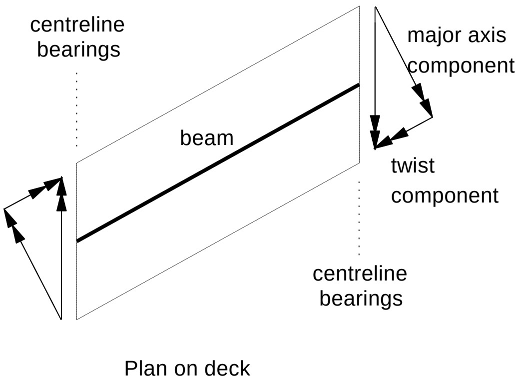

Figure 2 *Vectorial components of the end rotations on a skew deck*

The effect can also be illustrated by considering a plan view on one of the beam ends, as in Figure 3.

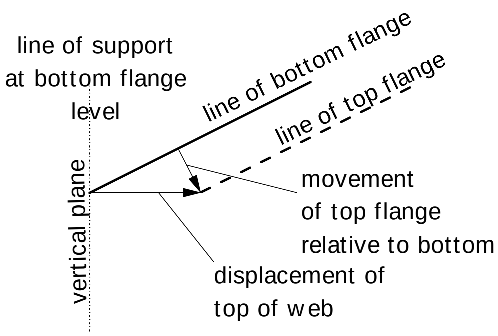

Figure 3 *Relative movement of flanges*

A similar rotation (about the beam's longitudinal axis) occurs if there is bracing square to the beams, instead of along the line of the supports, as shown in Figure 4. Clearly, the deflection of one end of the bracing but not the other, will cause rotation about the main beam axes.

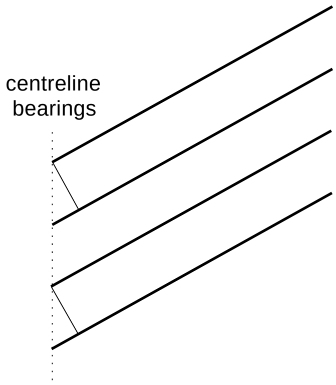

Figure 4 *Skew deck with bracing square to beams*

At the ends of a single span, the twist can be significant if the skew is large. The end rotation of a typical bridge beam, due to dead and superimposed loads, can be of the order of 0.005 rad. If the girder is 1600 mm deep and at 45° skew, the movement of the top of the web relative to the bottom will be 5.6 mm. (Note that such a movement amounts to a significant part of a depth/300 tolerance and would exceed a depth/500 tolerance,)

Rotations in continuous spans

In a single span, although the twist is in the same sense all across the span, the rotations at the two ends will be in opposite directions.

At the intermediate support positions of continuous beams there is little net rotation in the plane of the web (unless loads are applied before the beam is made continuous) and therefore no resultant twist. The greatest effects occur at the free ends of the bridge. (But note that if a skew bridge is built as a series of single spans, the twists at the two ends on an intermediate support would be in opposite directions and it may be difficult to achieve good alignment.)

Checking web verticality

To ensure compliance with a specification of verticality at completion, a compliance check would need to be carried out after completion of the deck, surfacing and installation of all permanent furniture. However, this is too late to be of any practical value.

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However, two alternative timings are possible: either during trial erection (if specified) or on completion of steelwork erection on-site. The latter is recommended. In either case, the designer should state clearly what is to be checked.

Checks carried out on completion of steelwork erection but, before deck construction, afford the opportunity to correct any out-of-tolerances before the steelwork becomes locked in position.

Dealing with twist

In a composite bridge, the tendency to twist will occur predominantly under the wet concrete and formwork loading condition. If measures are to be taken to ensure verticality at completion, there are three alternatives for dealing with twist on skew decks:

(i) Pre-set the beams during erection to offset the rotation which will tend to occur during concreting.

(ii) Set the beams to be vertical at the end of steelwork erection and provide a form of temporary bracing at the supports that will prevent the rotation during concreting.

(iii) Set the beams to be vertical at the end of steelwork erection and allow in the design for the calculated values of twists.

Option (i) is the recommended method. However it relies on calculation of the preset that is required. The effects at the beam ends can be evaluated from a grillage model; the model should include members to represent main beams, support diaphragms/trimmers and any other bracing between beams. The dead loads should be applied to a series of models to match the construction sequence.

Note, however, that if the bracing between a pair of beams, particularly diagonal bracing, is fabricated to the correct length in the completed condition, and that the connections are well fitted (i.e. bolt holes all in good alignment), the beams will automatically be preset so that the beam webs are vertical on completion, assuming that vertical deflections are as predicted.

Option (ii) can only be achieved where there is the opportunity to place temporary torsional restraint square to the ends of each beam, and this is rarely possible.

Option (iii) is used by designers who prefer to allow for the predicted twist during concreting as an additional tolerance. This implies that greater out-of-vertical (than depth/200) is acceptable (it is usually visually imperceptible). See further comment below.

Predicting twist during concreting

Predicting final deflections exactly can be difficult for composite bridges, particularly skew composite bridges, owing to imponderables such as partial composite behaviour of slabs cast in stages, variations in concrete density and modulus, amount of cracking at internal supports, etc.

In most cases, twists that occur at supports during concreting tend to be less than predicted. Some designers therefore prefer to specify that the webs should be vertical at the bare steel stage but in design allow for the full predicted twist plus and an assumed initial out of vertical of, typically, depth/200 (as in PD 6695-2). This would normally give a conservative value for the out of verticality on completion and the value would then be used to derive design values of restraint forces.

Restraint forces due to non-vertical webs

EN 1993-1-1 allows the consideration of imperfections such as lack of verticality either by modelling the actual geometry or by applying equivalent forces to the structure. Whilst the former approach will give the most accurate representation of the restraint forces, it will involve significant additional modelling effort because of the need to include second order effects and imperfections. An alternative is to use the method of restraint force calculation in PD 6695-2, 10.2.3.

References

1. EN 1090-2 Execution of steel structures and aluminium structures. Technical requirements for steel structures.
2. Bridge Group: Model project specification for the execution of steelwork in bridges (P382), SCI, 2009.
3. PD 6695-2: 2008, Recommendations for the design of bridges to BS EN 1993, BSI.
4. Manual of Contract Documents for Highway Works, Volume 1, Specification for Highway Works, Series 1800, 2014.