Steel Bridge Group

Guidance Note

Allowing for permanent deformations

No. 4.03

Scope

This Guidance Note gives information about the determination of allowances for permanent deformation (chiefly, the vertical deflection of the main girders). These deformations arise as a result of the shrinkage or distortion during fabrication, the self-weight of the construction works (weight of steel structure, concrete deck, surfacing, etc.) and the shrinkage effects of the reinforced concrete deck slab.

For additional considerations in skew bridges, see GN 1.02 and GN 7.03.

Bridge profile

The required final vertical profile of a bridge is determined by the requirements for the profile of the highway or railway which is carried on it, and on any clearance gauge above or below that needs to be observed. The actual profile on completion depends on the cut shapes of the steelwork components; these depend on allowances for 'dead load' deflections, on the actual distribution of the loads, on the actual behaviour of the structure and on the accuracy to which the structure can be built.

The designer specifies the required profile of the bridge (longitudinally and transversely) on completion (see further comment below on required final profile). He chooses the structural configuration of the bridge and analyses its behaviour for an assumed construction sequence and in service. He is therefore well placed to be able to give the constructor information about the expected behaviour. (The CDM Regulations (Ref 1) can be interpreted as requiring him to do so, although this has not been tested in the courts.)

Construction of a steel (non-composite) bridge involves only one major structural element, the steelwork. The behaviour of the steelwork under load, even for a statically indeterminate structure, is predictable to a reasonable degree of accuracy, the main uncertainties being relaxation due to relief of residual stresses (sometimes called shake-out) and in the alignment or fit-up of connections.

Construction of a composite bridge involves two major structural elements, the steelwork and the reinforced concrete deck. As before, the behaviour of the bare steelwork is reasonably predictable, but the behaviour of the composite structure is less predictable on several counts. The first is that all the concrete cannot be placed in an instant, and the stiffness that is gradually acquired by the first-placed concrete modifies the structural behaviour as later concrete is placed. Also, concrete in tension does exhibit some stiffening effect, and the usual allowances for cracked regions can only be approximate. Further, the stiffness of the concrete varies with age and strength and cannot be predetermined with the same reliability as that for steel.

For a composite bridge, the fabricator manufactures the steel girders, the erector lifts and connects the steelwork together, the concreting contractor places the concrete, and another contractor places the surfacing or ballast. When should the profile of the bridge be checked, to which theoretical profile, and whose 'fault' is it when the profile is not exactly as intended (i.e. within tolerance)?

Provision of deflection allowances

The designer should provide the contactor with information about the difference between the profile of the prefabricated elements (when not subjected to any applied loads including self weight) and the intended final profile once the structure has been completed. These differences are the calculated vertical deflections for the assumed method of construction, for the presumed behaviour of the structure.

These allowances for permanent deformation are usually shown on the steelwork general arrangement drawing in a diagrammatic form.

This information is sometimes called 'camber' or 'camber allowance' or 'pre-camber', but see comment below on terminology.

In addition, for a composite bridge the designer should provide calculated differences from the unloaded profiles of the elements for the stage when all the steelwork has been erected (the 'bare steel' condition). This set of differences will allow the fabricated and erected profiles of the steelwork to be checked (and agreed as acceptable) both on despatch from the workshop and after erection, before the concrete is added. *Once the concrete has been added there is usually very little that can be done to correct any errors in the profile of the steelwork.*

Accuracy of allowances for deflection

How should the designer estimate the deflection during construction and what should be done about any deviation from the intended profile at the end of construction?

The deflection of bare steelwork under load is predictable, but it is important to remember that when there is any degree of indeterminacy (even if only due to secondary bracing or secondary bending effects in nominally 'pinned' connections) the deflections will depend on the actual construction sequence.

In a composite bridge, the designer generally assumes that each stage of placing concrete is instantaneous, and calculates deflection due to dead and superimposed loads using the long-term modulus of the concrete. This usually results in an overestimate of the deflection that will have occurred at the end of construction. Since the greatest deflections occur in mid-span regions, the as-built profile will be higher (in relation to the intended profile) at midspan than at the supports.

If considered necessary to 'correct' for any error in as-built profile, regulation (over-thick surfacing or additional bottom ballast) could be applied over the supports, with little consequences on moments or shears or indeed on reactions and foundation loadings. But if the as-built profile is low, adding regulation in midspan may not be structurally acceptable because of the significantly increased moments at the supports.

Allowances made by the fabricator

Fabrication allowances are made by the fabricator appropriate to the welding and cutting processes to be used and the sequence of fabrication. These are the only allowances that are within the control of the fabricator.

Shrinkage during welding is the main source of permanent deformation during fabrication, but any treatment involving heat (such as cutting) can lead to deformations. Residual stresses, either due to rolling or to earlier stages of fabrication, may be relieved by heat; the fabricator will make allowances for these effects.

Rectification of errors in fabrication

Steel is not totally predictable in its behaviour when heated, as this releases locked-in stresses that are due to the manufacturing process. Some differences between expected and actual fabricated shape have to be tolerated, but these should be small.

Any significant errors in the shape or size of components that arise during fabrication can be corrected before erection, provided that they can be identified (see GN 5.07). The additional information about deflection of steelwork (of a composite bridge) in the 'bare steel' condition referred to above will allow a useful check either during trial assembly (if specified in accordance with EN 1090-2 clause 6.10) or after erection of the (bare) steelwork.

The girder profiles of individual girders can be directly compared with the pre-cambered profile defined by the designer [refer GN 7.04].

To check the deflection of the assembled bare steel, the girders would need to be assembled with the web vertical and with temporary splice connections, to allow the intermediate supports to be de-propped after assembly. This is rarely done, unless specifically requested by the designer, because of the workshop space and time involved.

Rectification of errors in profile

Contractually, the achievement of the required final profile is the responsibility of the Main Contractor. However, the designer has had some input to the result (allowances for dead load deflections, based on an assumed construction sequence). Any failure of the structure to respond exactly as predicted, particularly for a composite bridge, cannot be held to be the 'fault' of the fabricator, nor is it likely to be that of the contractor placing the concrete (provided that the sequence assumed by the designer is followed and all the concrete in any stage is placed within a reasonable period). The designer and contractor need to cooperate in reaching solutions to deviations that appear during the course of construction.

The responsibility for providing any necessary regulation can be placed on the contractor, who can make allowances (in his tender) for the amount of regulation likely to be needed, on the basis of his experience and of the deflections predicted by the designer. The consequences on programme should then be allowed for by the contractor but, if considered necessary, an additional clause could be added to the item coverage in the BoQ Preambles.

Effects of camber on bearing slopes and positions

Translation due to camber fall-out

Drawing offices rarely set out along the neutral axis of the girder, instead setting out along the bottom flange. Defection due to camber fall-out introduces bearing translation when the neutral axis is a significant distance above the bearing slide plane.

In some extreme cases, simply supported, deep single span girders will require either longitudinal adjustment to the bearing position or an increase in the design movement range for the bearings to compensate for the longitudinal translation caused by girder end rotations.

End Rotation due to camber fall-out

The fabricator’s drawing office will adjust the slope of all bearing plates to anticipate the rotation about the axis of the end supports caused by camber fall-out, based upon all of the camber falling out.

The term “residual camber” is sometimes used to describe a contingency provided in addition to the self-weight deflection to compensate for live load effects or to provide a hogging profile. Where such a residual camber is provided, it should be stated clearly on the contract drawings, to avoid overestimating the bearing rotation.

Tolerances

It is difficult to apply any tolerances to the confirmation of the correct profile of the steelwork once concrete and surfacing or ballast has been placed. Hence, there is a need for the designer to provide deflection information for the steelwork alone, to facilitate checks and agreement that is complied with at the trial erection stage or at the bare steel after erection stage. EN 1090 clause 9.6.4 deals with trial erection and, while it only suggests consideration of trial erection for reasons other than proving the as-built profile, reference should be made to Annex D.2.15 *Functional erection tolerances – Bridges – Bridge elevation or plan profile,* for the permitted deviation from the nominal profile.

Terminology

As explained above, the vertical shaping of steel bridge girders depends on three components:

(1) The specified ‘required final profile’ of the finished bridge, usually following a vertical curve longitudinally (see comment below).
(2) Allowances to counteract deflections of the structure under the dead loads of the steelwork, deck concrete, surfacing or ballast, and finishes.
(3) Allowances to counteract fabrication effects.

These components are shown schematically in Figure 1.

The terms “camber” and “pre-camber” are often used in relation to the profile of a girder, but they are not always used in the same sense, nor do all parties necessarily agree which of the above three components should be included in them.

Most references to “camber”, are made in the sense of an allowance above a clearance gauge or to avoid unsatisfactory appearance, i.e. functionality. It does not necessarily imply a simple vertical curve profile (which may in any case be provided for other reasons) nor just an allowance for dead load deflections. The use of “camber” in this sense is best avoided.

Camber (or pre-camber) is often implied by designers to mean their calculated allowances for deflection (2 above), but sometimes the designer means the deflections plus the offset from a straight line between supports (i.e. 1+2 above). Fabricators usually consider camber as the sum of the two allowances (i.e. 2+3 above).

EN 1090-2 Annex D, Table D.2.15 No.2, covers bridge elevation or plan profile but seems to mean curvature generally: it does not specifically identify any one (or combination) of the above items, nor does it make it clear at what stage the checking is performed.

The reference points and locations for erection tolerances are specified in accordance with EN 1090-2 clauses 12.7.3.3 and 12.7.3.4. Client requirements such as SHW1800 and

project-specific supplements provide clauses for further definition of location and frequency of measurements (Ref 3).
However the dimensional information is presented, and however it is referred to, it should be made clear exactly what is meant and which of the three components is included in the values. The word “camber” may be used on drawings and in documents, but it should be used with care and with a clear definition of what it means

Required final profile
(Although the specification of profile is not the subject of this Note, the following comments may be helpful.)

The required profile of the carriageway surface of a road bridge is normally a positive (upward) vertical curve. This profile is to be achieved under the effects of (Serviceability Limit State) dead and superimposed dead loads, without any live load. If the road surface requires no vertical curvature and is level, there may nevertheless be a requirement for a small upward curvature of the structure to ensure that a clearance gauge is maintained under SLS loads, or that the bridge does not appear to sag under the effects of live load

The required profile of a rail track is normally straight in elevation (or at least with only a very large curvature). Rail authorities normally specify that a rail bridge should not appear to sag under the effects of (SLS) dead plus live loads and they therefore also specify a positive vertical curvature as the required final profile over the length of the bridge.

For further comment about the specification of vertical curve profiles in skew bridges, see GN 1.02.

References

1. Managing health and safety in construction, CDM Regulations 2007, Approved Code of Practice. HSE Books 2007.
2. EN 1090-2: 2008+A1:2001, Execution of steel structures and aluminium structures. Technical requirements for steel structures.
3. Manual of Contract Documents for Highway Works, Volume 1, Specification for Highway Works, Series 1800, TSO, 2014.

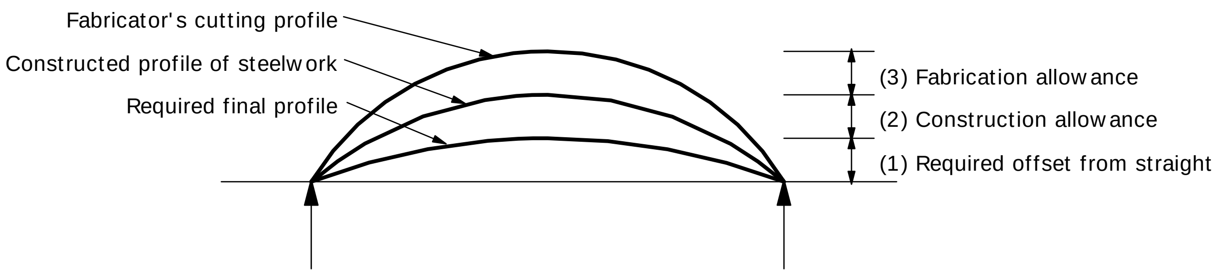

Figure 1 *Schematic illustration of shaping of steel girders*

Notes:
1 The required final profile is usually determined by the highway or railway engineer; this may or may not be a vertical curve.
2 The construction allowance is calculated by the designer to allow for self-weight deflection, prestress, shrinkage of concrete, etc. For a simple span this allowance will be an upward curvature, as illustrated.
3 The fabrication allowance is determined by the fabricator to allow for shape changes due to thermal cutting and welding, and due to shake-out of residual stresses during fabrication, transport and erection. It may be in either direction, upward or downward, depending on the fabrication details; an upward allowance is illustrated, for simplicity.

