

Guidance Note 4.03

Allowing for permanent deformations

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). They choose the structural configuration of the bridge and analyse its behaviour for an assumed construction sequence and in service. They are therefore well placed to be able to give the constructor information about the expected behaviour. (The CDM Regulations [1] can be interpreted as requiring the designer to provide this information, 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. Furthermore, 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 (usually the fabricator) lifts and connects the steelwork together, the concreting contractor places the concrete, and another contractor places the surfacing or ballast. At which stage the profile of the bridge should be checked is often a point for debate. In practice, the profile should be checked between each stage. The steel fabricator can only really be judged on whether the profile of the steelwork is within tolerance before any of the subsequent loads are applied.

Provision of deflection allowances

The designer should provide the contractor 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.

Therefore, 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.*

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

This information is generally referred to as 'camber', 'camber allowance' or 'pre-camber'. See section below on terminology.

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 midspan regions, the as-built profile could be higher (in relation to the intended profile) at midspan compared to the supports.

If considered necessary and with the agreement of the designer, to 'correct' for any error in as-built profile, regulation (over-thick surfacing or additional bottom ballast) could be applied over the supports, with minimal impact on moments or shears or indeed on reactions and foundation loadings. However, if the as-built profile is low, adding regulation in midspan may have an adverse effect on the structural integrity of the structure and may not be acceptable.

Allowances made by the fabricator

Fabrication allowances are added by the fabricator, appropriate to the welding and cutting processes 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 need to make allowances for these effects.

Rectification of errors in fabrication

Steel is not totally predictable in its behaviour. Locked-in stresses can be generated during the manufacturing process, which can then be released by controlled heating in specific areas. However, some differences between the expected and actual fabricated shape have to be accepted. See section on tolerances below.

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 BS 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 before delivery to site, 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. Due to the space and time required to do this, it is rarely done, unless specifically requested by the designer. Instead, the fabricator should carry out dimensional checks of individual components to ensure fit up and confirm the profile in the weightless (pre-camber) condition.

Rectification of errors in profile

Contractually, the achievement of the required final profile is the responsibility of the Main Contractor. However, the designer influences the final profile

through 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.

Effects of camber at bearing 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. Deflection 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 (and verticality of bearing stiffeners) 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 it is within tolerance during fabrication and at the bare steel after erection stage. After fabrication and prior to delivery to site, the fabricator will carry out as built survey checks of the steelwork against the fabrication drawings. This will include key dimensional checks of the individual girders and assemblies to be delivered to site, e.g. if the girders are to be delivered as braced pairs. The survey data, pre-delivery and after steelwork installation should be reviewed to confirm that it is within the tolerances specified within the contract specification and with reference to BS EN 1090-2 [2], Annex B.2 Manufacturing tolerances and Annex B.2 Erection tolerances. Generally, the tolerances will be as per the SBG guidance on completing Appendix 18/1 (SCI P451) [4].

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 all three allowances (i.e. 1+2+3 above).

The reference points and locations for erection tolerances are specified in accordance with BS 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 [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] Construction (Design and Management) Regulations 2015. Approved Code of Practice
- [2] BS EN 1090-2:2018+A1:2024, Execution of steel structures and aluminium structures. Part 2: Technical requirements for steel structures.
- [3] Manual of Contract Documents for Highway Works, Volume 1, Specification for Highway Works, Series 1800, April 2021.
- [4] Steel Bridge Group: Completion of Appendix 18/1 - For use with bridge steelwork specified to BS EN 1090-2:2018 (P451), SCI, 2025.

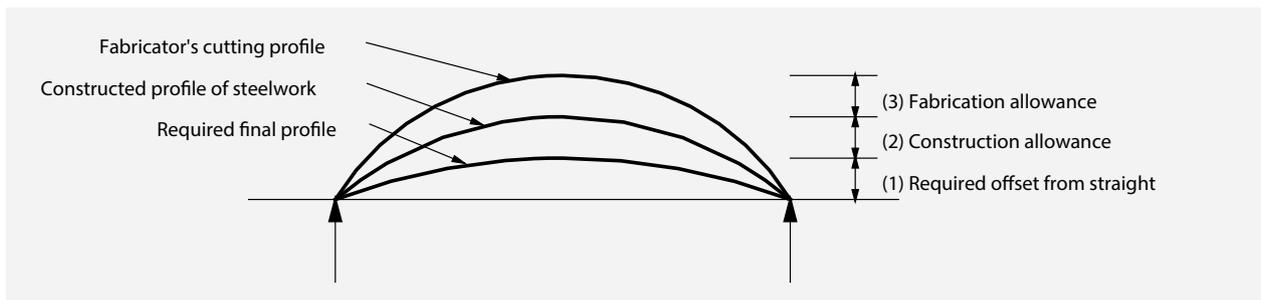


Figure 1 Schematic illustration of shaping of steel girders

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.