Guidance Note 5.03

# Geometrical tolerances

## Scope

This Guidance Note presents a brief consideration of what can be expected in terms of the accuracy of a structure's fully assembled length, width and vertical profile. Reference is made to BS EN 1090-2 [1] and to the special tolerances that were given in the Model Project Specification (MPS) [2]. Many of the special tolerances in the MPS are not included in the SHW 1800 [3] but can be included in the project-specific Appendix 18/1; these tolerances are included in the recommendations below.

## Execution Standard

BS EN 1090-2, Clause 11 defines three types of permitted geometrical deviations (tolerances):

- Essential tolerances, which relate to criteria that are necessary for mechanical resistance and stability, and which are used to support CE marking of components to BS EN 1090-1 [4];
- Functional tolerances, which relate to other criteria such as fit-up and appearance;
- Special tolerances, which may be specified for project-specific reasons and which need to be clearly defined in the execution specification.

The requirements relate to final acceptance testing and thus cover tolerances for both fabrication and erection.

At a cost, and given the time, very high levels of dimensional accuracy are possible, but the main issue is what can be justified for the particular structure.

## Types of dimensional imperfection

As with all manufactured items, fabricated components contain both random and systematic dimensional errors.

On larger structures, where many girders may be joined end-to-end, there will be a general tendency for the random errors to be self compensating: the statistical probability of all such errors accumulating in one sense will be very small. Systematic errors on the other hand, will generally accumulate.

The relationship between the magnitudes of random and systematic errors varies among fabricators, depending on their methods and their equipment, and will also vary with structural form.

In bridge construction, length is one of the most important dimensions that needs to be controlled. The overall dimensions of smaller structures, with few fabricated components in their length, will be influenced by both random and systematic errors; longer structures, with many components, will be influenced mainly by systematic errors.

Generally it can be expected that the ratio of total error to total dimension can be expected to be better on larger structures where there are more components and the random elements have a chance to cancel one another out, than on smaller structures with fewer elements where there is less chance of the random errors self compensating.

## Plan Position at Bearings

The accuracy with which the steelwork can be positioned on the substructure is affected by the build-up of fabrication and erection deviations. Figure 1 shows typical longitudinal and transverse deviations in plan position at reference temperature between the various components, together with a brief commentary.

When considering the tolerance on movement capacity of a sliding bearing, an allowance of +/- (20 mm + $L_s$/10000) should be made for the sum of random deviations in steelwork length and positioning the bearing bottom plates. See guidance in P406 [5].

## Adjustment of errors in length

The accumulation of small systematic errors in the fabricated length of girders can sometimes make it necessary to adjust the length of the steelwork in order to meet the tolerances on plan position at the bearings.

On long-span bridges, adjustment may be achieved by match marking and trimming joints in rolling assemblies at ground level, taking account of as-built surveys of the substructure. This approach is slow and expensive, but is essential for long structures (over about 250 m).

In viaduct work, adjustment points are normally pre-planned, and the main girder joints at those positions are not completed until dimensions are available from site indicating how the structure is matching the local bearing locations.

Such adjustments are assessed in relation to the substructure grid lines, which are themselves subject to tolerance, rather than being absolute overall dimensions. Given a good standard of fabrication and substructure set-out, such adjustment points would typically be at 150 m intervals.

Between adjustment points, errors accumulate. The amount of error that can be safely accommodated at each support position should consider the following:

- The allowable eccentricity in the support, which is a matter of design.
- The available spare movement capacity in sliding bearings, which is a matter of bearing selection and design.
- Any implications regarding expansion joint movements.
- The flexing of tall slender piers when fixed bearings are used

The selection of adjustment points in long structures should therefore be a matter of discussion and agreement between the designer, the main contractor and the fabricator, and should take place as early as possible in the project.

The assessment of misalignment at each support as construction proceeds needs careful observations, and should take into account average steel temperature together with any rotations and translations that will occur due to the action of self weight. The problems in assessing temperature effects are discussed in GN 7.02.

As bearing locations may have to be adjusted, it is recommended that only fixed bearings be fully grouted prior to erection. Pockets for bearing fixing dowels should be detailed to allow such adjustment of bearing base plates. Temporary bearing packing systems should be planned carefully in terms of capacity and disposition in order to safely support the steel self weight in all erection conditions

## Structure width

Errors in width will tend to be higher, relatively, than those in length. This is because there is usually a high number of joints (per unit width) and any dimensional errors tend to be dominated by systematic effects.

Bridges skewed in plan will tend to have greater relative error in width than those that are square in plan.

A general tolerance of width/1000 should be achievable. A tolerance of ±10 mm on spacing of top flanges is practical where permanent formwork is to be used and can generally be controlled by providing bracing and tolerance ties between adjacent girders.

## Vertical profile of steelwork

The weld shrinkages at the top and bottom flanges of bridge girders are often different, because of differences in weld size and flange cross section, and due to the sequence of welding. Such differentials give rise to a vertical curvature in the girder, and this may well be in the opposite direction to that of the vertical profile and the allowance for deformation due to permanent actions.

Fabricators use empirical rules to adjust the shape of the web to allow for such effects as shrinkage. This is not a precise science, and the control of the profile, particularly on slender girders, is a matter that requires experienced judgement by the fabricator.

To complicate the issue further, all 'as welded' fabrications have locations adjacent to welds where residual stresses are at or about the yield point for the material (the forces are in equilibrium with other internal forces). Externally applied vibrations or loads can give rise to stress relief at these locations, and to a resultant overall change in shape of the fabrication as the equilibrium in internal forces changes. This effect is not significant in the majority of bridge girders, but can be an issue in structures where the span to depth ratio is around 30 or more. Girders of such proportions have been known to alter in their profile during transportation.

For the above reasons, relative errors in profile tend to be greater in shorter spans. In longer spans, the girders tend to be inherently less slender, but also, since more individual girder pieces tend to make up the span and provide an opportunity for vertical rotational adjustment at each joint, considerably lower relative errors can be achieved in the overall profile of the span.

A tolerance of ± span/1000 (on midspan level, relative to the level at the supports, reducing proportionately as the distance to the support reduces) can be achieved; a tolerance of 35 mm can be achieved on spans exceeding 35 m. The designer can specify lesser values in situations which require tighter tolerances. Designers should, however, recognise what can be readily achieved by the fabricator/erector and not specify tighter tolerance except where strictly necessary.

In specifying the required tolerance for any particular project, the designer should consider carefully what the effects that deviations up to that tolerance value would have on vertical profile, drainage, self weight, surfacing thickness, etc.

Note, however, that the above discussion about tolerance on level relates to the bridge as a whole, not to each individual girder separately. Where there would be a lack of planarity at top flange level of a composite bridge, the need to maintain a minimum structural thickness of the slab will usually mean that the slab will be cast with its nominal depth over the highest girder, and with a greater depth over the lower girders. A tolerance of 20 mm on the level of one main girder relative to another, adjacent, main girder is appropriate for a slab of about 250 mm thickness. If any greater tolerance were to be accepted, the design should be checked for the consequent increase in self weight due to the thicker slab.

## Profile of road surface

The profile of the finished road surface of a highway bridge depends on three elements:

- the profile of the steelwork
- any variation in the thickness (and weight) of the deck slab
- any variation in thickness of the roadway surfacing.

There may be some scope for adjustment of steelwork during its construction if it is expected that the deviation from the required geometry will be too great. If the steelwork is not adjusted, the profile can be modified by ‘regulation’ of the deck slab and/or the surface thicknesses. In these cases the thickness is varied (usually increased at ‘low spots’) so that a better finished profile is achieved. However, additional thickness means additional self weight and this will increase design moments and forces. Additional thickness and self weight in midspan regions has a much greater influence on moments than does an increase local to the supports. It may therefore be prudent to ‘over-camber’ the steelwork in some cases to guard against variations (from the intended profile) on the low side. Such addition would be made to the specified ‘allowance for permanent deformation’ (see GN 4.03). If such a strategy is adopted, it should be made clear to all parties.

In railway bridges, deviations between intended and actual profile of the structure will be accommodated by variations in ballast thickness but, again, the consequences on effects due to self weight and on the level of the track need to be considered.

## Verticality of girders at supports

There is no tolerance given in BS EN 1090-2 for the verticality of stiffened webs at supports but verticality must be controlled in order to limit transverse rotation of the bearings and secondary effects.

The verticality of girders at supports is usually set by bracing or cross head systems connected with preloaded bolts. Given a good standard of fabrication there is usually sufficient clearance in the bolt holes to allow the appropriate degree of adjustment to achieve a tolerance of Depth/300 without resorting to reaming.

It is emphasised that this check applies to the web itself, and should not be translated to, or derived from, the horizontality or otherwise of the flange plates or bearings.

If this tolerance is not achieved and subsequent adjustment of the bracing system is not readily achievable, a check will be necessary to establish whether the bracing system is capable of sustaining the resulting additional horizontal forces. This situation may well be experienced at the abutments of skewed composite bridges. See comment on girder twist in GN 1.02.

## Functional tolerances

As noted above, functional tolerances relate to criteria such as fit-up and appearance, not to the limits needed to ensure mechanical resistance.

Consequently, the functional tolerances are not included in the acceptance criteria (to achieve conformance with the Standard) specified in clause 12.3 of BS EN 1090-2.

Two classes of functional tolerance are given in BS EN 1090-2. Class 1, which is the less onerous tolerance, is the default for routine work. Tolerance class 2 will require special and more expensive measures in fabrication and erection.

### Attachment of other prefabricated elements

It is necessary to give consideration to the accuracy of location of fittings required to support or avoid other prefabricated elements, including non-structural items such as parapets and fascia panels.

The BS EN 1090-2 class 1 functional tolerance for the location of web stiffeners is ± 5 mm, which is related to their required location shown as a simple dimension on the design and/or fabrication drawings. Whilst this degree of accuracy is reasonably easy to achieve within a single fabricated element, the consequences of accumulated errors over the joints in a series of consecutive elements should be taken into account in the detailing of the fixings themselves, and these should be provided with some adjustment facility.

If structural stiffeners are intended to serve a dual purpose (i.e. for attachment of fittings as well as for structural purposes), this should be clearly specified, so that any implications on tolerance can be identified.

## Recommended special tolerances

### Essential Tolerances

The final profile of the steelwork depends on work not covered by the specification for the steelwork. Nevertheless, the constructor is responsible for the lines and levels in the completed condition.

The following tolerances on steelwork dimensions and levels at completion are as recommended in P451 [2]:

The maximum allowable deviations on steelwork dimensions and levels at completion are as follows:

i. On level, relative to that specified:
   - at the supports: 5 mm;
   - at midspan: span/1000, up to a maximum of 35 mm.

ii. On level, of one main girder relative to another, adjacent, main girder: 20 mm.

iii. On plan position of steelwork at movement bearings (structure at reference temperature):
   - Length of steelwork measured from the reference point at the fixed bearing top plate to the movement bearing top plate:
     - ± (10 mm + $L_s$/10000)
   - Longitudinal position of movement bearing top plate relative to bottom plate:
     - ± (20 mm + $L_s$/10000)
   - Longitudinal position of movement bearing bottom plate relative to its specified setting-out position:
     - ± 5 mm
   - Longitudinal position of the fixed bearing relative to its specified setting-out position:
     - ± 5 mm
   - Transverse position of bearing top and bottom plates relative to the specified centreline of bearing: ± 15 mm

   where $L_s$ is the specified distance from the fixed bearing top plate to the movement bearing top plate.

iv. On spacing of top flanges where permanent formwork is to be used: ± 10 mm.

If the steelwork is not within tolerance, it should be reported to the designer of the permanent works and be adjusted, if necessary, to maintain the structural adequacy in accordance with the design rules.

If the level of the bridge soffit at midspan is close to a clearance gauge, the specified profile should include an allowance for adverse variation that is at least the construction tolerance allowed under this clause. In some cases, it might be preferable to specify tolerance on level at positions other than midspan.

It is essential to ensure that the bearing location relative to the steelwork matches the location as designed, and that the bearing is located on the support within the design requirements for it. Adjustability should be provided wherever possible between the three elements.

The tolerance in verticality of main girders applies to the completed (usually composite) structure. Measures may need to be taken to ensure that adequate conformity is maintained throughout the construction. See GN 7.03 and AD318 (available on www.steelbiz.com) [6].

### Functional Tolerances

The tabulated values in B.2 should apply and the tolerance class should be class 1. Where there are particular requirements, such as the achievement of a visually good alignment of fascias, these should be specified.

It may be noted that SHW 1811.3.2 applies BS EN 1090 functional class 1 except where class 2 shall be adopted:

- Table B.1, No 1 to No 6 at bearing and bearing stiffener locations; and
- Table B.6, No 3 and No 4.

However, as noted in this GN, functional tolerances do not form part of the acceptance criteria in BS EN 1090-2.

## References

[1] BS EN 1090-2:2018+A1:2024, Execution of steel structures and aluminium structures. Part 2: Technical requirements for steel structures.

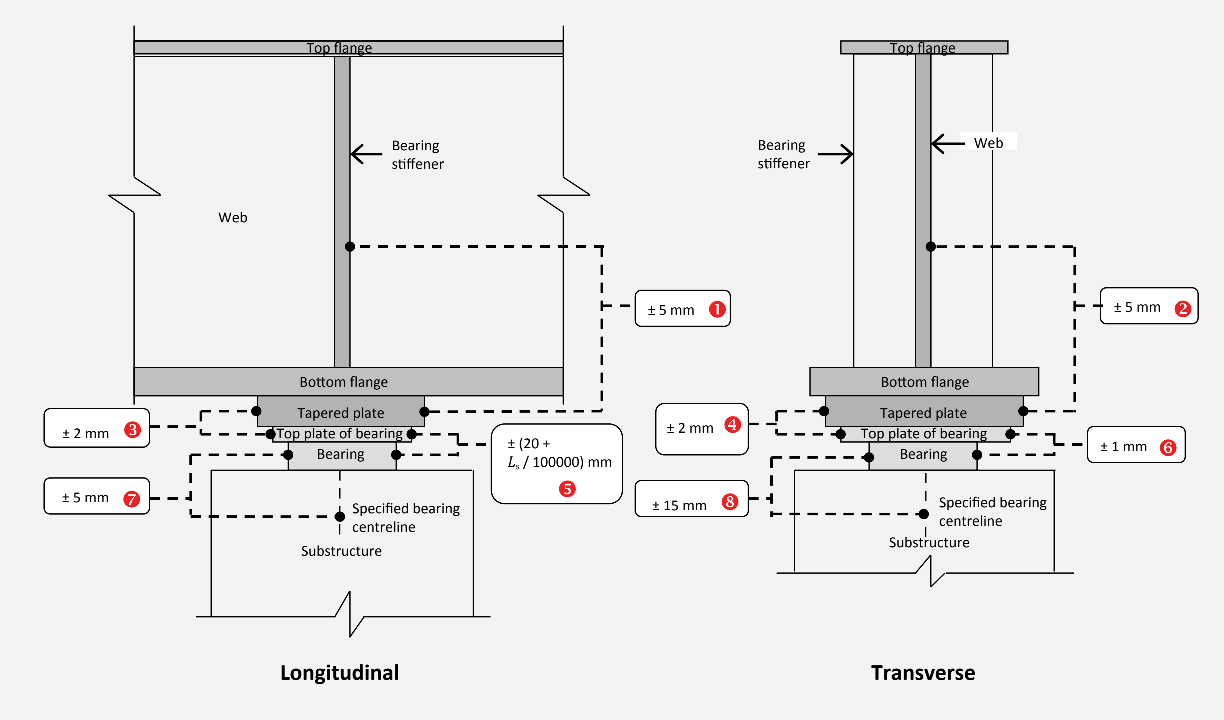
[2] Steel Bridge Group: Completion of Appendix 18/1 – For use with bridge steelwork specified to BS EN 1090-2:2018 (P451), SCI, 2020.

[3] Manual of Contract Documents for Highway Works, Volume 1, Specification for Highway Works, Series 1800, 2021

[4] BS EN 1090-1:2009+A1:2011, Execution of steel structures and aluminium structures. Part 1: Requirements for conformity assessment of structural components.

[5] Determining design displacements for bridge movement bearings (P406), SCI, 2015

[6] NSC Advisory Desk Technical Note AD318: Tolerances on plan position of steelwork in bridges, 2008




| Interface | | Commentary |
|---|---|---|
| Ref | Deviation | |
| 1 | Offset of bearing stiffener relative to tapered plate | Stiffeners and tapered plate are set out by hand, or installed to machine-generated powder-marks on theoretical bearing centreline. |
| 2 | Offset of web relative to tapered plate | The web is located manually or by T&I machine, and the centre of the tapered plate is set manually; both are set to the measured centreline of the flange. |
| 3 & 4 | Offset of fixing holes in tapered plate and bearing top plate | Both sets of holes are drilled using CNC machines. |
| 5 | Offset of top plate of bearing relative to bottom plate | This is caused by cumulative small systematic variations in girder lengths and splice gaps and deviations in the positions of the lower bearings at the fixed and movement bearings. It should be allowed for in the design translations for the bearings. |
| 6 | Slack in bearing | Top and bottom plates are held in position by transit cleats until the steelwork is erected, or by the guides. |
| 7 | Position of bearing on substructure | This is accommodated by clearance in the dowel pockets. |
| 8 | Position of bearing on substructure | This is due to offset of overall location and variations in width between girders arising from variations in positions of holes in bracing members and stiffeners, widths of stiffeners, gaps in welded joints, clearance in bolt holes, and offsets of webs and tapered plates. |

Figure 1 Geometrical deviations (based on information given in AD 318 [6])