DETERMINING DESIGN DISPLACEMENTS FOR BRIDGE MOVEMENT BEARINGS

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FOREWORD

This guide was prepared in response to the identification by the Steel Bridge Group of the need for guidance on the determination of design values of displacements for bridge movement bearings, for use in specifying the requirements for bearings designed and manufactured in accordance with EN 1337.

Bridges are usually constrained against horizontal displacement by providing a ‘fixed bearing’ at one support (which can resist horizontal forces) and movement bearings that permit linear displacement of the upper parts of the other bearings relative to their lower parts. The displacements occur principally due to thermal expansion and contraction. The guidance covers only the determination of linear displacements (in the direction of the span) from temperature effects; rotational displacements are not discussed, although the principles discussed can be applied to their determination. Allowance for uncertainty in bearing positions is discussed.

The guidance was prepared by David Iles (SCI), with input from members of the Steel Bridge Group, in particular John Lane, David Dickson, James Parsons and Ian Palmer. Valuable comment was also received from Brian Smith (Flint and Neill). SCI is grateful to BCSA and Tata Steel for financial support during the preparation of the guidance.

CONTENTS

SUMMARY

This document provides an overview of the determination of design values of displacement at movement bearings, for use in the preparation of a bearing schedule. The guide notes that the most significant displacements occur due to temperature variation but that there also has to be some allowance for the uncertainty of the relative position of the upper and lower parts of the bearing, as a result of the construction process.

Requirements in EN 1991-1-5 and EN 1993-2 are examined and it is found that there is some inconsistency and lack of clarity in the requirements. Guidance is offered that is intended to recognise the intent of the Eurocode rules and clarify how the designer can determine suitable design values for temperature displacement and allowance for uncertainty in setting of bearings.

The document provides guidance that is applicable to short and medium span bridges, where it is often expedient to make simple if slightly conservative provisions, and sets out principles for consideration in more complex projects.

INTRODUCTION

Bridges are normally designed in accordance with the relevant Parts of the Eurocodes, notably EN 1990 [1], EN 1991 [2] and, for steel elements, EN 1993 [3]. Composite bridges are additionally designed in accordance with EN 1994-2 [4] and EN 1992-2 [5]. These standards† provide the rules for determining design values of the effects of actions on the bridge for all parts of the structure, and for verifying the resistance and serviceability of the structure. Bridges are usually supported on structural bearings that are to be designed and manufactured in accordance with EN 1337 [6]. Typically, bridges are constrained against horizontal displacement by providing a 'fixed bearing' at one support and 'movement bearings' (which permit linear displacement of the upper parts of the bearings relative to their lower parts) at the other supports. For the design of the bearings, the design values of forces and displacements of the structure at the supports must be used as design values of actions on the bearings.

Guidance on the choice of bridge 'articulation' (the arrangement of fixed and movement bearings) is given in Guidance Note 1.04 and on the types of bearing in Guidance Note 3.03, both part of SCI publication P185 [7].

Unfortunately, the current versions of relevant parts of the Eurocodes are insufficiently clear and are inconsistent in providing rules to determine these design actions on the bearings. It is understood that revisions will be made to the Eurocodes to improve clarity, notably by withdrawing the informative Annex A from EN 1993-2 and introducing general requirements into EN 1990. To provide guidance until those revisions have been made, this document discusses the various requirements of the present Eurocode parts and offers an interpretation that complies with the intent of the Eurocodes.

† Generally, this document refers to the CEN versions of the European Standards, since much of the discussion is not specific to national requirements. Where UK requirements are discussed, such as those in a UK National Annex, the full BS EN reference is given.

BRIDGE GEOMETRY

The geometry of the bridge defined on the drawings can only be valid for a specific temperature; at other temperatures, the lengths of the elements will be different, because of expansion and contraction. That specific temperature is designated the 'reference temperature', as in EN 1993-2, A.4.2 (similar to the 'datum temperature' in some older specifications).

The temperature at which the bearings are 'set' (see discussion in Section 4) is not necessarily this reference temperature. Further, the 'initial bridge temperature … at the time the structural element is restrained' is not clearly defined (see further comment about that definition in Section 3.2.1) and in practice its value is also not likely to be this reference temperature.

A reference temperature should be defined in the contract specification; if it is not, the constructor will have to seek additional information, in order to build the structure.

The usual intent in defining the attachment positions of the upper and lower parts of a movement bearing to the superstructure and substructure is that the two parts will have a known relative position at the defined reference temperature. Expansion and contraction of the superstructure will displace the upper part of the bearing relative to the lower part from this initial position; the movement ranges can be calculated by the designer using the maximum contraction and expansion values of the uniform temperature component.

However, there are inevitable uncertainties in the length of the superstructure from the fixed bearing to the upper part of the movement bearing and in the distance to the support on the substructure of the lower part of the movement bearing, as a result of the construction processes. A discrepancy between the two lengths results in the upper part not being located correctly relative to the lower part at the reference temperature. The potential discrepancy (effectively an imperfection) needs to be allowed for in the bearing design by increasing the movement range that the bearing can accommodate (see Figure 2.1). Alternatively, the potential discrepancy can be reduced during construction by adjusting the positions of attachment of the upper and/or lower parts, as discussed in Section 4.

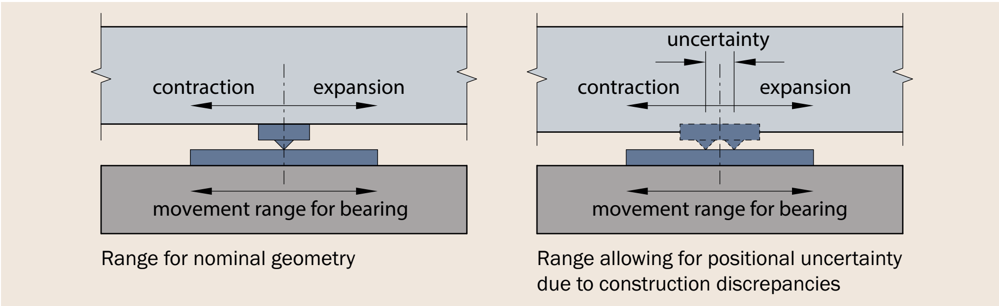

Figure 2.1 Diagrammatic representation of movement range required for bearing

ACTIONS ON BEARINGS

As noted in Section 1, the design values of the actions on the bearings are the design values of forces and displacements of the structure at the supports. The bridge designer must therefore provide a schedule of these design values for the bearing designer. The schedule can only give the values for the combined actions for relevant design situations, since the bearing designer cannot be expected to know which of the separate actions are combined for critical cases or which partial factors and combination factors should be applied to those separate actions.

3.1 Limit states and combinations of actions

EN 1990 defines two classes of limit state – ultimate limit state (ULS) and serviceability limit state (SLS). Design values of effects (internal forces, deflections etc.) due to combinations of actions (forces and imposed displacements) are defined for design situations at both ULS and SLS. For the design of the structure, ULS requirements usually prevail for steel structures and the effects at SLS are rarely evaluated. However, for the design of bearings, loads and movements at the bearings at SLS are often key considerations and therefore both ULS and SLS values should be specified for the supply of the bearings[†].

For maximum displacements at movement bearings, the combination of actions with temperature change as the leading action is normally appropriate. At ULS, the fundamental combination of actions for persistent and transient design situations (as defined in EN 1990, 6.4.3.2) should be considered (the bearings must be able to support the structure under this combination); at SLS the characteristic combination should be considered (the combination normally used for irreversible limit states, as noted in EN 1990, 6.5.3(2)), to avoid damage to the bearings.

It is worth noting that actions on the structure are normally defined as characteristic values and that partial factors (γ_G and γ_Q) are applied in the design combinations to cover uncertainty in the values of the actions and in calculating their effects. However, EN 1991-1-5 (Note 2 to 6.1.3.3) and EN 1993-2 (A.4.2.1) both require an increase in

† It is of interest to note the definitions in the former standard, BS 5400-9.1:
'*Serviceability limit state*: The design should be such that bearings will not suffer damage that would affect their correct functioning, or incur excessive maintenance costs during their intended life.'
'*Ultimate limit state*: The strength and stability of bearings should be adequate to withstand the ultimate design loads and movements of the structure.'

the value of thermal action to allow for uncertainty in the positioning of the bearing. As noted in Section 2, an allowance for such uncertainty seems a wise precaution but it is NOT a thermal action, it depends on construction procedures. Any allowance should be consistent with tolerances in the specification and appropriate characteristic and design values will be needed. See further discussion in Section 4.

3.2 Temperature changes

3.2.1 Values given by EN 1991-1-5

Characteristic values of temperature changes in bridges are defined in Section 6 of EN 1991-1-5. The rules define maximum and minimum uniform bridge temperature according to data in its relevant National Annex (NA). They also define “temperature difference”, generally the difference in a vertical direction (6.1.4.3 says that horizontal components only need to be considered in particular cases). Although a uniform component of temperature change and a temperature difference (gradient) should generally be considered simultaneously (EN 1991-1-5, 6.1.5) and the UK NA [8] recommends application of the full values of both (NA.2.12), the effects of temperature difference result mainly in rotations in the plane of the webs and are only significant at end supports in very deep girders, with bearings well below the neutral axis. Note that the application of the full values of both does increase the movement ranges slightly, since the temperature difference profiles given in 6.1.4 include a small uniform component.

To obtain design values of displacements and forces, the values of γ_Q at ULS and SLS should be applied for each design situation.

The characteristic values of maximum and minimum shade temperatures are given in the relevant National Annex for a 50 year return period. Annex A.1 of the EN provides adjustment for a longer design life (120 years for the UK, according to the NA to BS EN 1990 [9]). However, in Table NA.A.2.4(B) of BS EN 1990, Note 6 states that the value of $\gamma_Q = 1.55$ should be applied to the 50-year value for a design life of 120 years, or alternatively $\gamma_Q = 1.45$ may be applied to the value adjusted for 120 years, either is permissible. Since extreme temperatures are not actions (it is a change of temperature that is an action), the adjustment in EN 1991-1-5, Annex A.1 is more appropriate in determining extreme values for a different probability/return period. It is recommended here that, for road and railway bridges, the Annex A.1 adjustment should be made, rather than applying the larger γ_Q factor to the 50 year values‡. For footbridges, the 50-year return period is usually applicable, so no adjustment is necessary.

In determining maximum and minimum shade temperatures, adjustment for height above sea level is also required (see A.1(1) Note 2 in EN 1991-1-5).

‡ There is very little difference in the ULS value of the range for the two methods but the SLS value will be greater using the EN 1991-1-5 method.

The initial bridge temperature "at the time the structure is restrained" is defined as T_0 in EN 1991-1-5, 6.1.3.3(2). It is not clear what this phrase means, since it implies that it only applies when thermal expansion/contraction is constrained (e.g. by fixed bearings at both ends, or by constructing integral abutments); this interpretation is supported by the wording of 6.1.3.3 (1)P which refers to restraining forces due to temperature range – there are no such forces when the structure is free to expand. If this were the intention, then, strictly, it would seem that the rules in 6.1.3.3 would not apply when there is freedom to expand and contract. However, Note 2 explicitly refers to the expansion and contraction range for bearings, so the definition could be applied when there is normal articulation (fixed at one end, free at the other) and then T_0 should be taken to be the "reference temperature" for the definition of structural geometry.

Note 2 to 6.1.3.3 introduces an allowance for the uncertainty discussed in Section 2 above. Strictly, it is not appropriate to refer to the uncertainty (imperfection) as a thermal action, although in some situations a reasonable value for its magnitude might be obtained by considering it as a temperature change. See discussion later for determining a suitable allowance.

NA.2.21 to BS EN 1991-1-5 confuses matters further by defining two values of T_0 whilst apparently still applying the adjustment in the Note (see NA.2.6); it should be presumed that the NA intended to supersede Note 2 and the Note should be ignored. But, as discussed in Section 2, there can only be a single value of reference temperature, from which the thermal expansion and contraction due to temperature change in service are determined; allowance for uncertainty in structural dimensions should be considered separately.

3.2.2 Values given by EN 1993-2

The definition of temperature change is also addressed in A.4.2 of EN 1993-2, which conflicts with EN 1991-1-5. First, A.4.2 defines a "reference temperature" T_0 for which the geometry of the bridge is as shown on the drawings (see A.4.2.1(1)a)). It then defines upper and lower values $T_{0\max}$ and $T_{0\min}$, but ignores these values and calculates a "temperature difference" ΔT_d^* (by which it means the uniform component of change in bridge temperature, not a temperature gradient), based on the EN 1991-1-5 range (but presumably not including the allowance in Note 2 of 6.1.3.3 or the adjustment of its UK NA) and including two allowances for uncertainty. The "design value of the temperature difference" is expressed as:

$$\Delta T_d^* = \Delta T_K + \Delta T_\gamma + \Delta T_0$$

The allowances for uncertainty in EN 1993-2 ($\Delta T_0 = 15°C$ for 'Case 2' plus $\Delta T_\gamma = 5°C$) equal the values in EN 1991-1-5, 6.1.3.3, Note 2 but now the design range values are equal in each direction, rather than the different values when T_0 is not midway between maximum and minimum bridge temperatures $T_{e,\max}$ and $T_{e,\min}$.

The problem with the above expression is, as already discussed, that it confuses movement due to temperature change with uncertainty in the position of the upper part of the bearing relative to the lower. It also introduces confusion regarding the partial factors that should be applied at ULS and SLS. Note 3 to EN 1993-2, A.4.2.1 seems to acknowledge that the γ_Q factor should be applied at ULS, because it refers to “design criteria ... appropriate to ultimate limit states”. The application of γ_Q to thermal actions is consistent with past practice in the UK (BS 5400-2), with the approaches set out in in a Eurocode Workshop [10] and with Annex E of NA DIN EN 1990-A1 [11]. However, it would seem inappropriate to apply the partial factor for thermal actions to an allowance for uncertainty; ideally, a partial factor that respects the confidence in the allowance should be applied, although it might be noted that in the Workshop and the DIN, a unity factor was applied to allowances based on the increase in the temperature range.

3.3 Coefficient of thermal expansion

The values of thermal expansion and contraction depend on the coefficient of thermal expansion.

For steel structures, EN 1993-1-1, clause 3.2.6 gives $\alpha = 12 \times 10^{-6}\ \mathrm{K}^{-1}$.

For composite structures, EN 1994-2, 5.4.2.5 states that, for the calculation of change in length of the bridge, the coefficient should be taken as 12×10^{-6} per °C for all structural materials.

EN 1991-1-5, Table C.1 permits the coefficient to be taken as 10×10^{-6} per °C for composite structures. There is thus a conflict with EN 1994-2, although “should” in that Standard is more emphatic than “may” in EN 1991-1-5.

It is recommended here that the value given in EN 1994-2 be used.

It may be noted that whilst temperatures are expressed in °C, the proper unit for the mechanical property of expansion coefficient is per K. EN 1993-1-1 does express the coefficient so ($\alpha = 12 \times 10^{-6}\ \mathrm{K}^{-1}$) but EN 1994-2 and EN 1991-1-5 do not (12×10^{-6} per °C and 10×10^{-6} per °C). Numerically, the values are the same.

3.4 Other effects contributing to movement range

Other actions may result in displacements at bearings – for example rotations due to vertical loading cause displacements equal to rotation multiplied by distance of the bearing surface from the section neutral axis. Flexure of supports due to longitudinal loading (braking and traction), movement of the fixed bearing (“fixed” bearings aren’t necessarily rigid) and long-term foundation movements, e.g. due to pressure of abutment backfill may all contribute to movement at the bearing. Shrinkage in composite bridges also results in some (irreversible) displacement that must be considered.

All these effects should be considered in the design but are not discussed in detail here.

SETTING OF BEARINGS

4.1 General

The fixing of bearings to the super- and sub-structure is often referred to as 'setting'. If the upper and lower parts are fixed in their nominal locations, any discrepancy (between upper and lower parts) in the distance between the fixed bearing and the movement bearing at the reference temperature, would mean that the two parts of the movement bearing would be offset from the median position at the reference temperature. This offset can be accommodated if the design movement range for the bearing has included an allowance for the discrepancy/uncertainty, as discussed above.

Alternatively, when there is a discrepancy in relative length, either the upper or lower part can be offset from its nominal location, so that the two parts would be at or near their median position at the reference temperature; this would reduce or even eliminate the allowance needed in the movement range for uncertainty of bearing location. To make any such offset, there must be sufficient freedom in the fixing details (this usually means that the holding down bolts are detailed to accommodate an offset; there is not usually much opportunity to offset the upper part on the structure).

For bridge lengths up to about 100 m, providing an increased movement range for the bearing is likely to be the simplest and most economical solution. For longer bridges it may be beneficial to arrange the details such that the bearing can be offset from its nominal location, thus limiting the addition to the movement range required for the bearing.

To validate any adjustment, the relative positions of the upper and lower parts must be known at some particular temperature; when that is known, the discrepancy at the reference temperature can be determined and the constructor can determine the adjustment to be made (this may be limited by the detailing and it may not be possible to make an adjustment equal to the full value of the discrepancy).

The terms 'resetting' and 'presetting' are often used in relation to the adjustment of bearing locations but neither term is defined in the standards; any numerical values they give for such adjustments are therefore rather meaningless.

4.2 Uncertainty in bearing position

The uncertainty in the relative positions of upper and lower parts of a movement bearing at the reference temperature depends on the construction process.

Where the superstructure is prefabricated, the length between the position of the fixed bearing and the movement bearing is required to be within the tolerances specified for execution. For a steel structure, EN 1090-2 does not give a tolerance on overall length but, based on accuracy that can be achieved by UK fabricators, a tolerance on length of steelwork is given in AD318 [12] and P382 [13] as 10 mm + L/10000. For a 100 m long bridge that equals 20 mm or L/5000. To this might be added some (small) allowance for tolerance in setting out the substructure, possibly of the order of ± 5 mm, although any allowance should be consistent with specified tolerances.

The above tolerances might be compared with the provisions in EN 1993-2 (A.4.2.1, Case 2) and EN 1991-1-5 (6.1.3.3 Note 2), which introduce an adjustment to the thermal action of ± 20 °C (equivalent to 1/4167 of the distance from the fixed bearing).

Where the structural dimensions are determined on site, typically by casting a concrete bridge in situ, the uncertainty depends on the accuracy with which the temperature can be determined at the stage at which the dimensions are fixed and the accuracy of making allowance for the difference between the temperature at that stage and the reference temperature when setting the bearings (for a concrete or composite structure, shrinkage effects subsequent to setting the bearings also need to be considered). An allowance for this uncertainty should be made in determining the design movement range – its value will depend on the presumed accuracy when constructing in accordance with the specification.

For long viaducts, where sequential construction and possibly changing restraint locations are used, the allowance for uncertainty must take into account the agreed construction sequence and the requirements for dimensional control during construction.

4.3 Options for fixing bearings to steel superstructures

For a prefabricated steel superstructure, there are four possible options when fixing the bearings. Not all are practical but they cover the options in Table A.4 of EN 1993-2.

4.3.1 No adjustment of fixing locations

Simply fix the lower part to the nominal location on the substructure and the upper part to the nominal location on the superstructure. No temperatures are measured and the transit clamps (which fix the upper and lower parts in the specified relative position at the reference temperature) have to be released to allow the upper and lower parts to slide so that both parts can be fixed. Releasing the clamps is not favoured by some constructors because there is a risk that the parts can separate, not just slide, leading to potential damage to the bearing.

The full allowance for uncertainty should be added to the movement ranges that the bearing must accommodate (see Figure 2.1).

4.3.2 Adjustment without temperature measurement

Fix the bearing with the transit clamp in place, with the upper part at the nominal location on the superstructure and the lower part to the substructure wherever it sits. This can only be done where there is sufficient available clearance for the fixing bolts No temperatures are measured. Transit clamps should be released after this stage.

The allowance in the movement range for the bearing that is required for this option is reduced to a value corresponding to the maximum likely difference between the bridge temperature at installation and the reference temperature. In many circumstances this difference could be as small as 10 °C, if the reference temperature is about 12 °C and installation takes place in moderate weather conditions.

4.3.3 Adjustment with temperature measurement

Measure the temperature of the bridge at sufficient locations to determine the mean effective bridge temperature at the time that the relative positions of the upper and lower parts is determined. (Guidance on temperature measurement is given in GN 7.02, part of P185 [7].) Calculate the discrepancy that would exist at the reference temperature; this is the offset required.

Fix the upper part to the nominal location on superstructure and fix the lower part at the required offset from nominal position (or at the limit that the detail will accommodate). The bearing parts must be free to slide, to achieve this, unless the actual bridge temperature is the same as the reference temperature. Note, care is needed at this stage, to make sure that any offset is in the correct direction.

The allowance in the bearing movement range for uncertainty can be reduced by the tolerance that can be accommodated in fixing the lower part.

4.3.4 Adjustment with temperature estimation

This option is mentioned in Table A.4 of EN 1993-2 but offers little advantage over the previous method. Instead of measuring the temperature, it is simply estimated. The method does not offer the same reduction in allowance for uncertainty as the previous method.

4.3.5 Constructors' preferences

Constructors prefer to have the freedom to choose the method of installing the bearings and thus prefer that the design movement range includes the full allowance for uncertainty. This would allow them to choose any of the first three options above.

4.4 Options for fixing bearings to concrete superstructures

Although guidance for concrete bridges is generally outside the scope of this document, some comments are included here, for completeness and because the options would also be applicable to a steel superstructure where there is the ability to adjust to length (between fixed and movement bearing) during construction, or there is freedom to position the upper part of the bearing according to the actual length.

In these cases, the bearing is installed either with the upper and lower parts in their median position (where the bearing is intended to be at the reference temperature) or the bearing is installed with the parts offset by an amount dependent on the temperature at the time of installation.

4.4.1 Installation with no offset

The bearing movement range should include an allowance for the maximum likely difference between temperature at installation and the reference temperature. That difference depends on both the specified reference temperature and the time of year that construction takes place.

4.4.2 Installation with measured temperature

If careful temperature measurement is to be made at the time of installation, and the bearing offset accordingly, only a small allowance need be included in the movement range for the bearing. The specification must include detailed requirements for temperature measurement.

4.5 Options for long viaducts

The construction of long viaducts may involve the use of temporary restraints at various stages of construction. The bridge articulation may also include several fixed bearings, on relatively flexible supports. In such cases, the determination of movement ranges must take full account of the construction sequence and the requirements in the project specification.

4.6 Future clarification of Eurocode requirements

It is hoped that allowance for uncertainty in fixing the bearing position will be addressed more fully in future revisions of EN 1990, EN 1991-1-5 and EN 1337-1 – greater clarity is certainly needed in defining, separately, movement ranges, which are independent of bearing location, and allowances for uncertainty in the positioning of the bearing. The effects of construction sequence should be covered, at least by defining principles to be observed. A consistent definition of reference temperature is needed, clarification of which limit states and combinations are to be considered for the bearings and clarification of the partial factors that apply to the various effects. Terminology should be consistent. A new bearing schedule template is to be introduced when EN 1337-1 is revised and that should be made consistent with the Eurocode requirements.

RECOMMENDATIONS

The following recommendations are based on the above observations and are intended to offer a clearer statement for the designer to use in determining design values of displacements for movement bearings.

5.1 Temperature changes

1. Determine the 50-year (0.02 probability) characteristic value of maximum and minimum shade air temperature (T_{max} and T_{min}), for the bridge location, from (in the UK) Figures NA.1 and NA.2 of the NA to BS EN 1991-1-5 and include adjustment for height above sea level, where appropriate.
2. Adjust the values for a 120-year return period (0.0083 probability), where that is the specified design life, according to Figure A.1 of BS EN 1991-1-5 (multiply minimum temperature by 1.14 and maximum temperature by 1.05).
3. Adjust the values for deck type (Figure 6.1 of EN 1991-1-5) and depth of waterproofing (Table NA.1), to derive $T_{e,max}$ and $T_{e,min}$.
4. Select the reference temperature T_0. Ideally this should be the median or most likely temperature of the bridge during its life, which is approximately midway between the two extreme temperatures given by EN 1991-1-5. Typically, in the UK, this will be between about 10 °C and 15 °C; a ‘rounded value’ of the mean of the extreme temperatures is adequate. This reference temperature will be specified in the contract documents (the Appendix 18/1 and its addendum, for contracts using the *Specification for Highway Works* [14]), so that the constructor can create the required geometry.
5. Calculate characteristic values of expansion and contraction ranges:

$$\Delta T_{N,exp} = T_{e,max} - T_0$$
$$\Delta T_{N,con} = T_0 - T_{e,min}$$

5.2 Design movement range

Assume that the upper and lower parts of the bearings are to be set to nominal locations on the superstructure and the substructure (no offsets made to accommodate any discrepancy in length from the fixed bearing).

Assume a tolerance on length from the fixed bearing equivalent to 15 mm + $L/10000$ (for short bridges this is greater than the 20 °C adjustment in EN 1993-2 but is consistent with achievable construction tolerances for steelwork). The same value may be used for both ULS and SLS as there is no data on which to base a partial factor to apply at ULS.

The movement ranges (in mm) would then be:

	MOVEMENT	ULS	SLS
EXPANSION	$v_{x,max} =$	$\alpha L\,\gamma_Q\,\Delta T_{N,exp} + 15 + L/10000$	$\alpha L\,\Delta T_{N,exp} + 15 + L/10000$
CONTRACTION	$v_{x,min} =$	$\alpha L\,\gamma_Q\,\Delta T_{N,con} + 15 + L/10000$	$\alpha L\,\Delta T_{N,con} + 15 + L/10000$

Where:

L = the length from the fixed bearing (mm)

α = 12×10^{-6} per K, for steel and composite structures (EN 1993-1-1, 3.2.6 and EN 1994-2, 5.4.2.5).

Where bearings can be set to adjust for any discrepancy in lengths from the fixed bearing (and provided that this is catered for in the specification and that the detailing can accommodate the adjustment), the allowance may be reduced, but see comment in Section 4.3.5.

REFERENCES

References are generally to the CEN versions of European standards. References to UK National Annexes are to the BS EN versions.

[1] BS EN 1990:2002+A1:2005,
Eurocode, Basis of structural design.
BSI, 2002.

[2] BS EN 1991-1-5:2003,
Eurocode 1. Actions on structures. General actions. Thermal actions.
BSI, 2004.

[3] BS EN 1993-1-1:2005+A1:2014,
Eurocode 3. Design of steel structures. General rules and rules for buildings.
BSI, 2005.
BS EN 1993-2:2006,
Eurocode 3: Design of steel structures. Steel bridges. (Each with its UK National Annex.)
BSI, 2006.

[4] BS EN 1994-2:2005,
Eurocode 4. Design of composite steel and concrete structures. General rules and rules for bridges.
BSI, 2005.

[5] BS EN 1992-2:2005,
Eurocode 2. Design of concrete structures. Concrete bridges. Design and detailing rules.
BSI, 2005.

[6] BS EN 1337-1:2000,
Structural bearings. General design rules.
BSI, 2000.

[7] Iles, D.C.
Steel Bridge Group: Guidance notes on best practice in steel bridge construction,
6th Issue (P185).
SCI, 2015. Available on www.steelbiz.org.

[8] NA to BS EN 1991-1-5:2003,
UK National Annex to Eurocode 1. Actions on structures. General actions. Thermal actions.
BSI, 2007.

[9] NA to BS EN 1990:2002+A1:2005,
UK National Annex for Eurocode. Basis of structural design.
BSI, 2004.

[10] *Bridge Design to Eurocodes. Worked examples.*
Vienna, 4-6 October 2010.
Publications Office of the European Union, 2012.

[11] DIN EN 1990/NA/A1:2012-08,
National Annex - Nationally determined parameters - Eurocode: Basis of structural design; Amendment A1.
Beuth, 2012.

[12] Iles, D.C.
Tolerances on plan position of steelwork in bridges (Advisory Desk Note 318). *New Steel Construction*, Vol. 16, No. 2.
BCSA, 2008. Available on www.steelbiz.org.

[13] Hendy, C.R. and Iles, D.C.
Steel Bridge Group: Model project specification for the execution of steelwork in bridge structures (P382).
SCI, 2012. Available on www.steelbiz.org.

[14] *Manual of Contract Document for Highway Works. Volume 1 - Specification for Highway Works.*
TSO, 2002.

APPENDIX A: WORKED EXAMPLES

A.1 Two-span highway bridge in P357

Worked example 1 in SCI publication P357 is a 2-span integral highway bridge (spans 28 m + 28 m). Values for the thermal effects were calculated in that publication and were used to determine soil pressures. For the present purposes of illustrating specification of bearings, the two spans are now considered with a fixed bearing at one end and a sliding bearing at the other. Displacements at ULS and SLS are then calculated.

A.1.1 Thermal actions

Shade temperatures

1-1-5/ NA.2.20 Maximum and minimum shade air temperatures for the UK, for a 50-year return period are defined in EN 1991-1-5, NA.2.20. For this bridge location, the values are:

$T_{max} = +33°C$

$T_{min} = -17°C$

For a 120 year design life, these values are adjusted using Figure A.1. The values then become:

$T_{max} = +35°C$

$T_{min} = -20°C$

The values of maximum/ minimum uniform bridge temperatures are given by
1-1-5/ 6.1.3.1 Figure 6.1; these are referred to as $T_{e,min}$ and $T_{e,max}$

For Type 2 deck (concrete slab on steel girders):

$T_{e,max} = T_{max} + 4 = 35 + 4 = 39°C$ (value read from Figure 6.1)

$T_{e,min} = T_{min} + 5 = -20 + 5 = -15°C$ (value read from Figure 6.1)

1-1-5/ NA.2.4 *(The adjustments for surfacing thickness over 100 mm given by the NA would result in a small reduction to the range and have been neglected.)*

Thermal ranges

The characteristic values from a reference temperature of 10 °C are:

1-1-5/6.1.3.3 $\Delta T_{N,exp} = T_{e,max} - T_0 = 39 - 10 = 29°C$

$\Delta T_{N,con} = T_0 - T_{e,min} = 10 - (-15) = 25°C$

A.1.2 Design movement range for sliding bearing

4-2/5.4.2.5
Table NA.A.2.4(B)

For change of length in composite sections, the coefficient of linear thermal expansion is 12 × 10⁻⁶ per °C.

$\gamma_Q = 1.45$ (for 120 year design life values)

Allowance as Section 5.2

Allow for tolerance on length from fixed bearing: $15\text{ mm} + L/10000$

$L = 56\text{ m}$

The ULS design values to be specified for the bearings are therefore:

Expansion: $(1.45 \times 29) \times 56000 \times 12 \times 10^{-6} + 15 + 56000/10000 = 49\text{ mm}$

Contraction: $(1.45 \times 25) \times 56000 \times 12 \times 10^{-6} + 15 + 56000/10000 = 45\text{ mm}$

To avoid confusion about which direction should be set with the greater movement, this range could be specified as ± 49 mm

The SLS design values to be specified for the bearings would be:

Expansion: $29 \times 56000 \times 12 \times 10^{-6} + 15 + 56000/10000 = 40\text{ mm}$

Contraction: $25 \times 56000 \times 12 \times 10^{-6} + 15 + 56000/10000 = 37\text{ mm}$

A.2 Steel footbridge, overall length 80 m

Consider a steel deck and plate girder footbridge in the UK, say near Sheffield.

A.2.1 Thermal actions

Shade temperatures

1-1-5/ Figure NA.1 & NA.2

Maximum and minimum shade air temperatures are:

$T_{max} = +34°C$

$T_{min} = -16°C$

1-1-5/ Figure A.1 Adjust for 120 year return period:

$T_{max} = +36°C$

$T_{min} = -18°C$

1-1-5/ 6.1.3.1 This is a Type 1 deck, with plate girders, so the maximum and minimum bridge temperatures are given by EN 1991-1-5 Figure 6.1 and its Note 2:

$T_{e,max} = 36 + (17 - 3) = 50°C$ (read from Figure 6.1 and adjusted by 3 °C)

$T_{e,min} = -18 - 3 = -21°C$ (read from Figure 6.1)

(Note that the maximum temperature would be 4 ° higher again if the deck were only waterproofed but that is not considered here).

Thermal range

1-1-5/ 6.1.3.3 The characteristic values from a reference temperature of 10 °C are:

$\Delta T_{N,exp} = 50 - 10 = 40°C$

$\Delta T_{N,con} = 10 - (-21) = 31°C$

A.2.2 Design movement range for sliding bearing

1-1-1/3.2.6
Table NA.A.2.4(B) For change of length in steel sections, the coefficient of linear thermal expansion is 12×10^{-6} per °C.

$\gamma_Q = 1.45$ (for 120 year design life values)

Allow for tolerance on bridge length equivalent to the thermal movement due to a temperature change of 20 °C

The ULS design values to be specified for the bearings are therefore:

Expansion: $(1.45 \times 40) \times 80000 \times 12 \times 10^{-6} + 15 + 80000/10000 = 79$ mm

Contraction: $(1.45 \times 31) \times 80000 \times 12 \times 10^{-6} + 15 + 80000/10000 = 66$ mm

To avoid confusion about which direction should be set with the greater movement, this range could be specified as ± 79 mm.

The SLS design values to be specified for the bearings would be:

Expansion: $40 \times 80000 \times 12 \times 10^{-6} + 15 + 80000/10000 = 61$ mm

Contraction: $31 \times 80000 \times 12 \times 10^{-6} + 15 + 80000/10000 = 53$ mm

A.2.3 Reduced movement range where installation temperature is to be measured

If the temperature during installation is carefully measured and the fixing of the bearings to the structure or the support has sufficient tolerance to accommodate a discrepancy from nominal dimensions, the design movement range can be reduced.

It is suggested that the fixings should accommodate a tolerance equivalent to full allowance for uncertainty in length, i.e. $\pm 15 + L/10000$ or ± 23 mm (say 25 mm, for the detailing).

It is nevertheless appropriate to include a small allowance for discrepancy in the movement range – an allowance equivalent to 20% of the full allowance is suggested ($+ 0.2 \times 25 = 5$ mm) and thus the ULS design range would be:

Expansion: $1.45 \times 40 \times 80000 \times 12 \times 10^{-6} + 5 = 61$ mm

Contraction: $1.45 \times 31 \times 80000 \times 12 \times 10^{-6} + 5 = 48$ mm

DETERMINING DESIGN DISPLACEMENTS FOR BRIDGE MOVEMENT BEARINGS

Bridges are usually constrained against horizontal displacement by providing a fixed bearing at one support and movement bearings that permit linear displacement of their upper parts relative to their lower parts at other supports. Such displacements occur principally due to thermal expansion and contraction. This publication provides guidance on the determination of design values of linear displacements for bridge movement bearings, for use in specifying the requirements for bearings designed and manufactured in accordance with EN 1337.

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