Steel Bridge Group

Guidance Note

Bridge articulation

No. 1.04

Scope

This Guidance Note gives advice on the selection of the articulation arrangements, the choice of bearing types and dispositions of bearings, for bridges where relative movement (translation and rotation) between the deck and supports is accommodated. Bridges that do not allow relative movement are known as 'integral bridges' - they are not covered here. Movable bridges (bascule, lifting, etc.) are also not covered in this Note.

Much of the advice is applicable to railway bridges as well as road bridges (unless otherwise noted), but designers of rail bridges should also refer to the particular requirements and guidance of the relevant railway authority.

See GN 2.09 for advice on ensuring that bearings are properly aligned.

General

Bridges are subjected to a variety of influences that cause displacement of the bridge deck and its supports. If these movements are resisted, forces will be generated within the structure. To control the development of restraint forces it has become normal practice to place the bridge deck on support bearings which allow some freedom of relative movement between the deck and supports. The arrangement of supports and freedoms of movement is known as the 'articulation'.

Sources of movement

Sources of movement include:

- temperature change (uniform and differential)
- shrinkage and creep of concrete
- dead load deflections/rotations
- traffic load deflections/rotations
- deflections/rotations due to horizontal loads (braking, traction, skidding, wind loads)
- settlement of supports
- earth pressure on abutment walls
- deflections of slender piers
- vehicular collision
- seismic effects (not generally in UK)

The design values of movements due to combined actions are determined in accordance with EN 1990. Characteristic values of actions are given by the various Parts of EN 1991. Forces on bearings and joints are calculated for the relevant design situations.

Basic principles for good articulation

A bridge can be articulated in one of a number of ways. The following principles should generally be followed:

Minimise the number of bearings and joints by the use of continuous spans.

The fewer the number of deck joints, the fewer the number of bearings and the less the opportunity for water to leak through and create potential durability problems. (The ultimate expression of this principle is to use 'integral bridges'.)

Proportion the spans and detail the superstructure to ensure that uplift does not occur at a bearing under any load combination.

Choose an arrangement that provides simple restraint against longitudinal loads.

Provide longitudinal fixity at only one support, unless the supports are flexible enough to allow sharing of longitudinal loads.

Provide only one lateral restraint at each support, unless the supports are flexible.

As well as unequal sharing of reactions, restrained bearings may restrain rotation of the beams about their longitudinal axes, thus inducing extra forces on the bearings.

Anticipate the need during construction for temporary lateral restraint of individual girders

Each girder, or pair of braced girders, will require temporary restraint. Choose the location of the permanent restraint to facilitate the temporary restraint.

Consider at which end the bridge should be fixed

In highway bridges, take account of the geometry and drainage provisions, to minimise the exposure of the major expansion joint to surface water flow. Rail bridges are ideally fixed (subject to abutment capacity) such that the beams are in tension under the dominant longitudinal force for the prevailing direction of traffic. On continuous structures, centre fixing may be an option.

Try to choose as the fixed or guided bearings those with the largest minimum vertical loads coexistent with the maximum horizontal load.

Guided or fixed bearings with low minimum vertical loads are likely to require special designs and may be more expensive. Alternatively, use a separate guided bearing that does not carry vertical load.

Consider the effect of fabrication tolerances

Consideration should be given to making an allowance for fabrication tolerances in calculating design values of positions and translations for the bearings - including systematic growth/ shrinkage of steelwork - see GN 5.03, Tolerances on length.

Avoid buried movement joints on steel bridges (unless spans are very small or there is an integral configuration).

Larger rotations/deflections on steel bridges (compared to concrete bridges) can lead to early joint failures.

Horizontal restraint

A continuous bridge needs only three horizontal restraints to be statically determinate. That can be achieved most easily by one longitudinal restraint and two lateral restraints, which can be arranged by having a fixed bearing at one end and a laterally restrained bearing at the other. All other bearings can be free. However, it is common to provide one guided bearing at each intermediate support to carry transverse loads (the structure is then a continuous beam in plan as well as in elevation). In a multi-girder bridge, the fixed and guided bearings would normally be under an inner girder, where there is always a significant co-existent vertical load.

Some designers consider it safer (because of greater redundancy) and more economic to assume that longitudinal load can be shared by more than one bearing, even by all the bearings on a bridge with four or more girders. However, it should be remembered that fixed or guided bearings may allow a movement of up to 2 mm (because of clearances in the bearing), and consequently it is probably unwise to assume equal sharing of horizontal loads. Also, in some circumstances (such as when the cross section tries to 'warp', because the rotations in elevation are different for each girder) opposing reactions can be developed without any externally applied horizontal load. Similarly, lateral restraint to more than two (closely spaced) girders would restrain 'distortion' (different rotations about longitudinal axes of the girders) and should normally be avoided.

Consider the following in positioning fixed bearings:

- can the substructure withstand the loads transmitted?
- do slender piers need to be laterally restrained at the top to reduce their effective length?
- if there is more than one fixed or guided bearing, is there sufficient flexibility to share loads?
- can structure/bearings withstand extra forces generated (e.g. due to expansion between two fixed bearings)?
- can the structure be fixed at the centre, to reduce movements at abutments and to balance bearing friction and associated restraint forces?
- can the structure span laterally between bearing restraints?

In addition, full consideration should be given to enabling erection to commence at the position of longitudinal fixity, thus avoiding the need to provide temporary fixity and the probability of having to jack assembled steelwork longitudinally to set the bearings correctly.

In some circumstances, it is desirable to share longitudinal forces between a number of supports, but without any loads being induced by thermal strain. In such cases, shock transmission units may be used; these can resist suddenly applied loads (e.g. braking and traction forces) but provide very little resistance to thermal movements (which occur very slowly).

Curved bridges

On continuous curved multi-span structures, careful consideration must be given to the alignment of the guided bearings, to the consequences on movement at expansion joints and to lateral forces that may result from the constraint of the expansion of the curved configuration.

There are three basic alignments that may be considered:

- provide guidance such that the deck expands radially in plan from one fixed point
- provide guidance such that there is radial expansion and rigid body rotation in plan
- provide guidance such that the deck moves in plan tangentially to the curve of the structure at each bearing.

The first of the above arrangements means that at the end furthest from the fixed point the movements are at an angle to axis of the deck and thus the expansion joint has to accommodate displacements along its length as well as expansion/contraction. If the angle is large, this may be difficult to achieve.

The second arrangement overcomes the transverse displacement at the expansion joint by aligning all the guided bearings to achieve movement at the expansion joint along the bridge axis only. As this is achieved by some plan rotation, movements at intermediate supports are neither tangential nor radial, but will be at some angle in-between and different at each support. This will complicate definition of guided bearing alignment at these supports. A typical configuration is illustrated in Example 8 (Figure 8).

The third arrangement effectively guides the expansion around the original curvature by aligning all the guides tangentially to the curve. This necessarily imposes lateral forces on the bearings (particularly those on the end spans at either end of the deck) and forces plan bending of the deck. A typical configuration is illustrated in Example 9 (Figure 9).

If the deck has a varying curvature along its length the third arrangement should be chosen because it is very difficult to permit free expansion at the same time as providing lateral restraint (against wind forces etc.) at intermediate supports. It would also be appropriate where the alignment includes a mixture of straight and curved lengths, but movements need to be carefully analysed (an expanding straight pushing into a tight curve may produce high loads on guided bearings).

Skew bridges

On skew bridges, in general, set the direction of movement of bearings parallel to span, not perpendicular to support.

On highly skewed bridges, the movement parallel to the joint may exceed that perpendicular to the joint.

Line rocker bearings

Line rocker bearings provide longitudinal and transverse restraint to movement; they provide no rotational restraint about the axis of the line contact, but do provide rotational restraint perpendicular to that axis. That restraint may be employed in certain situations..

When considering use of line rocker bearings to provide torsional restraint to main girders the designer needs to take into account skew angle and span to width aspect ratio when determining the arrangement of the transverse members of the deck and/or the bracing between main girders. Line rockers would not normally be used with deck type bridges employing multi girder or ladder deck type steelwork systems.

Line rockers are often used, particularly in half-through U-frame bridges, to provide torsional restraint to steel beams at their support (see PD 6695-2, EN 1993-2 and EN 1993-1-5). However, significant moments can be induced on the bearings in such situations and line rockers should not be used where rotational restraint (about an axis square to the rocker) is effectively provided by other stiff components, such as diaphragms. In most cases, there are three choices:

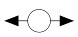
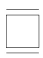
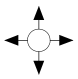
1. Provide torsional restraint to the main beams through transverse beams or bracing and not use line rockers.

2. Use line rockers to provide torsional restraint and keep the stiffness of members transverse to the beam to a minimum, for example deck slab only (do not provide a moment connection between a deeper trimmer beam and the main girder). For small skews, the line rockers can be square to the beam or parallel to support line.

3. (More often used in half-through railway bridges.) Provide line rockers for torsional restraint and provide transverse beams that are either pin connected to the main beam or supported on their own bearings. The transverse beams then act as simply supported beams.

For a bridge with significant skew, line rocker bearings are usually inadvisable, because the twist deflections caused by the skew can produce particularly large moments on the bearings. However, for very large skew (60° or more), line rocker bearings may be required at acute corners because it is difficult to provide torsional restraint to those beams by any other method.

Symbolic representation
It is common practice to indicate symbolically on drawings the different movements or restraints at each bearing. The representation should follow that of Table 1 of EN 1337-1, which also indicates bearing type. Examples are shown below. Only the pot bearings are used in the example arrangements; elastomeric bearings might be used for smaller bridges.

Symbol	Type	Sym-bol	Type
	Pot bearing (movements restrained)		Elastomeric bearing
	Pot bearing with uni-directional sliding part		Elastomeric bearing, restrained in one direction
	Pot bearing with multi-directional sliding part		

Examples of articulation arrangements
Eight examples are presented, each with brief comments, illustrating typical arrangements and the use of the symbols.

Example 1: Simply supported road bridge

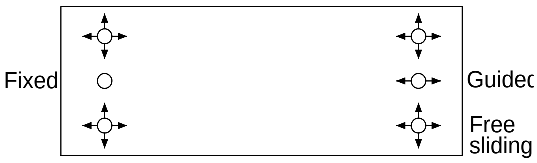


Figure 1 *Arrangement for example 1*

The composite deck has multiple steel girders; only three are indicated, for simplicity.

The fixed and guided bearings are on the same beam, to avoid problems with alignment of the guided bearing.

The fixed and guided bearings are on a centre beam to reduce transverse movements, but they could be on an outer beam.

Example 2: Two span continuous road bridge

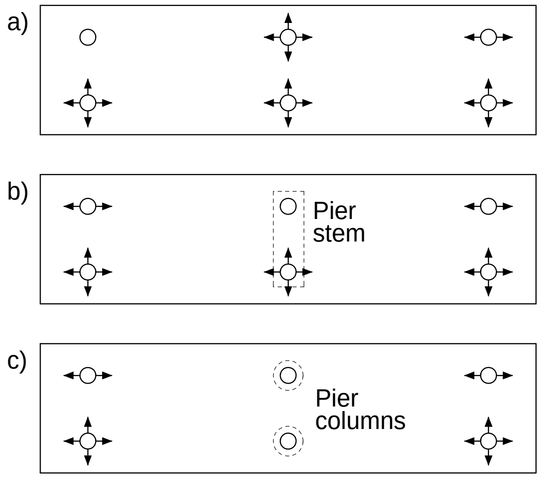


Figure 2 *Arrangement for example 2*

Three alternative arrangements are shown:

a) can be used if there is no horizontal load on the pier, other than friction.

b) can be used to reduce maximum movement, the pier resisting deck longitudinal forces.

c) can be used if there are slender pier columns needing restraint, the piers resisting deck longitudinal forces and accommodating transverse expansion forces
Railway bridges are typically single spans of half-through construction, with two main beams, one at each edge of the deck.

Example 3 Typical single span railway bridge

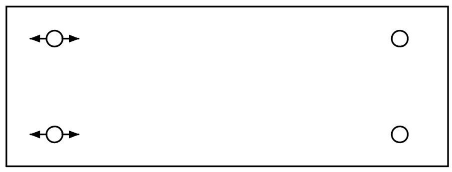


Figure 3 *Arrangement for example 3*

For square span railway bridges, the bearings under both beams are usually fixed at one end of the bridge. The bearings at the other end are guided, to ensure that movement of the bridge is parallel to the tracks. Movements transverse to the tracks are usually insignificant.

Example 4 Typical skewed road or railway bridge

Figure 4 *Arrangement for example 4*

For skew bridges, the usual configuration is for the bearing at one corner to be fixed, the bearings at the two adjacent corners guided and the other bearing free (see Figure 4). All four bearings supporting half-through deck type beams should allow for rotation about a longitudinal axis (parallel to the main girders), unless allowance is made in the design for the higher loads on the inner side of the bearings, due to the rotation of the beams under load. These higher loads are most significant for railway bridges.

Example 5 Heavily skewed railway bridge

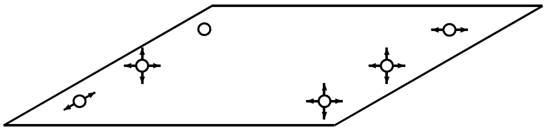


Figure 5 *Arrangement for example 5*

For heavily skewed railway box girders in accordance with the standard bridge design, additional supports may also be provided under the trimmer girder. The bearings of such supports are usually free at both ends of the bridge.

Multiple span road bridges involve more extensive articulation arrangements.

Example 6: Multi-span continuous
There are four possible arrangements (see Figure 6):
a) may be used if longitudinal loads can be resisted at the abutment

- this leads to the largest bearing movements (at the far end)
- intermediate guided bearing(s) are needed if the deck cannot span laterally between abutments

b) reduces the maximum movement compared to (a)

- a strong pier is required at the fixed bearing to resist the longitudinal loads.
- the deck acts in plan as a two-span beam.

c) If the pier columns are flexible laterally, each bearing may be guided; if the central columns are strong enough, they may provide the longitudinal restraint, as in (b).

d) If the central piers are tall and flexible, they may share in providing longitudinal restraint.

Note that in (c) and (d) the columns are restrained transversely at the top by the deck.

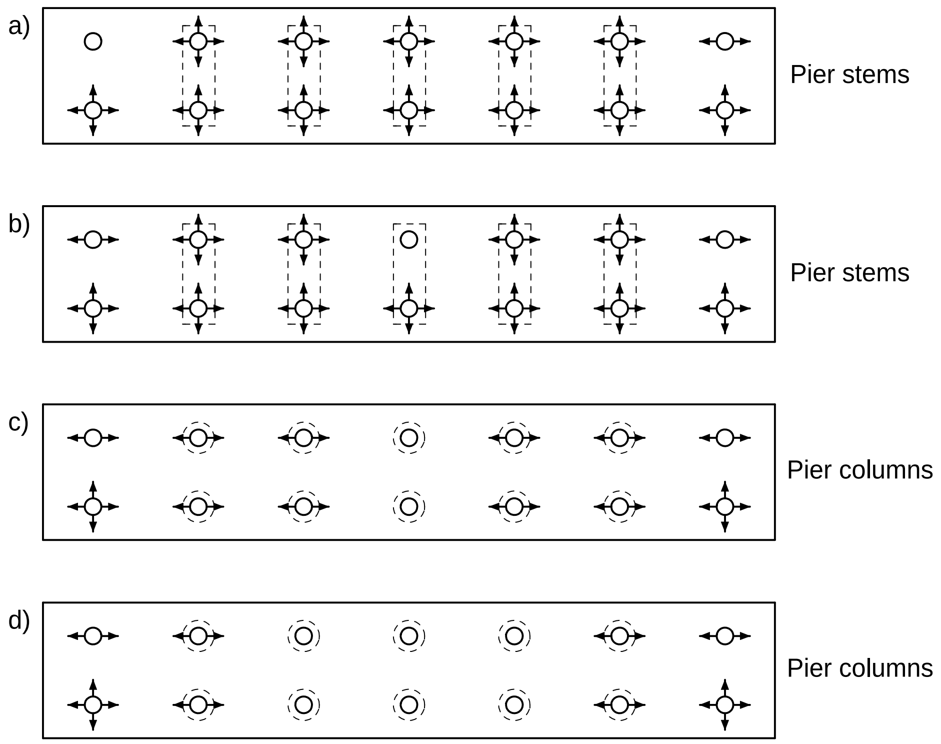


Figure 6 *Arrangements for example 6*

Examples 7, 8 and 9
The deck for these three alternative articulation arrangements is an indicative example of a three-span curved bridge with two bearings at each support. For multi-girder bridges, there would usually be more bearings at each support.

In the first arrangement, shown in Figure 7, the guided bearings are aligned radially from a fixed bearing at one abutment. This arrangement has the distinct disadvantage that the expansion joint (at the opposite end from the fixed bearing) must accommodate both normal and transverse displacements.

The second arrangement (shown in Figure 8) aligns each of the guided bearings at an angle θ to the radial line from the fixed bearing, such that the movement at the expansion joint is guided to be only in a direction normal to the joint. The angle θ is the same at all guided bearings and is the angle between the radial line from the fixed bearing to the guided bearing at the expansion joint and the normal to the joint (i.e. to the end of the deck). Expansion and contraction in this arrangement results in rigid body rotation in plan, as well as change in length.

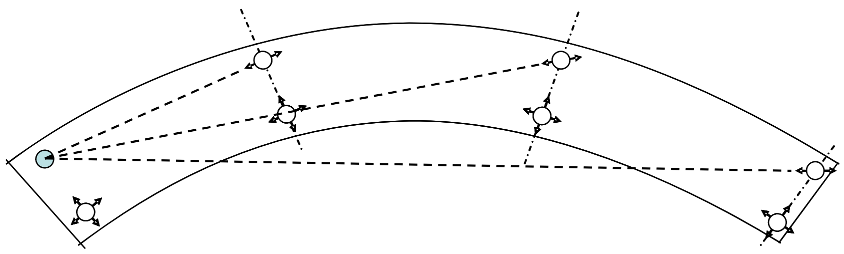


Figure 7 *-Curved deck with radial articulation*

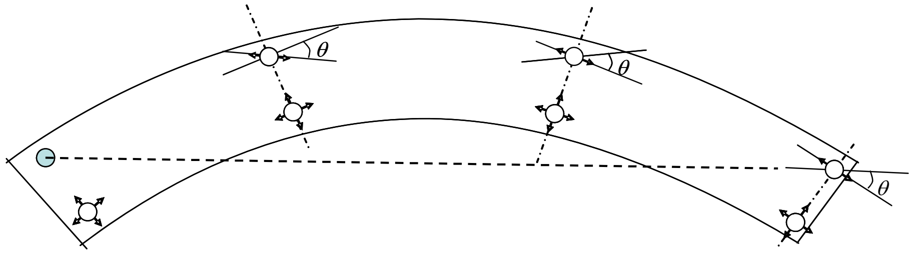


Figure 8 *Curved deck with articulation for normal movements at expansion joint*

The third alternative articulation for the curved deck is shown in Figure 9. At each pier and at the abutment remote from the fixed bearing, the guided direction follows that of the longitudinal axis of the bridge at that point. Thus the expansion/contraction is forced to follow the curve through the guided bearings and in so doing, the deck is forced to bend in plan (because, if free to expand, the radius and curvature would increase/decrease at the same rate as the change in length). This articulation arrangement is very easy to specify and install (there is less scope for confusion when aligning bearings than in the arrangement in Figure 8 but the constraint results in forces normal to the guided direction.

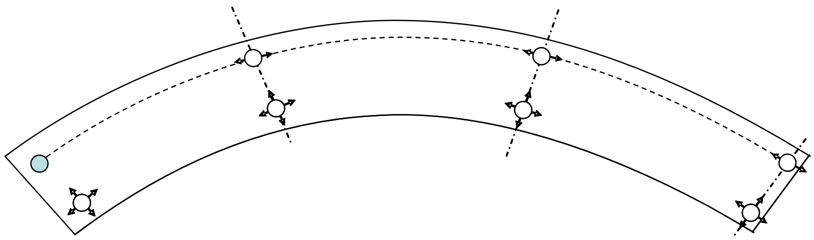


Figure 9 *Curved deck with movement guided tangentially to the curve*

References

1. Lee DJ, Bridge bearings and expansion joints, 2nd edition, E & FN Spon, 1994.
2. Ramberger G., Structural Bearings and Expansion Joints for Bridges, IABSE Structural Engineering Documents 6, 2002
3. EN 1990:2002 Eurocode: Basis of structural design
4. EN 1991: Eurocode 1: Actions on structures (in numerous Parts)
5. PD 6695-2:2008, Recommendations for the design of bridges to BS EN 1993
6. EN 1337 Structural bearings