Guidance Note 1.10

Half-through bridges

Scope

This Guidance Note describes the structural behaviour and typical applications of this type of bridge. Aspects requiring particular attention are identified.

Basic form and structural action

The basic half-through deck configuration (Figure 1) is characterised by two essential features:

- The concrete deck slab or steel deck is located towards the bottom flange or chord of the main (longitudinal) girders or trusses (referred to here as main members).
- No lateral bracing members exist between the main member top flanges or chords.

Additionally, where the main girders rely on U-frame action for stability, connections of adequate stiffness must exist between the deck and the main members.

These features have implications for design and detailing, some of which are described below.

The most important aspect of the half-through configuration, from the structural point of view, is that stability of the top compression flange, or chord, in sagging moment regions, is achieved by virtue of the flexural stiffness of 'U-frames' formed by the webs (usually having vertical stiffening which aligns with the cross members) and the deck slab and/or cross member. The ends of the main members will often be restrained by stiffer end U-frames or by a suitable arrangement of trimmer beam and bearing stiffeners. Line rocker bearings may also be used to provide end restraint.

The stiffer the U-frames, the greater the degree of restraint afforded to the top flange or chord and hence the greater capacity of the main members Inevitably, however, a compromise has to be reached between maximising the bending capacity of the main members and providing an optimum U-frame configuration related to the selected cross member spacing and web stiffening requirements.

The mathematical model underlying design guidance for half-through decks (i.e. that in BS EN 1993-2 [4]) is the beam on elastic foundation (BEF) model. The model comprises a strut (the isolated compression flange) laterally restrained by springs. The effective length of flange or chord calculated from this model is used to determine flange slenderness and hence the limiting stress.

It should be realised that overall stability relies upon the deck being rigid in plan for the full span length, unless some other bracing restraint system is provided.

The inherently high torsional rigidity of box girders means that the requirement for restraint against buckling is less than for a plate girder or truss; however, the degree to which this is true is dependent on the box width to span ratio. In most cases, box girders require no intermediate restraint, but they must then be restrained against overall instability (twisting about the longitudinal axis) at the supports (by the use of twin bearings or wide line rocker or roller bearings).

The U-frame stiffness (expressed as the parameter C_d in BS EN 1993-2) is determined by the aggregate stiffness of the three component parts of the frame, viz:

- the deck and/or transverse members forming the invert of the U-frame.
- the webs of the main members, plus associated stiffeners, that form the vertical legs of the U-frame.
- the joint between the deck and the main members.

It should be noted that Table D.3. in BS EN 1993-2 gives expressions for C_d that do not include a term for joint stiffness/flexibility but the flexibility of the joints should be allowed for. (The point is made, in principle, in BS EN 1993-1-1, 5.1.2, and BS EN 1993-1-8, 5.1.1, although the rules are expressed in terms more familiar to building designers.) The joint flexibility can be allowed for by adding the term h^2EI_v/S_j in the denominator of the expression in row 1a of Table D.3, where S_j is the stiffness of the joint. (In the absence of values of S_j appropriate to the type of joints used in bridge U-frames, values of $1/f$ may be used as guidance, where f is the flexibility parameter given in Section 9 of PD 6695-2:1980.

Individual U-frames must possess sufficient stiffness and strength if they are to restrain the compression flanges in the desired manner. Although it is stiffness rather than strength which theoretically determines the effectiveness or otherwise of the lateral restraint, the requirement for adequate strength cannot be ignored. Lateral forces on the top flange or chord from vehicle impact may need to be allowed for. Codified design guidance therefore provides both minimum stiffness and strength criteria for U-frames.

The design force, F_{Ed} for the U-frame restraints to the compression flange are derived in BS EN 1993-2 6.3.4.2(5). The formulae given is derived from a beam on elastic foundations model adopted for checking the compression flange itself. Initial bow imperfections in the compression flange give rise to forces in the restraints when the flange is loaded and the bow grows further. However, the design force calculated in BS EN 1993-2 (6.11) is overly conservative as the relevant deformation to be magnified when calculating the spring force should be the actual flange geometric imperfection, not the equivalent geometric imperfection that includes residual stresses applicable to the design of the flange. Furthermore, the relevant length over which to calculate this imperfection is the half wavelength of buckling, L_w, rather than the effective length. The second generation of BS EN 1993-2 will address this issue and the design force F_{Ed} for the U-frame restraints to the compression flange, that depends on the distance between the springs representing the U-frames, d_s, will be:

$$F_{Ed} = \frac{N_{Ed}}{100} \qquad \text{if } L_{cr} \leq 1.2\, d_s$$

$$F_{Ed} = \frac{N_{Ed}}{N_{cr} - N_{Ed}} \times \frac{C_d L_w}{500} \qquad \text{if } L_{cr} > 1.2\, d_s$$

The half wavelength of buckling, L_w, can be determined by taking L_R/L_w as the next integer below L_R/L_{cr} but not less than unity, noting that L_R is the length between rigid restraints and L_{cr} is the effective length of the compression flange associated with the critical buckling load N_{cr} – see Figure 1.

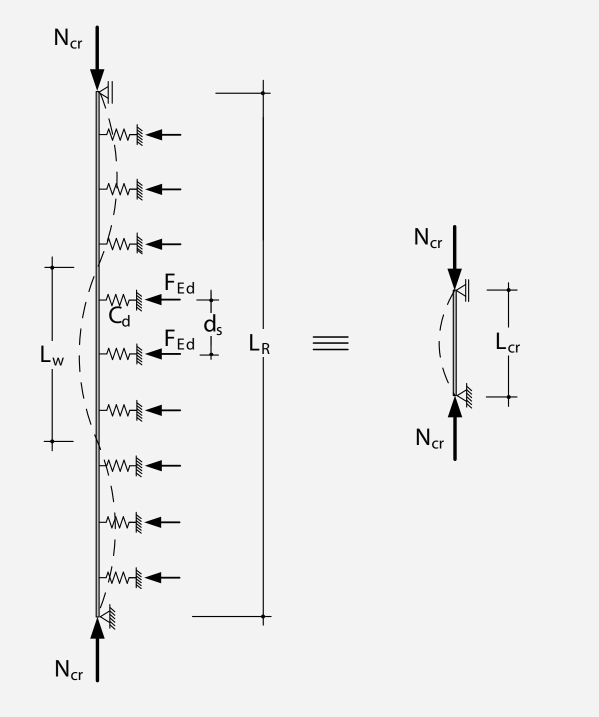

Figure 1 Relationship between L_w, L_{cr} and L_R

Where a continuous half-through deck is used in a multiple span application, stress in the top flange or chord becomes tensile in hogging moment regions and, consequently, buckling instability is not in question. In these regions the compression (i.e. lower) flange or chord is laterally restrained by the deck.

A general point is worthy of note here: a point of contraflexure in the bending moment diagram is not equivalent to a lateral restraint. A point of contraflexure, with no lateral restraint framing into it, can displace laterally; consequently it cannot be relied upon to form a ‘node’ in the plan buckling configuration.

Second order 3-dimensional analysis may be appropriate to evaluate action effects and considerations of buckling stability of half-through bridges, especially for heavily skewed spans. The successful completion of such an analysis will need to ensure a rigorous treatment of the effects of worst case geometric imperfections, joint / material non-linearities and residual stresses. Correlation of the analysis output against physical testing and research results is recommended whenever possible.

Advantages of half-through construction

The principal advantage afforded by the half-through deck is minimum effective construction depth; see Figure 1. (This is also true for a fully through deck, where, instead of U-frame action, lateral bracing is provided above the traffic.) Consequently, where deck soffit levels are constrained to be as high as possible and carriageway or rail levels on the structure as low as possible, a through or half-through deck will frequently be the preferred, if not the only feasible, solution.

Minimum effective construction depth sometimes has the added advantage of minimising the volume of fill material required for approach embankments, or where the depth of a cutting must be minimised, for example when a new roadway is to be constructed beneath an existing railway. This may or may not be significant for a particular scheme.

Typical applications of half-through decks

Perhaps the two most common applications of half-through construction are pedestrian bridges (Figure 2) and railway bridges (Figure 3). For railway bridges it is usual practice for intermediate vertical stiffeners to be external to simplify the form of joints to cross girders. Guidance on railway bridge design is given in Reference [1]; this illustrates various forms of half-through construction and discusses the considerations for their design.

Half-through construction has not been used to the same extent for highway underbridges. There are perhaps a few reasons for this:

- Minimum effective construction depth is rarely the overriding design consideration.
- Required deck widths are frequently large enough to render the U-frames very flexible. In turn, this means low levels of restraint to the compression flange and inefficient use of material in the main girders.
- The increased risk of vehicle collisions with the main girders (vehicles carried by the half-through bridge). In some cases it may be necessary to provide ‘P6’ parapets to minimise the risk of collision damage to the main girders.
- The aesthetics of a plate girder half-through deck may be less acceptable especially if main girders are stiffened on the external face.

Nevertheless, half-through highway bridges based on plate girders or trusses are perfectly possible (Figures 4 & 5), provided that decks are not too wide.

Erection considerations

Although compression flange stability is provided by U-frame action in the completed structure, the erection scheme must consider buckling and overall stability before the U-frames are formed and the permanent plan rigidity has been achieved.

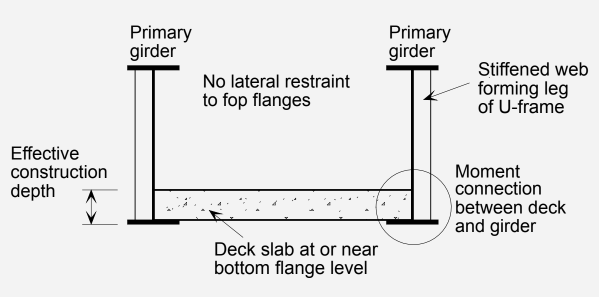

Figure 2 Basic configuration of half-through bridge deck

Skew spans

The designer should note that half-through construction for heavily skewed decks requires particular consideration of the U-frame stiffness between the obtuse and acute corners of the bridge, the form and orientation of the bearings, and interaction with trimmer girders, particularly in relation to interpretation of codified design guidance. For example, L-frames rather than U-frames provide compression flange restraint at the ends of the deck, but the codes do not explicitly cater for skew.

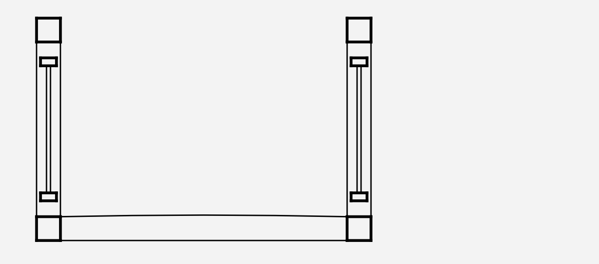

Figure 3 Typical half-through pedestrian bridge (truss and vierendeel girder construction)

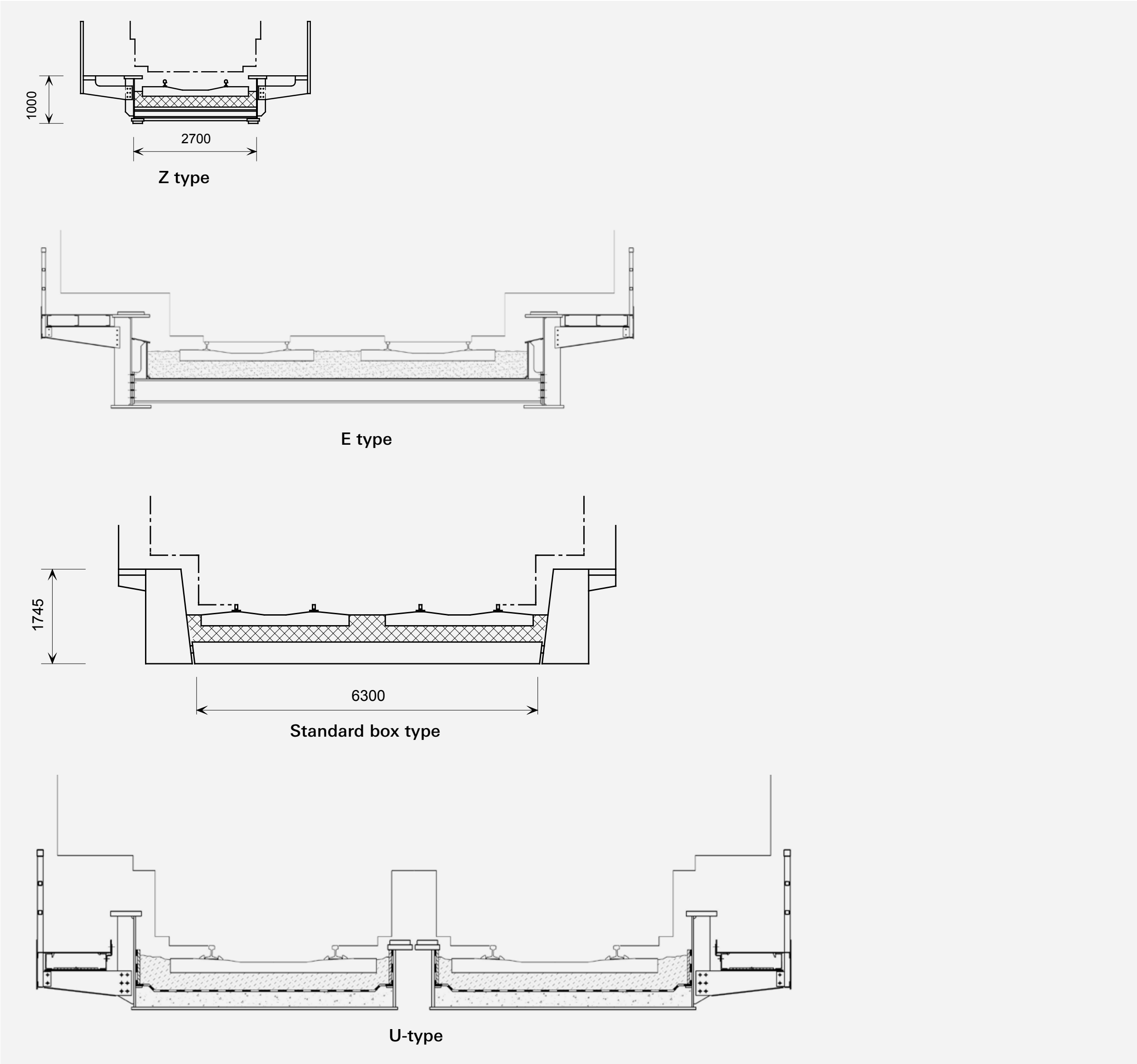

Figure 4 Standard half-through railway bridges

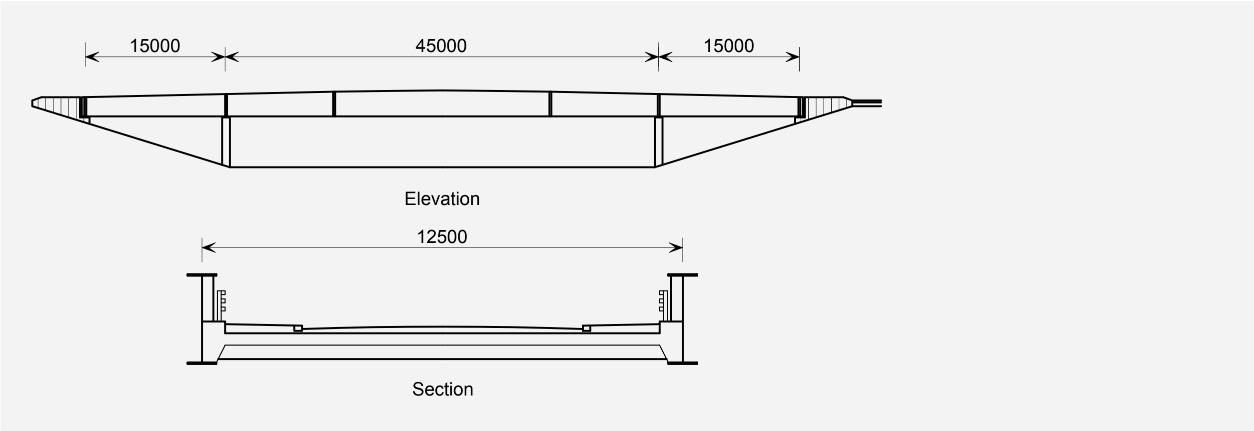

Figure 5 Typical multi-span half-through plate girder highway bridge

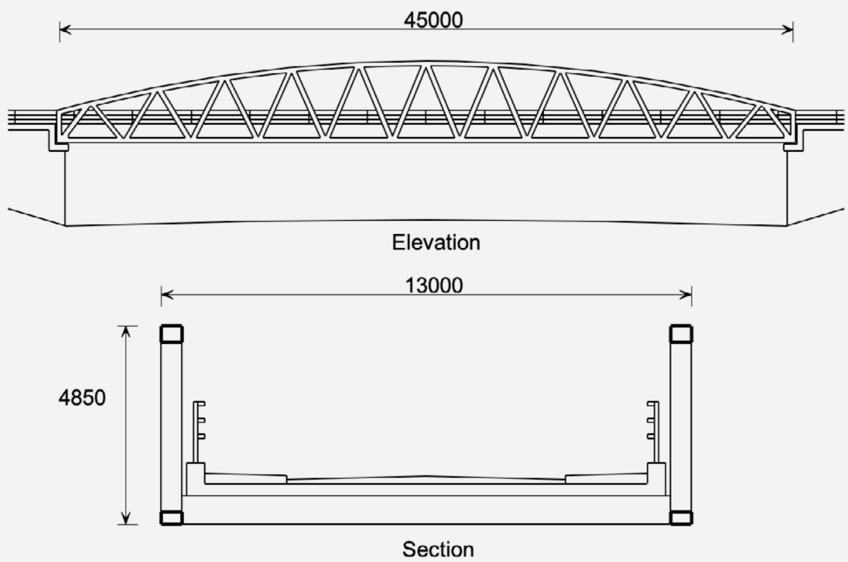

Figure 6 Typical half-through truss highway bridge

References and further reading

[1] Design guide for steel railway bridges (P318), The Steel Construction Institute, 2004

[2] BS EN 1993-2:2006, Eurocode 3: Design of steel structures – Part 2: Steel bridges.

[3] BS EN 1993-1-1:2005, Eurocode 3: Design of steel structures – Part 1-1: General rules and rules for buildings.

[4] BS EN 1993-1-8:2005, Eurocode 3: Design of steel structures – Part 1-8: Design of joints.

[5] PD 6695-2:2008, Recommendations for the design of bridges to BS EN 1993-2