Guidance Note 1.05

# Structural arrangement

## Scope

This Guidance Note covers the structural arrangement of deck type composite bridges (concrete deck slab on top of steel beams, plate girders or box girders). Whilst the Note is written principally with I-section steel bridge girders in mind, much of the information is also equally applicable where steel box girders are used for short and medium spans (see also GN 1.08). The information is presented generally in the order in which it will be considered during the course of the design.

## Bridge arrangement

The designer will determine the span lengths of the bridge from consideration of the physical dimensions of the obstacle to be crossed, the required clearance envelopes, the available locations for the bridge abutments and intermediate piers (if more than one span) and aesthetics. The geometry of the crossing may require the bridge to be skewed (see GN 1.02).

The use of 'fully 'integral' bridge construction is often appropriate and this form has grown to cover a large proportion of new-build highway bridge construction in the UK (see Reference [4]). This form of construction has both durability and structural efficiency benefits, however the interaction between the superstructure, substructure and abutment backfill needs to be considered in the design. The UK DMRB Standard CD 350 requires that fully integral construction be adopted for all bridges with an overall length up to 60 m or skews of up to 30°, but also permits its use beyond these limits.

In practice it is possible to adopt fully integral construction on much longer bridges provided that the substructure and abutment backfill is designed and detailed to accommodate the thermal movements.

On longer bridges and viaducts where the use of fully integral construction is not be feasible due to the need to accommodate large thermal movements it is usually

possible to use integral connections at all or some of the intermediate piers. This is usually termed "semi-integral" bridge construction. SCI have produced a guide on the design and detailing of integral steel bridges (see Reference [3]).

Where there are three or more spans and the deck is simply supported at the end supports, end spans are normally proportioned to be 0.7 to 0.85 of the length of the adjacent interior span. With spans in this ratio, the end span sagging moment will be of similar magnitude to that in the adjacent span, and it is unlikely that there will be uplift at the end support.

For bridges of more than one span, variable depth beams, plate girders or box girders may be used, although the saving in girder weight (at midspan) will usually only be significant for span lengths greater than about 40 to 45 m. On multi-span bridges with variable depth beams, plate girders or box girders, care should be taken with the appearance. Whilst haunching the beams, plate girders or box girders over the main span piers will give a satisfactory appearance, multiple haunched spans can be visually disturbing. Reference [1] gives guidance on the appearance of bridges.

Unless particular circumstances such as mining subsidence warrant otherwise, multi-span bridges should always be continuous over intermediate supports (see Reference [1] and GN 1.04). Steelwork for well designed continuous decks will invariably be more economic and sustainable than that for the equivalent simply supported spans. Continuity also offers robustness and redundancy in the event of damage to the supporting substructure.

## Deck type

The choice of deck type will usually be a function of a number of factors, the most important of which is the maximum bridge span. For short spans (up to 25 m)

it is possible to adopt standard rolled beam sections (UK, HEB) etc., however beyond this span fabricated plate girders or box girders are required.

## Beam/plate girder Decks

The number of main beams or plate girders in the deck cross section is determined principally by the required width of the deck and the economics of the steelwork. In composite construction the two arrangements that are most commonly used are:

- multiple parallel longitudinal main girders spaced at 3 to 4 m centres with the deck slab spanning transversely (see Figure 1)

- the 'ladder deck', comprising two longitudinal main girders with the deck slab spanning longitudinally between cross beams that are spaced at about 3 to 4 m centres (see Figure 2)

A span of 3.5 m is about the optimum for a 250 mm reinforced concrete deck slab and also allows the use of proprietary permanent formwork.
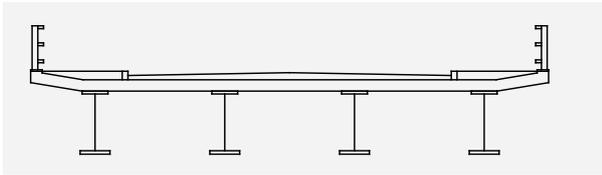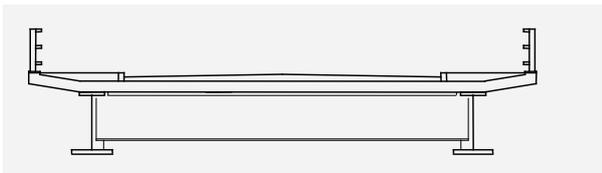


Figure 1    Multiple girder bridge



Figure 2    Ladder deck bridge

Where there are limitations on construction depth, multiple girders with a closer spacing may be required, or, if depth is severely limited, through or half-through types of construction may be utilised (see GN 1.10). Ladder decks usually prove to be economical for spans upwards of 35 – 40 m, and are best suited to bridge decks up to about 12 m in width.

The two main girder ladder deck arrangement can prove cost effective on wider decks, although the loading on the two main girders can become very heavy. Doubler plates may have to be used to provide flanges of the required size, or a third main girder added. Irrespective of the width of the deck, ladder

deck girders will usually have a greater section depth than those in a multiple girder arrangement because the individual girders carry heavier loads.

On bridges with spans greater than 45 m and with wide decks, by spacing the main girders wider than 4 m apart and by haunching the deck slab, fewer girders can be used, and a significant saving in material in the girder webs can be made (see Figure 3). For spans in the range 80 -100 m, plate girder composite decks of this form can be very economical where a ladder deck arrangement cannot be used.
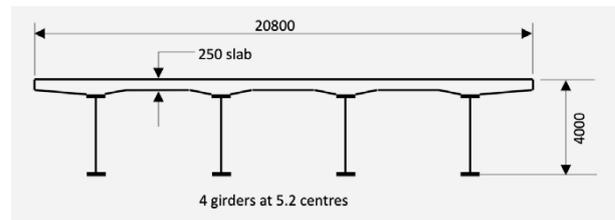


Figure 3    Deck with haunched slab

Whichever arrangement is chosen for the deck cross section, careful consideration should be given as to how best to provide required crossfalls or superelevation. Most commonly the levels of the girder top flanges are set to define the soffit level of the deck slab, either by setting the bridge bearings to varying levels or by varying the girder heights. Less commonly, and usually only on smaller decks, the thickness of the deck slab is varied (see Figure 4).
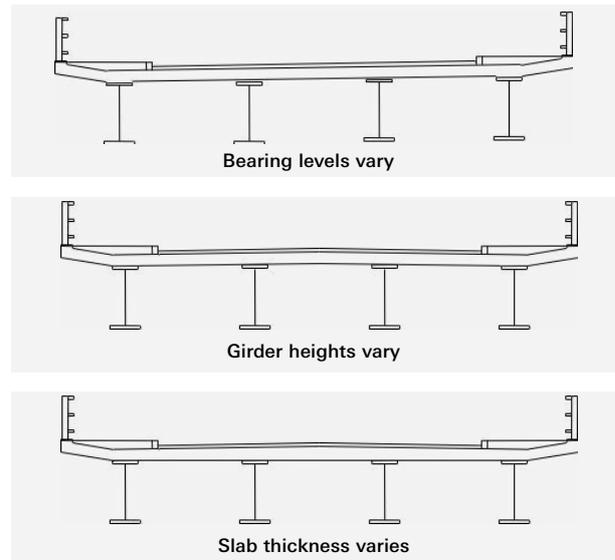


Figure 4    Superelevation and crossfall

With I-section girders the deck cross section will invariably have the girder top flange horizontal.

## Box Girder Decks

Box girders tend to be used either for long spans where the flanges of a plate girder would otherwise become excessively thick or for situations where high torsional stiffness is required (e.g. plan curvature). Box girders may also be selected for aesthetic reasons as they do not normally require external bracing or stiffeners.

Box girders are usually "tub" or "open" configuration with a composite concrete top flange but can also be used with an orthotopically stiffened top flange in situations where it is important to keep the girder weight down.

Box girders may be trapezoidal in shape with sloping webs or rectangular with vertical webs. This choice is usually a function of the deck width and the need to limit the length of the cantilevers, however there may also be aesthetic considerations.

It is usual to vary the web heights to provide the slope (see Figure 5). Sometimes the whole girder may be tilted so that the top flange is sloped parallel to the upper surface of the slab (this keeps the box geometry orthogonal, which may have advantages during fabrication, particularly of closed boxes).
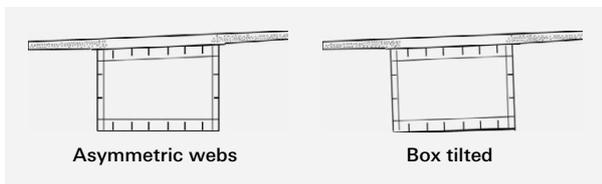


Figure 5    Crossfalls on box girders

Longitudinal stiffening of box girders is often used to control the panel buckling of webs and compression flanges, however the efficiency savings in web and flange material that result are not necessarily reflected in the economy of the solution due to the increased fabrication costs and testing required for this extra stiffening.

Orthotopically stiffened fully steel boxes using thin outer flange and web plates are usually adopted on long span cable-supported bridges where the permanent weight of the deck is a significant proportion of the total force in the cables (see Figure 6). Orthotropic boxes may also be used for active travel bridges where the lightweight section permits a more slender appearance to be achieved.
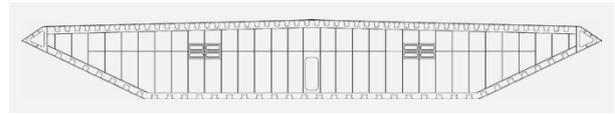


Figure 6    Orthotropic box girder

## Deck erection

The designer should always bear in mind the method of erection. An even number of girders will facilitate erection in pairs by crane. If the steelwork is to be erected by launching, then constant depth girders are virtually a necessity.

There may be particular constraints at the erection site that limit the transport, handling and erection of the girders. In such cases the erection cost of a small number of heavy main girders may outweigh the savings in material cost and carbon over a greater number of smaller girders.

## Deck slab cantilever

With a multiple girder arrangement, the length of the deck slab cantilever will usually be about half the girder spacing. For both ladder deck and multiple girder arrangements, it is customary to limit the maximum length to not more than about 1.5 m for a 250 mm slab. A longer cantilever will require the deck slab at the cantilever root to be thickened, and with multiple girders will result in the outermost girder being more heavily loaded than the inner girders. Generally, a short cantilever is to be avoided for aesthetic reasons and because the cantilever should have sufficient length to protect the edge girder from the elements. With a high containment parapet (e.g. H4a), a short cantilever may, however, be unavoidable.

Deck cantilevers can be constructed in-situ using a traditional formwork system supported from the main girders or, as is increasingly being adopted, through the use of precast units.

When using in-situ construction the designer should consider the stage at which the cantilever is to be constructed. From a construction point of view, casting the full width of the deck in one operation is generally preferred. This is usually done using a cantilever formwork system (see Figure 7) that is fixed to the outside face of the edge girder by bolting each temporary frame to a proprietary attachment that is

welded to the upper surface of the top flange. The formwork system can be attached to the girder before erection, which is a particular advantage if the bridge has to be erected in a limited possession.
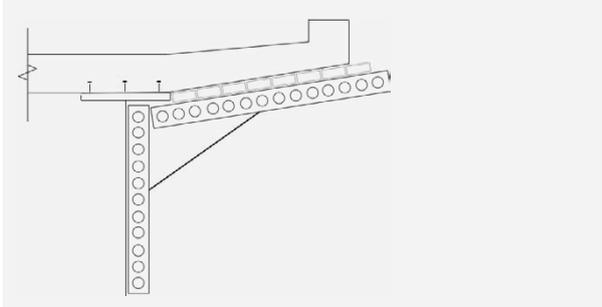


Figure 7    Cantilever formwork

Alternatively, the cantilevers can be cast as a second stage, after the slab over the girders has been constructed and is acting compositely (see Figure 1). Note that the arrangement shown in Figure 6 will put a large torsion on the edge girder when the cantilever is concreted, and this torsional loading should be taken into account in the design and detailing of the bracing system.

A two-stage construction sequence is particularly advantageous for long cantilevers, as the cantilever wet concrete dead load is carried by the composite deck rather than by the edge girder in the bare steel condition. Also, with two stage construction, it is easier to obtain the correct line and level of the cantilever tip and stringcourse. If a two-stage sequence has to be used, this should be stated on the drawings and provision for deflection allowance (precamber) made accordingly (see GN 4.03).
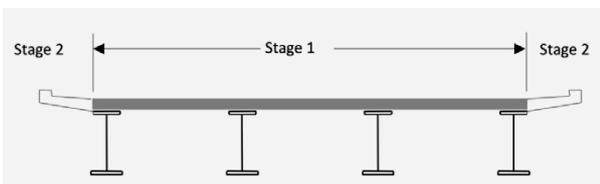


Figure 8    Two stage construction

When construction uses precast units, the cantilever may either be supported using temporary "strongbacks" from the outer pair of girders (see Figure 9) or incorporated into a precast deck unit that also spans between the outer girder pair (see Figure 10). The advantage of this latter option is that it is self-supporting and does not require any temporary works, however it inevitably results in a heavier unit

and the need to group the girder shear connectors into pockets formed within the precast deck slab units.

With precast deck slab construction there is a need to form in-situ concrete connections between the units themselves and with the steel girders to ensure composite behaviour.
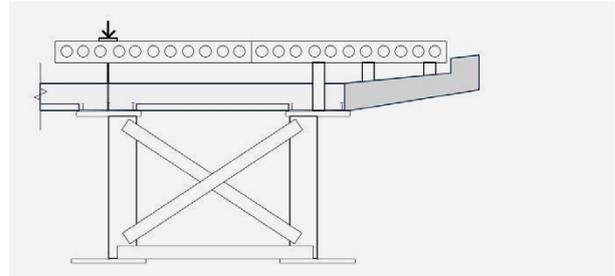


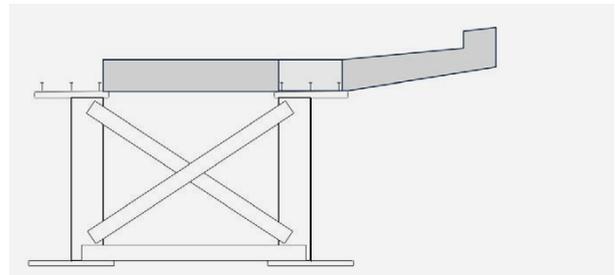Figure 9    Precast cantilever support



Figure 10    Precast deck unit incorporating cantilever

## Support to the deck

Generally, for a single span bridge deck the girders will be supported directly on the bridge abutment. Most simple single span highway bridges can be built fully integral with the exception of those with high skews or cable supported decks. Where integral construction is not possible a bearing is provided at the ends of each girder.

Where there is more than one span the arrangement at the abutment will be similar to that for a single span and the girders will also be supported on the intermediate piers which may or may not be integral with the deck depending on the thermal movements.

With multiple girders the form of the substructure can be chosen so that either:

- each girder is supported on a temporary or permanent bearing, usually in conjunction with leaf piers or, less frequently, on portal type piers or individual columns (see Figure 11 for integral pier and Figure 12 for bearing supported pier)
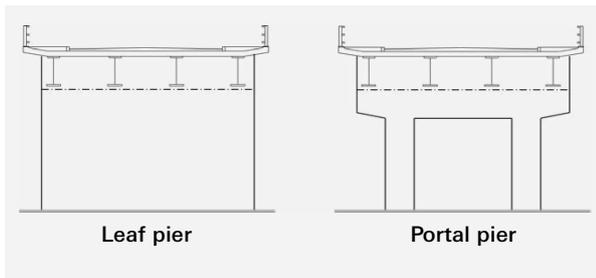
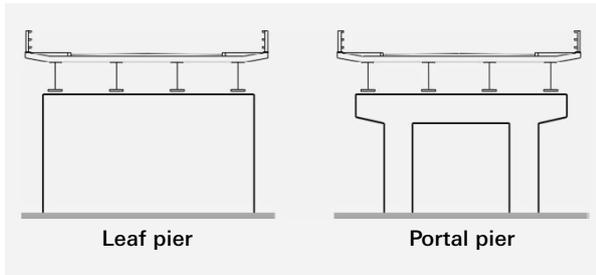Figure 11   Leaf and portal piers (all girders integral)



Figure 12   Leaf and portal piers (all girders on bearings)

or

▪ there are fewer bearings than girders; this requires the use of steel or reinforced concrete crossheads (see Figure 13)
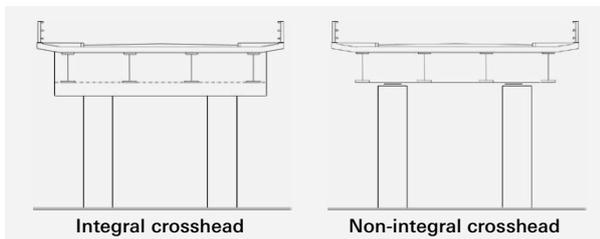


Figure 13   Crosshead

Use of crossheads with haunched girders can be unsatisfactory visually, because the point of the haunch appears to be unsupported. The combination of haunching and integral crossheads is best avoided, especially where the supports are skewed.

Where non-integral crossheads are used, the stability of the steelwork during erection must be considered. If the girders are erected one at a time, temporary propping/support will be required. If they are lifted in pairs the integral crosshead can be landed directly on the supporting pier.

Appropriate restraint against sideways rotation should always be provided.

For relatively narrow decks (usually with just two girders) a single column intermediate support is often preferred for aesthetic reasons. A single column support may also have to be used at a skew crossing where there is insufficient space to accommodate an

orthogonal leaf type pier – for example in the central reserve of a dual carriageway. In such instances the designer should ensure that torsional loading is adequately distributed by the deck.

Usually with a ladder deck arrangement each of the girders is supported on a bearing seated directly on column type piers (see Figure 14) or, less frequently, on leaf type piers. With this arrangement the main girders can be landed directly on the supporting pier. The cross beams are usually erected and bolted once both main girders have been erected. A deeper cross beam or additional bracing will often be required at the support positions (see GN 2.03).
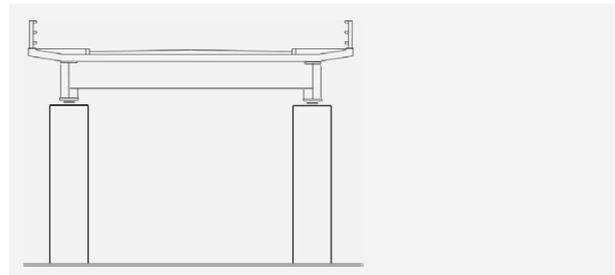


Figure 14   Typical ladder deck pier

## References

[1]   CD 351 The design and appearance of highway structures Design Manual for Roads and Bridges, Highways England, 2020

[2]   CD 350 The design of highway structures, Design Manual for Roads and Bridges, Highways England, 2020.

[3]   Integral Steel Bridges (P450), SCI, 2025

[4]   Integral bridges - SteelConstruction.info