Preliminary Steel Composite Bridge Design Charts
(Eurocode version)
User Manual

1. Introduction

The charts provided give initial estimates of flange area and web thickness for typical composite bridge cross sections as described in the SCI guide to composite highway bridge design.[1] There are two sets of charts covering multi-girder bridges and ladder deck bridges respectively (Figures 1 and 2). An excel spreadsheet is also available which uses the data in the charts to give plate girder sizes directly.

The charts were derived using resistances from BS EN 1994-2[2] and actions from BS EN 1991-2[3] with the relevant UK National Annexes[4]. Grillage models were used to take transverse distribution into account. Continuous and simply supported plate girders are covered. The multi girder charts give a different design for inner and outer girders. Two load models, LM1 and LM3, were considered and elastic (Class 3 & 4) and plastic (Class 1 & 2) designs are provided. ULS and SLS moment, shear and moment shear interaction have been considered in the designs.

It is emphasised that the sizes obtained do not represent final designs, which must always take into account all factors, such as bridge configuration and loading. Some of the additional effects that must be considered for integral, curved and skewed decks are discussed in section 4.

The charts are based on the following assumptions:

<u>Slab / Surfacing</u>

- (i) Deck slab 250 mm average thickness.
- (ii) Longitudinal deck reinforcement is 20 mm high yield bars at 150 mm centres top and bottom.
- (iii) Deck slab is C40/50 concrete
- (iv) No haunches on deck slab
- (v) Parapet edge beam 500 mm x 500 mm
- (vi) Cantilever at edge 1600 mm long
- (vii) 120 mm thick surfacing
- (viii) Deck slab cast in one stage

<u>Steelwork</u>

- (i) Steel grade S355

(ii) Minimum top flange width 350 mm to fit at least 2 rows of shear studs and formwork seating

(iii) Transverse stiffeners provided at lesser of 8 m centres or 1/3 span length

(iv) Torsional bracing provided at transverse stiffeners locations

(v) For ladder decks workable cross girder dimensions have been assumed. These are summarised in Table 1 below.

Main Girder Depth	Main Girder Spacing (m)	Top Flange (mm)		Web (mm)		Bottom Flange (mm)		Total Depth (mm)
		b	d	b	d	b	d	
≥750mm	5	250	15	16	227	150	8	250
	10	250	15	12	720	250	15	750
	15	250	15	12	705	500	30	750
	20	250	15	12	695	700	40	750
<750mm	5	250	15	16	227	150	8	250
	10	250	15	12	465	350	20	500
	15	250	15	15	450	600	35	500
	20	250	15	16	435	800	50	500

Table 1: Assumed Cross Girder Dimensions for Ladder Decks

Live Loading

(i) Load Model 1 consists of UDL, Tandem Systems and 2 m wide footway loading

(ii) Load Model 3 consists of UDL, Tandem Systems, SV196 and 2 m wide footway loading

(iii) Traffic loading is always the leading effect

(iv) Coexistent temperature effects have been considered.

General

(i) Single span designs are based on a single girder size throughout its length.

(ii) For continuous decks separate pier girders and span girder designs are given with the pier girder lengths being 0.4 x main span, centred over the pier.

(iii) Continuous span designs are based on 3 span models with side spans 70% the length of the central span. The charts are applicable if adjacent continuous spans are roughly equal in length.

(iv) The steelwork is assumed to be unpropped during construction and therefore not acting compositely under its own weight and that of the concrete slab. The steel is however composite for all superimposed loads applied after the concrete deck slab has cured.

(v) The designs take into account lateral torsional buckling during the casting of the deck slab. It is assumed that the bracing at 8 m centres provides full torsional restraint and the check is based on the BS5400 approach. If a more accurate elastic critical buckling moment was derived, as permitted in the Eurocodes, the bracing requirements could be reduced.

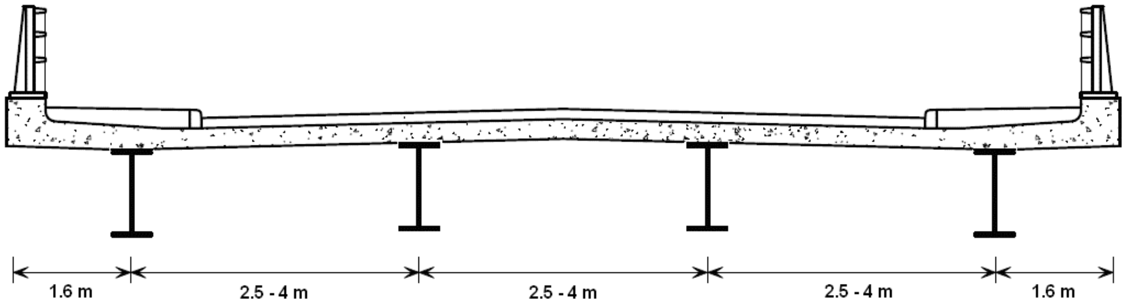


Figure 1: Typical Multi Girder Cross Section

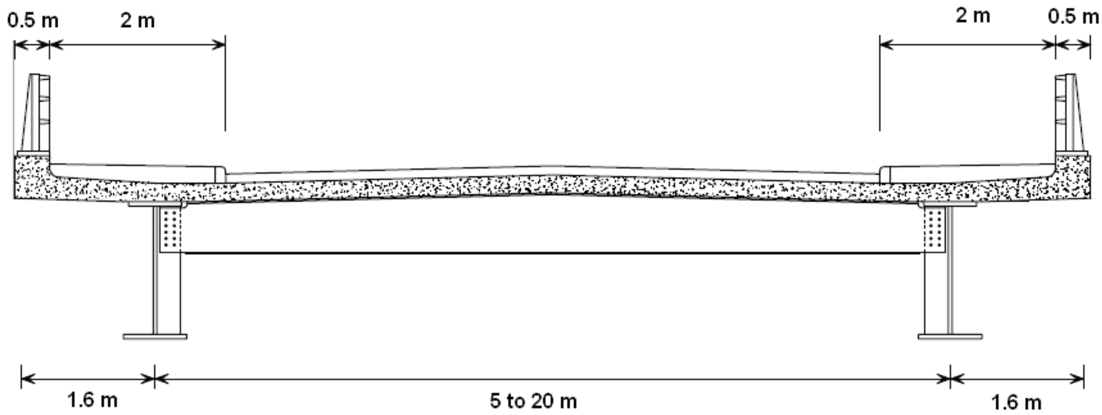


Figure 2: Typical Ladder Deck Section

2. Use of Charts

Elastic / Plastic Design

Total plate girder area charts are provided. These show total steel area plotted against span for plastic and elastic designs. There are separate sets of charts for:

- (i) Simply supported bridges
- (ii) Continuous bridges – Span girders
- (iii) Continuous bridges – Pier girders

For the multi girder charts areas are given for inner and outer girders. For the ladder deck charts areas are given for cross girder spacing of 3 and 4 m.

For a given girder spacing, girder type, load model, span to depth ratio and span the total girder areas for an elastic and plastic design can be determined. Based on these the designer then chooses whether to use an elastic or plastic section. If intermediate span to depth ratios or girder spacings are required the elastic design or plastic design areas can be obtained by interpolating between charts. (The spreadsheet does this automatically.)

The span to depth ratio is based on the total depth of the girder and slab, see Figure 3.

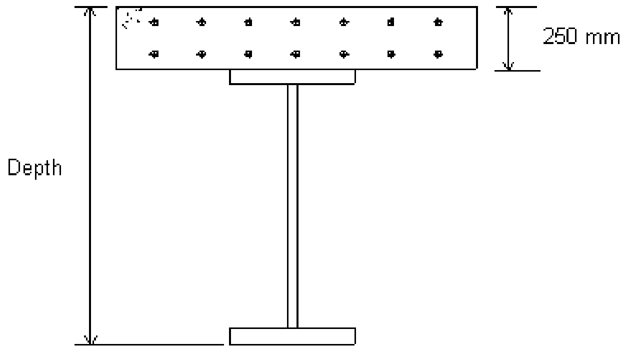


Figure 3 Depth Used for Span to Depth Ratio

Plate Girder Sizes

The individual flange areas and web thickness can be obtained from the plate size charts. There are separate charts for different girder type, spacing and inner and outer girders. The web depth is not given directly as it is a function of the span to depth ratio and span. When selecting flange dimensions, the limits on flange outstands for elastic and plastic section given in Table 5.2 of EN 1993-1-1 should be taken into account. (The spreadsheet indicates compliance with this automatically.)

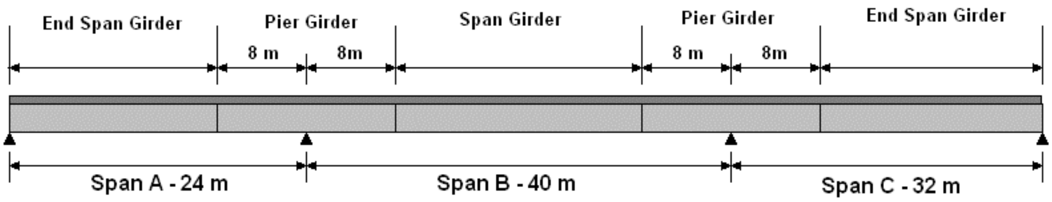
Continuous Spans

Pier Girder and internal Span Girder charts are provided for continuous spans. For end span girders, suitable plate sizes can be obtained by taking a span increased by 25% from the actual end span and using the continuous span girder charts.

3. Worked Examples

3.1 Continuous Multi Girder Bridge

A composite highway bridge has 3 continuous spans – A, B and C of 24, 40 and 32 m. There are 4 girders at 3 m centres. The carriageway carries SV196 loading (i.e. LM3). The section depth including the slab is 1.75 m. Estimate the main girder sizes.



3.1.1 Span Girders

Span A

This is an end span so take the span as 1.25 x 24 = 30 m, S/D = 30m / 1.75m = 17 so assume S/D = 20, which is slightly conservative, and use S/D = 20 for the charts (and spreadsheet if doing a cross-check)

From *Area – Span – 3m Spacing* chart:

Inner Girder - Elastic Area = 0.0295 m^2 (j) – i.e. from line 'j'

- Plastic Area = 0.0290 m^2 (b)

Outer Girder - Elastic Area = 0.0285 m^2 (n)

- Plastic Area = 0.0270 m^2 (f)

These values show that the plastic design is more efficient, so this will be used.

From *Span Girder – 3m Spacing – Inner* chart:

Inner Girder - Top Flange Area = 7500 mm^2 (b), so could use 350 mm x 21 mm

- Bottom Flange Area = 9500 mm^2 (j), so could use 400 mm x 24 mm

- Web Thickness = 10 mm (r)

From *Span Girder – 3m Spacing – Outer* chart:

Outer Girder - Top Flange Area = 7500 mm^2 (b), so could use 350 mm x 21 mm

- Bottom Flange Area = 8000 mm^2 (j), so could use 400 mm x 21 mm

- Web Thickness = 9.5 mm (r)

Span B

S = 40 m, D = 1.75 m, so S/D = 23 so assume S/D = 20

(It would be possible to use an interpolation between S/D = 20 and S/D = 30 here.)

From *Area – Span – 3m Spacing* chart:

Inner Girder - Elastic Area = 0.0370 m^2 (j)

- Plastic Area = 0.0355 m^2 (b)

Outer Girder - Elastic Area = 0.0360 m^2 (n)

- Plastic Area = 0.0340 m^2 (f)

These values show that the plastic design is more efficient, so this will be used.

From *Span Girder – 3m Spacing – Inner* chart:

Inner Girder - Top Flange Area = 7500 mm^2 (b), so could use 350 mm x 21 mm

- Bottom Flange Area = 9500 mm^2 (j), so could use 400 mm x 24 mm
- Web Thickness = 11 mm (r)

From *Span Girder – 3m Spacing – Outer* chart:

Outer Girder - Top Flange Area = 7500 mm^2 (b), so could use 350 mm x 21 mm

- Bottom Flange Area = 8600 mm^2 (j), so could use 350 mm x 25 mm
- Web Thickness = 10.5 mm (r)

Span C

This is an end span so take the span as 1.25 x 32 = 40 m (i.e. the same a span B)

3.1.2 Pier Girders

Take L as the greatest of the two adjacent spans i.e. assume S = 40m at both supports, hence S/D = 40m/1.75m = 23, so assume S/D = 20

(It would be possible to use an interpolation between S/D = 20 and S/D = 30 here.)

From *Area – Pier – 3m Spacing* chart:

Inner Girder - Elastic Area = 0.0570 m^2 (j)

- Plastic Area = 0.0760 m^2 (b)

Outer Girder - Elastic Area = 0.0600 m^2 (n)

- Plastic Area = 0.0760 m^2 (f)

These values show that the elastic design is more efficient, so this will be used. EN1994–2 clause 6.2.1.3 (2) limits the plastic bending resistance in a span girder to 0.9 $M_{pl,Rd}$ when elastic and plastic sections are mixed if the ratio of lengths of the spans adjacent to that support is less than 0.6. In this case this does not apply. If it did apply the size of the span girder would need to be increased slightly.

From *Pier Girder – 3m Spacing - Inner* chart:

Inner Girder - Top Flange Area = 6000 mm^2 (f), so could use 350 mm x 17 mm

- Bottom Flange Area = 27000 mm^2 (n), so could use 750 mm x 37 mm
- Web Thickness = 13 mm (v)

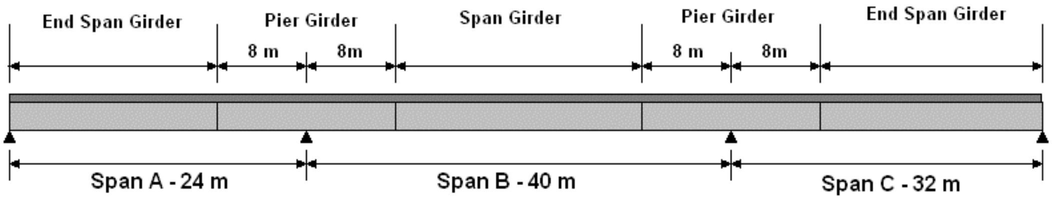
From *Pier Girder – 3m Spacing - Outer* chart:

Outer Girder - Top Flange Area = 9000mm^2 (f), so could use 400 mm x 24 mm

- Bottom Flange Area = 29000 mm^2 (n), so could use 750 mm x 39 mm
- Web Thickness = 13 mm (v)

3.2 Continuous Ladder Deck Bridge

A composite highway bridge has 3 continuous spans – A, B and C of 24, 40 and 32 m. The main ladder deck girders are 10 m apart with cross girders at roughly 3 m centres. The carriageway carries Load Model 1 loading only. The section depth including the slab is 1.75 m. Estimate the main girder sizes.



3.2.1 Span Girders

Span A

This is an end span so take the span as 1.25 x 24 = 30 m S/D = 30m / 1.75m = 17 so assume S/D = 20, which is slightly conservative, and use S/D = 20 for the charts (and spreadsheet if doing a cross-check)

<u>From *Area – Span – 10m Spacing* chart:</u>

- Elastic Area = 0.044 m^2 (i) – i.e. from line 'i'
- Plastic Area = 0.041 m^2 (a)

These values show that the plastic design is more efficient, so this will be used.

<u>From *Span – 10m Main Girder Spacing – 3m Cross Girder Spacing* chart:</u>

- Top Flange Area = 0.008 m^2 (a), so could use 350 mm x 23 mm
- Bottom Flange Area = 0.017 m^2 (i), so could use 450 mm x 37 mm
- Web Thickness = 13 mm (q)

Span B

S = 40 m, D = 1.75 m so S/D = 23 so assume S/D = 20.

(It would be possible to use an interpolation between S/D = 20 and S/D = 30 here.)

<u>From *Area – Span – 10m Spacing* chart:</u>

- Elastic Area = 0.057 m^2 (i)
- Plastic Area = 0.054 m^2 (a)

These values show that the plastic design is more efficient, so this will be used.

<u>From *Span – 10m Main Girder Spacing – 3m Cross Girder Spacing* chart:</u>

- Top Flange Area = 0.009 m^2 (a), so could use 350 mm x 26 mm
- Bottom Flange Area = 0.019 m^2 (i), so could use 450 mm x 43 mm
- Web Thickness = 15 mm (q)

Span C

This is an end span so take the span as 1.25 x 32 = 40 m i.e. the same as span B

3.2.2 Pier Girders

Take L as the greatest of the two adjacent spans i.e. assume S = 40m at both supports, hence S/D = 40m/1.75m = 23, so assume S/D = 20.

(It would be possible to use an interpolation between S/D = 20 and S/D = 30 here.)

From *Area – Pier – 10m Spacing* chart:

- Elastic Area = 0.116 m^2 (i)
- Plastic Area = 0.100 m^2 (a)

These values show that the plastic design is more efficient, so this will be used.

From *Pier – 10m Main Girder Spacing – 3m Cross Girder Spacing* chart:

- Top Flange Area = 0.007 m^2 (a), so could use 350 mm x 20 mm
- Bottom Flange Area = 0.024 m^2 (i), so could use 600 mm x 40 mm
- Web Thickness = 42 mm (q)

4. Guidance on more complex bridge layouts

The charts do not specifically cover integral, curved or skewed decks. Where these features are required, the charts can be used to roughly estimate the required girder sizes. However the additional effects that need to be designed for will generally require larger girder sizes than given by the charts. These additional effects are discussed below.

4.1 Integral Bridges

Integral bridges are subject to axial forces under temperature loading. The girders will need to be designed for the combined bending, shear and axial forces. This can be done by using a reduced web strength to account for shear and then linearly combining axial force and bending moments, or using the moment shear interaction equations with the moment capacity reduced for axial force. Examples of these methods are discussed in the Designers Guide to EN1993-2[5]

The magnitude of the axial force can be determined from a line beam model of the deck and abutments, including the effects of soil pressure. To obtain a conservative initial estimate the abutments could be assumed to provide full restraint and the axial force based on area x Young’s Modulus x change in temperature x thermal coefficient. The design charts provide a design which is fully stressed for moment and shear interaction and so larger plate girders would be required for an integral bridge.

Rotational restraint at the abutments will alter the moment distribution in the beam. The moments in single and end spans will be closer to, but not the same as, those in a central span of a continuous bridge.

For integral bridges the critical loadcase could either be temperature leading or traffic actions leading depending on the bridge configuration. In the production of the design charts only the traffic actions leading case was considered.

4.2 Curved Beams

Where the angle subtended between supports in each span is less than the values given in Table 2 the plate girder sizes from the charts could be used as a starting point with additional allowance made for the transverse bending effects in the flanges. The entire torsion would have to be conservatively assumed to act on the slab in this case.[6]

Number of Girders	Angle for 1 span	Angle for 2 or More Spans
2	2°	3°
3 or 4	3°	4°
5 or more	4°	5°

Table 2: Curvatures below which a straight model can be used for main beam moments and shears

For larger curvatures, and to obtain a less conservative design an appropriate 3D space frame model or a shell finite element model should be used to determine following the additional effects:

1. **Transverse bending in flange.**

   Warping torsion in the flanges will generate transverse bending moments in the flanges. The twist of the section due to torsion will also introduce minor axis moments equal to the major axis moment multiplied by the angle of rotation. The stresses due to these moments need to be included in the flange stress check and in the flange lateral buckling checks.

2. **St Venant torsional shear stresses in the web.**

   At ULS it is often simplest to assign a low St Venant torsional stiffness and assume all torsion is taken by warping stresses in the flanges. Where this is not possible EN 1993-1-1 clause 6.2.7 gives a reduction in *plastic* shear resistance for St Venant torsional stress. The Eurocode provides no guidance on reducing the shear *buckling* resistance for slender webs. The circulatory St Venant torsional shear flow will not promote overall shear buckling but will contribute to yielding. The equation in EN 1993-1-1 clause 6.2.7 could be used to reduce the shear bucking resistance or alternatively an additional term, St Venant torsional stress / design shear yield stress, can be added to the shear usage factor in the interaction equation in EN 1993-1-5 clause 7.1.

3. The curvatures effect on the web shear resistance.

The elastic critical shear resistance of a curved web panel is greater than that of an equivalent straight panel, however a greater reduction factor slenderness is required due to a reduced post-buckling strength. It is conservative to take the ultimate shear resistance of a curved web panel as the elastic critical buckling shear force for an equivalent straight panel.

Shear-moment interaction can be checked as for a straight beam, using a reduced shear resistance due to the torsion and reduced flange resistance due to the warping and minor axis moments.

4.3 Skew Bridges

For small skews the plate girder sizes from the design charts will be valid. For larger skew angles larger plate sizes may be required. The cross bracing arrangement in the bridge will affect the distribution of load in the structure and so the required girder sizes. To obtain an accurate estimate of the girder size a grillage model with bracing would be required.
For simply supported spans, the total girder areas for a skew deck are likely to be similar to the total girder areas for a square deck albeit distributed in a different manner.

---

[1] SCI Publication P356, Composite highway bridge design in accordance with Eurocodes and the UK National Annexes.

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

[3] BS EN 1991-2: 2003 Actions on structures. Traffic loads on bridges

[4] NA to BS EN 1994-2:2005 UK National Annex to Eurocode 4. Design of composite steel and concrete structures. General rules and rules for bridges, December 2007.
NA to BS EN 1991-2:2003 UK National Annex to Eurocode 1. Actions on structures. Traffic loads on bridges, May 2008.

[5] Designers' Guide to EN1993-2 Eurocode 3: Design of steel structures. Part : Steel Bridges. Hendy and Murphy, Thomas Telford

[6] Guide Specifications for Horizontally Curved Highway bridges (1997), AASHTO, Washington