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1 Introduction

Bridges are an essential part of the transport infrastructure.

1.1 General
A bridge is a means by which a road, railway or other service is carried over an obstacle such as a river, valley, other road or railway line, either with no intermediate support or with only a limited number of supports at convenient locations.

Bridges range in size from very modest short spans over, say, a small river to the extreme examples of suspension bridges crossing wide estuaries. Appearance is naturally less crucial for the smaller bridges, but in all cases the designer will consider the appearance of the basic elements, which make up his bridge, the superstructure and the substructure, and choose proportions which are appropriate to the particular circumstances considered. The use of steel often helps the designer to select proportions that are aesthetically pleasing.

Bridges are an essential part of the transport infrastructure. For example, there are more than 15,000 highway bridges in the UK, with approximately 300 being constructed each year as replacements or additions. Many of these new bridges use steel as the principal structural elements because it is an economic and speedy form of construction. On average, around 35,000 tonnes of steel have been used annually in the UK for the construction of highway and railway bridges.

The guide describes the general features of bridges, outlines the various forms of steel bridge construction in common use, and discusses the considerations to be made in designing them. It describes the steps in the design procedure for a composite plate girder highway bridge superstructure, explaining how to choose an initial outline arrangement and then how to apply design rules to analyse it and detail the individual elements of the bridge. Reference is made to simplified versions of the Structural Eurocodes for bridge design, which are available for student use (see Ref. 1 on page 31). In addition, the guide outlines material specification issues and the various approaches to corrosion protection.

Above: Renaissance Bridge (Photo courtesy of Angle Ring Co.), Bedford, England
Opposite: Clyde Arc Bridge, Glasgow, Scotland
Front cover: Hulme Arch, Manchester, England
1.2 Basic features of bridges

Superstructure
The superstructure of a bridge is the part directly responsible for carrying the road or other service. Its layout is determined largely by the disposition of the service to be carried. In most cases, there is a deck structure that carries the loads from the individual wheels and distributes the loads to the principal structural elements, such as beams spanning between the substructure supports.

Road bridges carry a number of traffic lanes, in one or two directions, and may also carry footways. At the edge of the bridge, parapets are provided for the protection of vehicles and people. The arrangement of traffic lanes and footways is usually decided by the highway engineer. Traffic lane and footpath widths along with clear height above the carriageway are usually specified by the highway authority. Whilst the bridge designer has little influence over selecting the layout and geometry of the running surface, he does determine the structural form of the superstructure. In doing so, he must balance requirements for the substructure and superstructure, whilst achieving necessary clearances above and across the obstacle below.

Rail bridges typically carry two tracks, laid on ballast, although separate superstructures are often provided for each track. Railway gradients are much more limited than roadway gradients and because of this the construction depth of the superstructure (from rail level to the underside or soffit of the bridge) is often very tightly constrained. This limitation frequently results in ‘half through’ construction (see Section 2.1). Railway loading is greater than highway loading and consequently the superstructures for railway bridges are usually much heavier than for highway bridges.

Footbridges are smaller lighter structures. They are narrow (about 2m wide) and are usually single span structures that rarely span more than 40m. There are a number of forms of steel footbridge (see Ref.4 on page 31), although they are outside the scope of this guidance publication.

Substructure
The substructure of a bridge is responsible for supporting the superstructure and carrying the loads to the ground through foundations.
To support the superstructure, single span bridges require two ‘abutments’, one at each end of the bridge. Where the bearing strength of the soil is good, these abutments can be quite small, for example a strip foundation on an embankment. Foundations on poor soils must either be broad spread footings or be piled. The abutments may also act as retaining walls, for example to hold back the end of an approach embankment.

Multiple span bridges require intermediate supports, often called ‘piers’, to provide additional support to the superstructure. The locations of these supports are usually constrained by the topography of the ground, though where the superstructure is long the designer may be able to choose the number and spacing of piers for overall economy or appearance. Intermediate supports are generally constructed of reinforced concrete.

**Integral construction**

Traditionally, movement (expansion) joints have been provided at the ends of the superstructure, to accommodate expansion/contraction. Experience in recent years has been that such joints require on-going maintenance, yet they inevitably leak and result in deterioration of the substructure below the joint. For bridges of modest overall length, it is now common to use integral construction, with no movement joint. In its simplest form, the ends of the superstructure are cast into the tops of the abutments. Integral construction requires the consideration of soil-structure interaction and is likely to be beyond the scope of a student project.
2 Forms of steel bridge construction

Structural steelwork is used in the superstructures of bridges from the smallest to the greatest.

Steel is a most versatile and effective material for bridge construction, able to carry loads in tension, compression and shear. Structural steelwork is used in the superstructures of bridges from the smallest to the greatest.

There is a wide variety of structural forms available to the designer but each essentially falls into one of four groups:

• beam bridges
• arch bridges
• suspension bridges
• stayed girder bridges

The fourth group is, in many ways, a hybrid between a suspension bridge and a beam bridge but it does have features that merit separate classification.

The following sections describe the range of forms of steel and composite (steel/concrete) bridge that are in current use, explaining the concept, layout and key design issues for each type.

Below left: Trent Rail Bridge, Gainsborough, England.

Opposite: Severn Bridge, Bristol, England.
2.1 Beam bridges

Beam and slab bridges
A beam and slab bridge is one where a reinforced concrete deck slab sits on top of steel I-beams, and acts compositely with them in bending. There are two principal forms of this beam and slab construction – multi-girder construction and ladder deck construction. Between them, they account for the majority of medium span highway bridges currently being built in the UK, and are suitable for spans ranging from 13m up to 100m. The choice between the two forms depends on economic considerations and site-specific factors such as form of intermediate supports and access for construction.

Multi-girder decks
In multi-girder construction a number of similarly sized longitudinal plate girders are arranged at uniform spacing across the width of the bridge, as shown in the typical cross section in Figure 1 below. The girders and slab effectively form a series of composite T-beams side-by-side. The girders are braced together at supports and at some intermediate positions.

For smaller spans it is possible to use rolled section beams (UKBs), but these are rarely used today for bridges: plate girders are almost always used. Typically, plate girders are spaced between about 3m and 3.5m, apart transversely and thus, for an ordinary two-lane overbridge, four girders are provided. This suits an economic thickness of the deck slab that distributes the direct loads from the wheels by bending transversely.

Ladder decks
An alternative arrangement with only two main girders is often used. Then the slab is supported on crossbeams at about 3.5m spacing; the slab spans longitudinally between crossbeams and the crossbeams span transversely between the two main girders. This arrangement is referred to as ‘ladder deck’ construction, because of the plan configuration of the steelwork, which resembles the stringers and rungs of a ladder.

A typical cross-section of a ladder deck bridge is shown in Figure 2. The arrangement with two main girders is appropriate (and economic) for a bridge width up to that for a dual two-lane
carriageway. Wider decks can be carried on a pair of ladder decks.

For both deck types, the use of plate girders gives scope to vary the flange and web sizes to suit the loads carried at different positions along the bridge. However, the resulting economies must be weighed against the cost of splices. Designers can also choose to vary the depth of the girder along its length. For example, it is quite common to increase the girder depth over intermediate supports or to reduce it in midspan. The variation in depth can be achieved either by straight haunching (tapered girders) or by curving the bottom flange upwards. The shaped web, either for a variable depth girder or for a constant depth girder with a vertical camber, is easily achieved byprofile cutting during fabrication.

Half-through plate girder bridges
In some situations, notably for railway bridges, the depth between the trafficked surface (or rails) and the underside of the bridge is severely constrained and there is little depth available for the structure. In these circumstances, ‘half through’ construction is used. In this form there are two main girders, one either side of the roadway or railway and the slab is supported on crossbeams connected to the inner faces at the bottom of the webs. The half-through form is perhaps more familiar in older railway bridges, where the girders are of riveted construction, but it is still used for new welded railway bridges and occasionally for highway bridges.

In half-through construction using I-beams, the top flange, which is in compression, has to be provided with lateral stability by some means. The two main girders together with the deck and transverse beams form a rectangular U shape and this generates so-called ‘U-frame action’ to restrain the top flange. There has to be a moment connection between the cross-members and the main girders to achieve this. Under railway loading, the connection is subjected to onerous fatigue loading and an alternative using box girders has been developed.
Box girder bridges

Box girders are in effect a particular form of plate girder, where two webs are joined top and bottom by a common flange. Box girders perform primarily in bending, but also offer very good torsional stiffness and strength. Box girders are often used for large and very large spans, sometimes as a cable stayed bridge. They can also be used for more modest spans, especially when the torsional stiffness is advantageous, such as for curved bridges.

In beam and slab bridges, box girders are an alternative to plate girders when spans exceed 40-50m. They can show economies over plate girders, though fabrication cost rates are somewhat higher for box girders. Two forms are used:
- multiple closed steel boxes, with the deck slab over the top
- an open top trapezoidal box, closed by the deck slab, which is connected to small flanges on top of each web

Spans of 100 to 200m typically use either a single box or a pair of boxes with crossbeams. Boxes are often varied in depth, in the same way as plate girders, as mentioned earlier.

For very long spans and for bridges such as lifting bridges, where minimising structural weight is very important, an all-steel orthotropic deck may be used instead of a reinforced concrete slab. The form of deck has fairly thin flange plate (typically 14mm) to the underside of which steel stiffeners have been welded; the stiffened plate is then able to span both transversely and longitudinally (to internal diaphragms) to distribute the local wheel loads.

Above about 200m, box girders are likely to be part of a cable stayed bridge or a suspension bridge. The box girders used in suspension bridges are specially shaped for optimum aerodynamic performance; they invariably use an orthotropic steel deck for economy of weight.

The principal advantages of box girders derive from the torsional rigidity of the closed cell. This is particularly important as spans increase and the natural frequencies of a bridge tend to reduce; stiffness in torsion maintains a reasonably high torsional frequency.

Torsional stiffness also makes boxes more efficient in their use of material to resist bending, especially when asymmetrical loading is considered. Comparing a single box with a twin plate girder solution it can be seen that the whole of the bottom flange of the box resists vertical bending wherever the load is placed transversely.

The aesthetic appeal of box girders, with their clean lines, is especially important where the underside of the bridge is clearly visible.

Although the fabrication of box girders is more expensive than plate girders, the margin is not so great as to discourage their use for modest spans. For large spans, the relative simplicity of large plated elements may well lead to more economical solutions than other forms. Erection is facilitated by the integrity of individual lengths of the box girders. Sections are usually preassembled at ground level then lifted into position and welded to the previous section.

Box girders are also used for railway bridges in half-through construction, as an alternative to plate girders. Two box girders are used, with the deck simply supported between them. With this arrangement, there is no need to achieve
U-frame action, because of the torsional stiffness and stability provided by the box sections themselves.

**Truss bridges**

A truss is a triangulated framework of individual elements or members. A truss is sometimes referred to as an ‘open web girder’, because its overall structural action is still as a member resisting bending but the open nature of the framework results in its elements (‘chords’ in place of flanges and ‘posts’ and diagonals’ in place of webs) being primarily in tension or compression. Bending of the individual elements is a secondary effect, except where loads are applied away from the node positions, such as loads from closely-spaced crossbeams that span between a pair of trusses.

Trusses were common in the earlier periods of steel construction, since welding had not been developed and the sizes of rolled section and plate were limited; every piece had to be joined by riveting. Although very labour intensive, both in the shop and on site, this form offered great flexibility in the shapes, sizes, and capacity of bridges. As well as being used as beams, trusses were also used as arches, as cantilevers and as stiffening girders to suspension bridges.

A typical configuration of a truss bridge is a ‘through truss’ configuration. There is a pair of truss girders connected at bottom chord level by a deck that also carries the traffic, spanning between the two trusses. At top chord level the girders are braced together, again with a triangulated framework of members, creating an ‘open box’ through which the traffic runs. Where clearance below the truss is not a problem, the deck structure is often supported on top of the truss; sometimes a slab is made to act compositely with the top chords, in a similar way to an ordinary beam and slab bridge.

Today, the truss girder form of construction usually proves expensive to fabricate because of the large amount of labour-intensive work in building up the members and making the connections. Trusses have little advantage over plate girders for ordinary highway bridges. On the other hand, they do offer a very light yet stiff form of construction for footbridges, gantries and demountable bridges (Bailey bridges).

Trusses are still considered a viable solution in the UK for railway bridges, especially where the spans are greater than 50m. A high degree of stiffness can be provided by deep trusses, yet the use of through trusses minimises the effective construction depth (between rail level and the bridge soffit), which is very often crucially important to railways. The construction depth is dictated only by the cross members spanning between the main truss girders.

Very many footbridges are built using trusses made from steel hollow sections. Profile cutting and welding of the hollow sections is straightforward and economic. Half through or through construction is usually employed – the floor of the bridge is made at the bottom chord level between two truss girders.

Opposite page: A9 Bridge, Pitlochry, Scotland.


Below right: Brinnington Rail Bridge, Manchester, England.
2.2 Arch bridges

In an arch bridge, the principal structural elements (‘ribs’) are curved members that carry loads principally in compression. A simple arch ‘springs’ from two foundations and imposes horizontal thrusts upon them. Although the arch ribs are primarily in compression, arch bridges also have to carry asymmetric loading and point loading and the ribs carry this partly by bending. This is more conventionally seen (in masonry bridges, for example) as the displacement of the line of thrust from its mean path under dead load.

In masonry bridges, load is imposed on the arch from above; the roadway (or railway) is on top of fill above the arch. A steel arch can have a similar configuration, with a steel or concrete deck above the arch, supported on struts to the arch below, or the arch can be above the roadway, with the deck suspended from it by hangers.

One situation where the arch is still favoured is in deep ravines, where a single span is required; the ribs can be built out without the need for intermediate support. In such cases, the deck is usually above the arch.

Perhaps the most familiar arch is that of the Sydney Harbour Bridge. In that bridge, much of the deck is hung from the heavy arch truss, although the deck passes through the arch near the ends and is then supported above it.

One form of arch which is sometimes used for more modest spans is the tied arch. Instead of springing from foundations, the two ends of the arch are tied by the deck itself (this avoids horizontal reactions on the foundations). The deck is supported vertically by hangers from the arch ribs.

In recent years, arches and tied arches have become a little more common, partly because the use of an arch from which to hang the deck allows the construction depth of a suspended deck to be kept shallow, even at longer spans, and partly because the arches make a clear architectural statement. Arches are sometimes skew to the line of the deck and sometimes the arch planes are inclined (inclined arch planes have been used in many recent footbridges, for dramatic visual effect).

2.3 Suspension bridges

In a suspension bridge, the principal structural elements are purely in tension. A suspension bridge is fundamentally simple in action: two cables (or ropes or chains) are suspended between two supports (‘towers’ or ‘pylons’), hanging in a shallow curve, and a deck is supported from the two cables by a series of hangers along their length. The cables and hangers are in simple tension and the deck spans transversely and longitudinally between the hangers. In most cases the cables are anchored at ground level, either side of the main towers; often the sidespans are hung from these portions of the cables.

In the mid 19th century, wrought iron links were used to make suspension ‘chains’; by the end of that century, high strength wire was being used for suspension ‘cables’. Steel wire is still being used today. Sometimes, for more modest spans, wire ropes (spirally wound wires) have been used.

In addition to its action in carrying traffic, the deck acts as a stiffening girder running the length of each span. The stiffening girder spreads concentrated loads and provides stiffness against oscillation; such stiffness is needed against both bending and twisting actions.

Because of their fundamental simplicity and economy of structural action, suspension bridges have been used for the longest bridge spans. The graceful curve of the suspension cable combined with the strong line of the deck and
stiffening girder generally give a very pleasing appearance. The combination of grace and grandeur in such situations leads to the acknowledged view that many of the world’s most exciting bridges are suspension bridges.

In American suspension bridges, which pioneered long span construction, truss girders have been used almost exclusively. They are particularly suitable for wide and deep girders – some US bridges carry six lanes of traffic on each of two levels of a truss girder! Japanese suspension bridges have also favoured the use of trusses, again because of the heavy loads carried – some carry railways as well as highways. The longest suspension bridge span is that of Akashi-Kaikyo (1991m) and there the deck is of truss construction, carrying six lanes of traffic.

Box girders have been used for the stiffening girders of many suspension bridges. They provide stiffness in bending and in torsion with minimum weight. Some of the longest spans, such as the Humber Bridge (1410m), Runyang Bridge (1490m) and the Storebælt East Bridge (1624m) have steel box girder decks.

Left: Forth Road Bridge, Edinburgh, Scotland

Right: River Usk Crossing, Newport, Wales
2.4 Stayed girder bridges

In this form of bridge, the main girders are given extra support at intervals along their length by inclined tension members (stays) connected to a high mast or pylon. The girders thus sustain both bending and compression forces. The deck is ‘suspended’, in the sense that it relies on the tensile stays, but the stays cannot be constructed independently of the deck, unlike a suspension bridge, so it is a distinctly different structural form of bridge.

Stayed girder bridges were developed in Germany during the reconstruction period after 1945, for major river bridges such as those over the lower Rhine. Stayed bridges using plate girders and simple cable stays of high tensile wire have proved to be much cheaper than trusses and have therefore displaced them for longer spans (over about 200m).

Recent developments have extended the realm of the cable stayed bridge to very long spans, which had previously been the almost exclusive domain of suspension bridges. Several cable stayed bridges have been built with spans over 800m and Sutong Bridge, due to be completed in 2008, has a clear span of 1088m. Such development has only been made possible by the facility to carry out extensive analysis of dynamic behaviour and by using sophisticated damping against oscillation.

The visual appearance of stayed structures can be very effective, even dramatic. They are frequently considered appealing or eye-catching.

On a more modest scale, cable stayed construction is sometimes used for footbridges (spans of 40m and above), to give support and stiffness to an otherwise very light structure.

2.5 Advantages of steel bridges

Regardless of the form of bridge construction, a material with good tensile strength is essential and steel is effective and economical in fulfilling that role. The advantages of steel in bridges are outlined below.

High strength to weight ratio

The lightweight nature of steel construction combined with its strength is particularly advantageous in long span bridges where self-weight is crucial. Even on more modest spans the reduced weight minimises substructure and foundation costs, which is beneficial in poor ground conditions. Minimum self-weight is also an important factor for lift and swing bridges, as it reduces the size of counter-weights and leads to lower mechanical plant costs.

The high strength of steel allows construction depths to be reduced, overcoming problems with headroom clearances, and minimising the length and height of approach ramps. This can also result in a pleasing low-profile appearance.

High quality prefabrication

Prefabrication in controlled shop conditions has benefits in terms of quality, and trial erection can be done at the works to avoid fit-up problems on site.

Speed of erection

Construction time on site in hostile environments is minimised, resulting in economic and safety benefits.

The lightweight nature of steel permits the speedy erection of large components, which minimises disruption to the public where rail possessions or road closures are required. In special circumstances complete bridges can be installed overnight.
Versatility
Steelwork can be constructed by a wide range of methods and sequences. For example the main girders can be installed by crane, by slide-in techniques or using transporters. Steel gives the contractor flexibility in terms of erection sequence and construction programme. Girders can be erected either singly or in pairs, depending on plant constraints, and components can be sized to overcome particular access problems at the site. Once erected, the steel girders provide a platform for subsequent operations.

Steel also has broad architectural possibilities. The high surface quality of steel creates clean sharp lines and allows attention to detail. Modern fabrication methods facilitate curvature in both plan and elevation. The painting of steelwork introduces colour and contrast, whilst repainting can change or refresh the appearance of the bridge.

Durability
Steel bridges now have a proven life span extending to well over 100 years. Indeed, the life of a steel bridge that is carefully designed, properly built, well-maintained and not seriously overloaded, is indefinitely long.

The structural elements of a steel bridge are visible and accessible, so any signs of deterioration are readily apparent, without extensive investigations, and may be swiftly and easily addressed by repainting the affected areas. Most major structures are now designed with future maintenance in mind, by the provision of permanent access platforms and travelling gantries, and modern protective coating systems have lives in excess of 30 years.

Modification, demolition and repair
Steel bridges are adaptable and can readily be altered for a change in use. They can be widened to accommodate extra lanes of traffic, and strengthened to carry heavier traffic loads. When the bridge is no longer required, the steel girders can easily be cut into manageable sizes and recycled, which is a benefit in terms of sustainability. Should the bridge be damaged, the affected areas may be cut out and new sections welded in. Alternatively, girders can be repaired by heat straightening, a technique pioneered in the US, and recently introduced to the UK.
3 Composite plate girder highway bridges

This section of the guide deals principally with beam and slab bridges using fabricated plate girders. It provides guidance that may help with an undergraduate bridge design project. Following a brief summary of the general layout, the construction aspects that need to be considered are described. Advice is given on scheme or concept design and an explanation of the design code checks that need to be made is offered. Advice on more detailed aspects of material specification are given in Section 4, and an introduction to corrosion protection is given in Section 5.

3.1 General layout

The cross-sectional layouts of bridges discussed in this section are the multi-girder deck shown in Figure 1 on page 8, and the ladder deck shown in Figure 2 on page 9. The guidance offered relates both to constant depth girders (parallel flanged beams) and to beams with variable depth, although the design code checks of the latter may be beyond the scope of an undergraduate project. For these bridges, the proportions of the girder section (depth, width of tension and compression flanges and web thickness) are chosen by the designer to suit both the in-service condition (carrying traffic loads) and the loadings at the various stages of construction. The girders are continuous over intermediate supports (when there is more than one span) and are braced together at supports and at some intermediate positions.

Composite action between the slab and girder is usually achieved by using stud connectors (headed dowel bars) welded on the top flange; the number and spacing of studs depends on the level of shear flow between steel girder and concrete slab.

In continuous construction, the slab is in tension in the hogging moment regions over the intermediate supports. It is necessary to provide sufficient reinforcement to the slab in these regions to share the tensile forces and to limit the consequent crack widths to an acceptable level.

At abutments and intermediate supports, the girders sit on bearings fastened to the bottom flange. The girders need to be stiffened to carry the...
bearing loads at these points. In addition, transverse bracing is required between girders at supports to provide torsional restraint and to carry lateral forces (chiefly wind) from the plane of the deck slab to the bearings.

At other positions in the span, transverse bracing may be required to provide lateral restraint to slender compression flanges. This is required in midspan regions during construction, before the deck slab concrete has cured, and adjacent to intermediate supports both during construction and in service. In multi-girder decks transverse bracing normally takes the form of triangulated frames between pairs of beams. In ladder decks, the moment-connections to the cross girders provide the restraint to the main beams.

For longer spans, the depth of girders produces rather slender webs and it is customary to provide vertical web stiffeners in the regions of high shear near the supports to improve their resistance to shear buckling. (With ladder deck construction, the stiffeners to which the cross girders are attached perform this function). For a neater appearance, the web stiffeners for the outer girders of multi-girder decks are usually only on the inside faces, where they cannot be seen, except at bearing positions.

### 3.2 Girder construction

Fabricated I-girders are assembled from three plates, two flanges and a web. These are normally cut from a larger plate (plates from the rolling mills are typically 2.5m wide x 18m long).

The cutting of flanges and web from a larger plate is achieved by using computer controlled cutting equipment. In cutting a web plate, it is easy to cut to a required camber with very little wastage.

When the three plates have been cut, they are then fillet welded into the I-section. Traditionally this was carried out by manually assembling the pieces in a jig, tack welding them and then welding alternately on each side of the web. Now available in some fabricating shops are machines, which can locate and press a web onto a flange in an inverted T, then weld automatically and continuously on both sides from one end to the other. Repeating the process with the second flange creates the I-girder. This obviously saves labour and consequently reduces cost.

Vertical web stiffeners are fitted manually but in some fabrication shops the welding is carried out by computer-controlled equipment. It is often cheaper to choose a thicker web than to introduce a large amount of stiffening.

Each main girder is fabricated in several long pieces, which will be joined end-to-end or ‘spliced’ on site. The lengths of these pieces are chosen to suit the configuration of the bridge, with the fabricated length of each usually restricted to a maximum of 27m, since girders longer than this require special permission to travel on public roads.

Painting is almost always done in the fabrication shop, with the exception of the final coat, which is usually applied on site. Refer to Section 5 for details of corrosion protection systems.
3.3 Girder erection and slab construction

When the substructure is ready to receive them, the bare steel girders are erected first, usually by mobile crane. In some instances, partially assembled steelwork (braced pairs of multi-girders or ladder deck beams with cross girders) are 'launched', i.e. they are pushed out along the bridge axis from one abutment, though this is not common.

During erection, the consecutive girder sections are joined at the site splice positions. Such splices, which are normally arranged near the point of contraflexure, are most easily made using friction grip bolts, though welded joints are also used. Bolted splices use cover plates which lap over the ends of both girders. Covers are normally on both faces of flanges and web, thus sandwiching the girder material.

In multi-girder decks, the slender individual I-sections are rather unstable on their own, spanning across the full span; adjacent girder sections are therefore frequently braced together and lifted in pairs. In ladder deck construction, the main girders usually have to be erected individually and may require some temporary restraint before the cross girders are connected. (Alternatively, pairs of main girders with cross beams already connected can be lifted in one go, if a sufficiently large crane is available.)

With the girders in position, the next stage is for the concrete deck slab to be cast. During casting, the concrete needs to be supported and this is normally achieved using formwork supported by the steel girders. The traditional formwork comprises sheets of plywood laid on cross members, which are removed after the concrete has hardened. Alternatives to timber include glass reinforced plastic (GRP) panels which can be left in place, and precast reinforced concrete planks which become a structural part of the deck slab, acting with the in-situ concrete above them. The advantage of such permanent formwork is that the removal operation is eliminated. The use of precast planks is now becoming very common.

The steel girders alone carry the weight of wet concrete and all temporary works. As formwork cannot be relied upon to stabilise the top flange of the girders, the designer must ensure that girders and bracing are adequate for this loading condition. Temporary cross-bracing is sometimes provided (for example in midspan regions of simply supported girders) to stabilise the compression flange. This bracing is removed after the concrete has hardened.

Once hardened, slab and girders form a composite section that carries all further loads imposed on the bridge. It should be remembered that the stress distribution due to the weight of wet concrete on the bare steel girders remains unchanged; that weight is not carried by the stronger composite section.

With continuous girders, the bridge is subject to negative or hogging moments over the intermediate supports, putting the deck slab into tension. To minimise the built-in tensile forces in the slab reinforcement, it is usual to concrete the midspan lengths of slab first and then fill the lengths over supports.

When the concrete deck is complete, the surfacing is laid over the whole bridge. The weight of surfacing is therefore carried on the composite beams.
3.4 Scheme design

General

For the designer to show his preferences and exercise his judgement, the greatest scope is at the initial stage when the first lines are drawn on paper. The road layout will have been determined by the highway engineer. There will be some constraints in placing the substructure, but the designer is often free to modify span lengths and support arrangements to achieve economy, appearance or other requirements.

At the same time as considering the longitudinal elevation of the bridge, the cross-section arrangement must also be considered. For a plate girder bridge, this means the number and spacing of the girders.

Elevation

The dominant parameter, which influences the elevation of the bridge, is girder depth. Girders may be deep or shallow; they may have parallel flanges or taper to a greater depth at intermediate supports (haunched); the soffit (bottom flange) may be curved in elevation, like an arch. In deciding upon an appropriate girder depth there are some useful rules of thumb that may be employed to produce an initial outline of the bridge. Typical arrangements and proportions are shown in Figure 3 above.

Girders with constant depth are, naturally, the basic form and the starting point from which to consider the elevation. These parallel flange girders are cheaper per tonne to fabricate than variable depth girders. For shorter spans, below about 35m, there is little advantage in choosing variable depth girders, and parallel flanges are usually selected. Continuous viaducts (many similar spans) use parallel flange girders, the appearance of numerous variations of girder depth being generally considered unattractive. Girders with haunches or a curved soffit are most suited to a three-span bridge or the major and adjacent spans of a viaduct. Curved soffit girders look particularly pleasing with a fairly low level bridge such as a river. Girders with tapered haunches are used in crossing motorways or larger spans over railways.

The design of variable depth girders is generally beyond the scope of the simplified design rules appropriate to student use (Ref.1 on page 31), so care should be exercised in applying them to project designs other than parallel flange girders.

The depth of a parallel flange bridge should normally lie between span/20 and span/30, the depth being measured from top of slab to underside of girder. Simply supported spans will usually be towards the deeper end of this range, with continuous spans toward the shallow end. Ladder deck bridges are often a little deeper, particularly where the deck is wide.

Variable depth girders allow reduced construction depth in midspan at the expense of greater depth over the intermediate supports. A central depth of between span/30 and span/40 can be achieved with a depth of about span/18 at the adjacent supports. A tapered end span needs a depth of about span/15 at the first intermediate support.

In selecting span sizes, it should be noted that where there are many spans, uniformity looks better than irregular spacing. It is better not to vary too greatly the spacing of adjacent spans: an end span of 80 per cent to the length of the next span is structurally well proportioned. For a bridge with variable depth girders, the spans either side of the major span should be between about 60 per cent and 80 per cent of the major span.

![Figure 3: Typical elevation of composite bridges.](image-url)
Cross section – multi-girder decks
The basic cross section appropriate to multi-girder composite plate girder bridges is shown in Figure 1, on page 8. The reinforced concrete slab sits on top of four steel girders. The spacing of girders is uniform and on each side of the bridge are cantilevers supported by the continuity of the deck slab.

Girder spacing is influenced by the design of the deck slab, which acts both as a top flange in longitudinal bending and as a slab in traverse bending. For present purposes, it is sufficient to note that girder spacing is normally between 2.5m and 4m and slab thickness between 240mm and 260mm, the actual value depending largely on the configuration necessary to suit the deck width. Cantilevers should not exceed about 2m and should certainly be less if they carry vehicle loading (even footways have to be designed for accidental vehicle loading unless protected by a crash barrier).

An even number of girders is to be preferred. This allows girders to be paired together by transverse bracing for lateral stability of the compression flanges; there is then no bracing between adjacent pairs.

If transverse bracing is continuous across many girders, it participates in the global bending of the bridge and becomes prone to fatigue damage — such continuity is best avoided.

In a multi-girder bridge, the webs are usually thin and require intermediate transverse web stiffeners to enhance shear resistance. In hogging moment regions (adjacent to intermediate supports) most of the web depth is in compression — the thin webs then limit the cross section to its elastic bending resistance (unlike sections with thick webs, which may develop plastic resistance).

Cross section - ladder decks
The basic cross section appropriate to ladder deck-girder composite plate girder bridges is shown in Figure 2, on page 9. The reinforced concrete slab sits on top of the cross girders and the main girders, and spans longitudinally between cross girders. The spacing of the cross girders is generally uniform (there is some variation local to the supports of skew decks, to suit the skew angle). The deck slab outside the lines of the main girders is not supported on beams, it cantilevers in the same way as in multi-girder decks.

The cross girder spacing is usually between about 3m and 4m and the slab thickness is between 240mm and 260mm, as for multi-girder decks. Cross girders can span up to about 18m.

Initial sizing
To make a start on detailed design, it is necessary to select some preliminary member sizes so that analysis can be carried out. Such initial selection can be based on fairly crude estimation of bending moments. In simple spans, overall moments can obviously be calculated quickly; in continuous spans, moments can be estimated as a proportion of the values calculated for a fixed-ended beam. In both cases, loads can be shared between girders by statics or by simple rule of thumb.
For continuous spans, dead and superimposed load moments should be taken as fixed-ended beam moments, possibly modified by the moment distribution method or other simple manual calculation if the spans are significantly unequal in length. Live load moments over an intermediate support should be taken as about 90 per cent of \( \frac{wL^2}{12} \) and at midspan they should be about 120 per cent of \( \frac{wL^2}{24} \) (where \( w \) is the load/unit length carried by an individual composite beam and \( L \) is the span).

For ladder decks, the traffic loads can be proportioned between the two main girders on the basis of a ‘static’ distribution. For multi-girder decks a ‘static’ distribution of the load from each lane between the two girders under that lane can lead to significant over-estimate of the load on an individual girder, because the slab spreads the loads transversely between all the girders. On the other hand, equal sharing of the total load between all the girders will give an underestimate. A value midway between these two alternatives could be used as a first guess, and a little experience with the subsequent analysis would aid future initial judgements in similar circumstances. For loads on the cross girders of ladder decks, the self weight and the UDL component of traffic load, (see the simplified Eurocodes document, Ref.1 on page 31) is shared equally between cross girders; the Tandem System (TS) component may be taken conservatively as being wholly supported on one cross girder.

From these simply calculated values of moments and shears, flange and web sizes can be selected using the principles of limit state design (see Section 4.5.2 of Ref.1 on page 31). Tension flanges may presume a design resistance based on yield strength. Compression flanges may conservatively presume a resistance based on 90 per cent of yield strength for the in-service condition. Webs may presume a resistance based on 60 per cent of the shear yield strength.
3.5 Design code checks

General
Design code checks are sometimes called ‘detailed design’, but it is more of a checking process than original creative design. The selected structural arrangement is analysed for the various loading conditions and then the strengths of the members are checked in detail to ensure that they are adequate to carry the moments and forces. Details such as stiffener sizes and bracing member sizes, etc, are chosen at this stage to suit the global actions of the main members.

Before commencing design checks, the designer should confirm and record the necessary parameters. He should know:

- the geometrical configuration to be achieved
- the loading to be applied
- the design standards to be observed
- the properties of materials to be used

For the purposes of student project design, the simplified versions of the Structural Eurocodes should be used. (Ref.1 on page 31). The project brief will define the geometrical configuration and perhaps the loading to be considered (if it is other than the simplified highway loading given in Ref.1 on page 31).

Limit state design
Modern design is based on limit state principles. Under this philosophy, structural adequacy is verified at two limit states, referred to as ultimate limit state (ULS) and serviceability limit state (SLS).

At each limit state the effects of nominal or ‘characteristic’ values of applied loads are evaluated and multiplied by a ‘partial factor’ to determine ‘design load effects’ that have a high level of reliability (i.e. a very low level of probability that they would be exceeded during the life of the bridge). These effects are the internal forces, moments and stresses within the structure.

The designer then verifies that the effects are acceptable throughout the structure. In practice The designer identifies the small number of positions where the effects will be greatest or most critical and evaluates the effects and the limits at these positions. Typically the designer will need to consider:

At supports:
- Maximum moment with coexisting shear
- Maximum shear with coexistent moment
- Maximum reactions (for bearing stiffener design and bearing selection)

In midspan regions:
- Maximum moment with coexisting shear
At changes of beam section:
- Maximum moments and shears

For cross girders of ladder decks:
- Maximum moment in midspan regions
- Maximum shear at the ends (for design of bolted connections)

At each position where adequate is verified, the design value of the resistance is determined, based on the nominal strength of the material and the geometrical proportions of the member and its cross section. In the calculation of the resistance, the ‘nominal’ strength is reduced by dividing by another ‘partial factor’, again to ensure a high level of reliability (a high probability that the strength would be at least this value).

Adequacy is achieved when the design resistance is at least equal to the design load effects.

The ultimate limit state (ULS) is reached when a member or part just fails, through rupture, buckling or fracture.

The serviceability limit state (SLS) is reached when damage becomes apparent, necessitates remedial action, or where the condition causes public concern, for example because of excessive vibration or deflection.

Partial factors on loads are normally greater for ULS than for SLS because a greater margin is demanded against failure than against first occurrence of damage.

In many instances, for example where ULS is deemed to be reached when yield occurs in an extreme fibre of the section, the lesser requirements for SLS need not be checked, since they will automatically be satisfied.
Loading
The loading carried by a bridge comprises dead load (the weight of the structure itself and any permanent fixtures to it) and the variable traffic load. The actual traffic loading experienced by bridges is of course extremely variable, and it would be impossible to examine any design for all possible vehicle combinations.

Instead, ‘load models’ are used to represent the traffic loading. To represent normal traffic a uniformly distributed load (UDL) is applied within each traffic lane over an appropriate length. Additionally, to represent the non-uniform nature of actual loading, a pair of heavy axles are applied at a position along the lane that causes the worst effect. In the Eurocodes, this loading is known as ‘Load Model 1’ (LM1).

To represent abnormal traffic – the heavy multi-axle commercial vehicles that are permitted within certain limitations on their movement – a separate load model is used. In the Eurocodes, a number of different axle arrangements and axle loads are defined for this load model (LM3).

The loading given in the simplified Eurocodes document (Ref.1 on page 31), are based on LM1, as interpreted by the UK national annex; a simplified LM3 is also shown, for information, but would not normally need to be considered for a student project.

Loading on footways is also modelled using a UDL – use either the value in the simplified Eurocodes document or the value specified in the project brief.

Analysis
To carry out the detailed design of an element of the structure, a global analysis is necessary to determine the forces and moments in the structure under the variety of loading conditions.

Moments and shears in the steel beams due to dead loads can be calculated by analysis of line beam models. For simple spans, manual calculations are straightforward.

Calculations of forces on the composite structure require global analysis that takes account of longitudinal and transverse stiffness throughout the structure. For a multi-girder deck, this analysis is usually carried out by computer using a grillage model in which the structure is idealised as a number of longitudinal and transverse beam elements in a single plane, rigidly inter-connected at nodes. Loads are applied, normal to the plane, at the node points. or the level of analysis appropriate to a student project, it is adequate to use a model with six equal spacings along the main beams in each span and one line of elements for each longitudinal beam. A typical grillage is shown in Figure 4 below.

Each beam element represents either a composite section (a main girder with associated slab) or a width of slab. Slab width should be calculated midway to the node on either side, or to the end of a cantilever.

For a ladder deck, beam elements are required for each transverse beam and for each longitudinal beam. Since the design of the slab itself is outside the scope of a student project, a finer mesh is not normally needed.

Gross section properties are used for global analysis. Properties for composite beams should include the full area of the appropriate slab width, except that the first longitudinal elements adjacent to an intermediate support in each span (about 15 per cent of the span) should be given cracked section properties (i.e. ignore the area of concrete because it is in tension and will be cracked, but include the area of reinforcement). Properties for a width of slab should include the full sectional area of the slab.

The short-term modulus for concrete should be used throughout. Divide the concrete area by the modular ratio to give equivalent steel areas for calculation of composite properties.

Strength checking
The strength check of the critical parts of the bridge is the heart of the design code checking process. To verify the adequacy at key positions, total design load effects need to be determined. Combinations of the effects due to the various loads, each multiplied by its appropriate partial factor, should be clearly set out in tabular form to avoid errors.

Note that the weight of the wet concrete is carried by the girders alone, not by the composite section. The calculation of moments and stresses must therefore be made separately for the two stages of construction and the effects added. For a simple design it is not necessary to consider a succession of stages representing sequential casting of the slab.

The design resistances must be determined for key positions in the structure. The Eurocodes provide rules for determining the various resistances.
of steel and composite sections, and for the design of the reinforced concrete deck slab. For detailed guidance appropriate to student project designs refer to the simplified version of the Eurocodes (see Ref.1 on page 31).

The method of determining resistance is to treat each local area of the bridge separately and assess separately the bending and shear strengths. Allowance is made in the rules for buckling, both of the beam members and of web panels in shear. The Eurocodes and the simplified version contain tables, figures and formulae for this purpose. Where there is interaction, for example between shear and bending, interaction relationships (limiting values for each in combination with the other) are defined.

Certain beam cross sections can develop plastic bending resistance, which is greater than elastic bending resistance. A classification system is given for deciding when plastic resistance may be relied upon (referred to as ‘class 2’ cross sections). The classification depends on the actual proportions of the steel elements that are in compression, but as a rough guide it may be noted that sagging regions of composite beams will usually be class 2, whilst hogging regions of composite beams will in a lower class. It should be noted that whilst the final composite section may be class 2, the steel girder alone (i.e. before the slab is cast) may be a lower class.

Special details such as bearing stiffeners are covered by rules that determine both the share of forces carried by the particular detail and its resistance.

For each element or part, the design resistance must at least equal the design load effects. Where this is not achieved, the design must be modified by increasing the flange size, reducing the spacing of bracing or in some other appropriate manner and rechecked.
4 Material properties and specifications

Steel derives its mechanical properties from a combination of chemical composition, mechanical working and heat treatment.

For structural use in bridges, steel products (plates, hot rolled sections and tubes) are cut to size and welded. In the structure, the material is subject to tensile and compressive forces. The steel generally responds in a linear elastic manner, up to a ‘yield point’, and thereafter has a significant capacity for plastic straining before failure.

Steel derives its mechanical properties from a combination of chemical composition, mechanical working and heat treatment. The chemical composition is essentially a balance between achieving the required strength through alloy additions, whilst maintaining other properties (i.e. ductility, toughness and weldability). Mechanical working is effectively rolling the steel; the more steel is rolled, the stronger it becomes, but this is at the expense of ductility. ‘Heat treatment’ covers the control of cooling as the steel is rolled, as well as reheating and cooling processes that can be employed to influence a range of material properties.

In these material standards, the designation system uses the prefix “S” to denote structural steels, followed by a three digit reference that corresponds to the specified minimum yield strength (in N/mm²). Various other letters and numerals may be appended to indicate other properties or manufacturing process routes. The most commonly specified steel for bridges is grade S355J2+N to BS EN 10025-2; the “J2” indicates a certain level of toughness and “+N” indicates the process route (i.e. which combination of heat treatment and rolling are used).

The principal properties of interest to the designer are:
- Yield strength
- Ductility
- Toughness
- Weldability

**Yield strength**

The yield strength is the most significant property that the designer will need to use or specify. The strength grades covered by the material standards include; S235, S275, S355, S420 and S460, all of which relate to the strength of material up to 16mm thick. Yield strength reduces slightly with increasing plate thickness, but for student design projects, the basic nominal yield strength may be assumed irrespective of thickness.

All new structural steel for bridges is ‘hot-rolled’ to one of the following European standards.
- BS EN 10025-2
  Non-alloy steels
- BS EN 10025-3 & 4
  Fine grain steels
- BS EN 10025-5
  Weather resistant steels
- BS EN 10025-6
  Quenched and tempered steels
- BS EN 10210
  Structural hollow sections

Steels of 355 N/mm² yield strength are predominantly used in bridge applications in the UK because the cost-to-strength ratio of this material is
lower than for other grades. Higher strength steels may offer other advantages, but they are less readily available and the additional strength is of little benefit if fatigue or maximum deflection governs.

**Ductility**
Ductility is a measure of the degree to which the material can strain or elongate between the onset of yield and the eventual fracture under tensile loading. Good ductility offers the ability to redistribute localised high stresses without failure and to develop plastic moment capacity of sections. Whether it is appreciated or not, the designer relies on ductility for a number of aspects of design and fabrication. It is therefore of paramount importance to all steels in structural applications.

**Notch toughness**
The nature of steel material is that it contains some imperfections, albeit of very small size. When subject to tensile stress these imperfections tend to open. If the steel were insufficiently tough, the ‘crack’ would propagate rapidly, without plastic deformation, and failure would result. This is called ‘brittle fracture’ and is of particular concern because of the sudden nature of failure. The toughness of the steel, and its ability to resist this behaviour, decreases as the temperature decreases. The requirement for toughness increases with the thickness of the material. Hence, thick plates in cold climates need to be much tougher than thin plates in moderate climates.

Toughness is specified by requiring minimum energy absorption in a Charpy V-notch impact test, which is carried out with the specimen at a specified (low) temperature and the requirement is given as part of the grade designation. For typical bridge steelwork, to BS EN 10025-2, the usual designation letters are J0, J2 or K2 (in increasing level of toughness).

BS EN 1993-1-10 describes the requirements for notch toughness in the form of a table, which gives a limiting thickness of a steel part, depending on the reference temperature, the steel grade (yield strength and toughness), and the stress in the element. From this table, the limiting thicknesses for a typical UK bridge (using grade S355 steel, at a reference temperature of -20°C with a tensile stress under the design loading at that temperature of 75 per cent of the yield strength) would be approximately:

<table>
<thead>
<tr>
<th>Toughness subgrade (BS EN 10025)</th>
<th>Limiting thickness (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>J0</td>
<td>35</td>
</tr>
<tr>
<td>J2</td>
<td>50</td>
</tr>
<tr>
<td>K2</td>
<td>60</td>
</tr>
</tbody>
</table>

If steels thicker than 60mm are needed, other grades, to BS EN 10025-3 & 4, would be needed.

**Weldability**
All structural steels are essentially weldable. However, welding involves laying down molten metal and local heating of the steel material. The weld metal cools quickly, because the material offers a large ‘heat sink’ and the weld is relatively small. This can lead to hardening of the ‘heat affected zone’ of material adjacent to the weld pool and to reduced toughness (often called embrittlement). The greater the thickness of material, the greater the reduction of toughness.

The susceptibility to embrittlement also depends on the quantity and nature of the alloying elements, principally the carbon content. This susceptibility can be expressed as the ‘Carbon Equivalent Value’ (CEV), and the material standards give an expression for determining this value. The higher the CEV, the more difficult it is to weld.

Weld procedure specifications are drawn up that set out the necessary welding parameters for any particular steel grade and weld type, to avoid embrittlement. For the purposes of a student project, it may be assumed that any thickness of structural steel to the standards mentioned above are weldable.
5 Corrosion protection

Corrosion protection is an important issue to consider when designing and detailing steel bridges.

In the UK, the ‘design life’ of a new bridge is usually taken to be 120 years. Because ordinary structural steel will rust if exposed to the elements, corrosion protection is an important issue to consider when designing and detailing steel bridges. Corrosion protection is usually achieved by the application of coatings (although there are some alternatives) which, with suitable maintenance, are capable of achieving the required design life. Various coating systems are currently available, and paint technology is advancing at a rapid pace with lives to first major maintenance in excess of 30 years anticipated for the latest systems.

The following remarks provide a general introduction, but for more detailed advice on the corrosion protection of steel bridges, see Ref.6 on page 31.

Paint coatings
Conventional painting systems involve the application of several coats – typically a primer, undercoats and a finishing coat, usually by spraying. Before painting, the steel surface must be abrasive blast cleaned to remove mill scale, dirt, etc. and to achieve a suitable standard of surface cleanliness and profile to which the paint can adhere. Various paint systems are specified by highway and railway authorities, based upon the environment, accessibility for maintenance, and the life until maintenance of the coating is necessary.

Recently, high-build paint systems developed for the offshore industry have been introduced to bridge construction. These systems achieve a thick and durable coating in only one or two coat applications.

Thermally sprayed metallic coatings
A coating of aluminium can be applied by heating the metal (in wire form) in a special ‘gun’ that sprays the molten metal onto the steel surface. Thermally sprayed aluminium coatings have been applied for many years to provide long-term corrosion protection to steel bridges. The aluminium acts as a barrier and is usually over-painted to form a ‘duplex’ coating system (see Figure 5, page 29). Such ‘duplex’ systems are frequently specified for Highways Agency and Railtrack bridges, because they provide a high level of corrosion protection, and long life to first major maintenance.

Hot-dip galvanizing
Hot dip galvanizing is a process where the steel component to be coated is immersed in a bath of molten zinc and then withdrawn. The steel surfaces are uniformly coated with zinc, which is metallurgically bonded to the structural steel. The zinc weathers at a slow rate giving a long and predictable life. In addition, if any small areas of steel are exposed (say through accidental damage), then the coating provides galvanic (sacrificial) protection by corroding preferentially. However, there are limitations on the size of components that can be galvanized due to the size of the zinc bath and there are potential complications when galvanizing welded fabrications.

Top: Hot-dip galvanised steel bridge, (Photo courtesy of Forestry Civil Engineering) Scotland.
Above: Hardy Lane Bridge, (Example of enclosure system), Gloucestershire, England.
Opposite page: Shanks Millennium Bridge, (Example of weathering steel), Peterborough, England.
Weathering steels
Weathering steel is a low alloy steel that forms an adherent, protective oxide film or 'patina' that, in a suitable environment, seals the surface and inhibits further corrosion. Weathering steel bridges do not require painting. Periodic inspection and cleaning should be the only maintenance required to ensure the bridge continues to perform satisfactorily. Weathering steel bridges are ideal where access is difficult or dangerous and where future disruption needs to be minimised but they are not suitable in salty environments, such as near the coast. For further details on weathering steel bridges (see Ref.5 on page 31).

Enclosure systems
Enclosure systems offer an alternative method of protection for the structural steelwork of composite bridges, whilst at the same time providing a permanent access platform for inspection and maintenance. The concept of enclosing the structural steelwork on composite bridges is based on the fact that clean steel does not corrode significantly if environmental contaminants are absent. Nevertheless, the steel within an enclosure is usually painted, but with a very modest system. Typically, enclosures are formed from light weight durable materials such as GRP. However, enclosures have not been widely used in the UK as they have proved to be relatively expensive.
Steel is an ideal material for bridges, and is widely used for all forms of bridge construction around the world.

Steel is an ideal material for bridges. The many advantages of steel have led to it being widely used for all forms of bridge construction around the world, from simple beam bridges up to the longest suspension bridges. However, its most widespread use in the UK over recent years has been on steel composite highway bridges.

Composite construction is an economical and popular form of construction for highway bridges. It combines high quality, factory-made products (the steel girders) with a cast in-situ reinforced concrete deck slab, utilising each element where it is most economic. It is appropriate for the great majority of spans, from 13m up to 100m or more.

Familiarity with the method of construction, an understanding of the part each element plays and the interaction of the elements is to be encouraged as a means to good effective design.

The design principles for a composite bridge are quite straightforward and readily understandable. The codified requirements of the design process are more complex, reflecting the fact that the structural behaviour of a bridge involves the interaction of many different effects. However, the essentials have been condensed into a ‘user-friendly’ document suitable for students (see Ref.1 on page 31).

By following the steps in this elementary guide and using the simplified Eurocodes document, students should be able to produce a basic project type design. In doing so, they should acquire valuable experience which can lead easily into full-scale design.

Below: Swansea Sail Bridge, Swansea, Wales.

Opposite above: Puente del Alamillo, Seville, Spain.

Opposite below: Puente de la Barquetta, Seville, Spain.
Design code checks for undergraduate projects

1 Bridge design to the Eurocodes – Simplified rules for use in student projects

Published by SCI the Steel Construction Institute, this document contains ‘simplified versions’ of sections of the Structural Eurocodes that are relevant to the design of composite highway bridges for the use of undergraduate students. It is written to explain both the Eurocode code provisions and background concepts at easily understood levels. It is emphasised that a bridge designed to this simplified version will not necessarily meet all the more detailed requirements of the Eurocodes, but it will provide a reasonable solution for undergraduate design projects.

Corus Brochures

A number of bridge related publications are available from Corus, giving introductory information on a range of issues. These may be downloaded in ‘pdf’ format from www.corusconstruction.com

2 Bringing steel to life – A comprehensive range of bridge related products and services
3 Composite steel highway bridges
4 The design of steel footbridges
5 Weathering steel bridges
6 Corrosion protection of steel bridges

Steel Construction Institute publications

For more detailed guidance on the design of steel bridges in full accordance with BS 5400, the SCI have a range of publications including:

7 Composite highway bridges – design to the Eurocodes (P356)
8 Composite highway bridges – worked examples using the Eurocodes (P357)
9 Design guide for composite box girder bridges (P140)
10 Steel Bridge Group, Guidance notes on best practice in steel bridge construction (P185)

Other publications

11 Steel Bridges, The practical aspects of fabrication which influence efficient design (published by British Constructional Steelwork Association, 2002)
12 BSCA Guide to the erection of steel bridges (published by British Constructional Steelwork Association, 2005)