Best Construction Methods for Concrete Bridge Decks - Cost Data

A state-of-the-art report

Technical Guide No. 14

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Contents

1. Introduction

The Concrete Bridge Development Group (CBDG) aims to promote excellence in the design, construction and management of concrete bridges. With a membership that includes owners, designers, academics, contractors and suppliers, it provides a focus for the use of best practice, innovation, training initiatives, and research and development.

This Technical Guide 14 has been produced by the Technical Committee of the CBDG, with financial support from Highways England and Transport Scotland, as well as from Banagher Precast Concrete, Shay Murtagh, BAM Nuttall and PERI. The construction industry is continually looking for better methods to enhance the value of its infrastructure projects. It is necessary for concrete bridge construction to remain innovative and competitive in this environment. Good design and construction techniques can make concrete the cheapest, fastest and most elegant material for bridge decks, whilst maintaining high quality, durability, robustness and safety.

This technical guide summarises all the key areas concerning concrete bridge decks. It will encourage early participation between the owners, developers, designers and contractors who are intending to construct a bridge. It sets out to help those teams to better understand the many factors that contribute to the best construction methods, and to appreciate the essential requirements and consequences of achieving these aims successfully. The best construction methods in this context mean any methods for concrete bridge decks that provide good value through economy, and the speed and ease of construction. It is essential, however, that quality should be maintained at a high level and that any decision regarding the construction method must also ensure the long-term performance of the bridge. All concrete bridge decks must also be designed and built in a manner that will enhance the built environment and promote the principles of sustainability.

There is not a unique approach to finding the best construction method for a concrete bridge deck. This guide reviews and considers the wide range of choices that need to be made for a variety of situations, enabling the owner, designer and contractor team to identify the most appropriate solution.

This technical guide includes Sections 2.1 to 2.3 on the conceptual, general and particular choices of bridge deck, and Sections 3.1 to 3.15 on the construction methods for each bridge deck type. Consideration is given in Sections 2.1 to 2.2 to the conceptual and general parameters that start to determine the type of solution, as the solution evolves from the owner to the designer/contractor. These parameters include the deck area, width and length, as well as typical spans, clearance requirements, alignment, sustainability and the overall aesthetic. The particular parameters of the construction methods are then described in detail in Section 2.3. These more particular parameters include, *inter alia*, the site access, layout and availability, programming and phasing, labour, material and plant supply, traffic management, and temporary works, as well as the overall casting, transportation and erection issues. Crucially, the effects of all these parameters on the overall balance of costs, programme and risks are highlighted. Construction methods that describe all the available in-situ options, including solid and voided slabs, twin ribs, span by span boxes and balanced cantilevering, are shown in Sections 3.1 to 3.4. All the available precast options, including standard and bespoke precast beams, segmental, whole span, incremental launching and the CBDG's own modular system, are shown in Sections 3.5 to 3.10. Descriptions are also given in Sections 3.11 to 3.15 for all the other available bridge types, including arches and frames, tunnels and boxes, cable-stayed and extradosed schemes, and stressed ribbons.

Each of these sections has a list of summary data for each bridge deck type, such as key deck features, typical spans, examples of when the method is best used, production rates and the range of formwork/falsework costs. This is followed by a detailed description of each method, together with the programming data and the detailed breakdown of all the deck costs. The major item of this technical guide is the provision of the combined formwork/falsework rates for each method – data that has never been made available in this form beforehand. A commentary is then given on the total deck costs, explaining why and when each different concrete bridge deck type is best used. The points that are discussed are illustrated by a variety of successfully built projects, both in the UK and around the world. The conclusions summarise all the key bridge deck cost data in Figures 95 and 96, together with an expert view of all these results.

Simple and radical design and construction methods can supplant an owner's more traditional or preliminary expectation. The use of major or new items of plant, such as moulds, transportation vehicles, lifting equipment or falseworks, can revolutionise both design and construction, making the casting or prefabrication of larger and heavier items both acceptable and competitive. These better construction methods, often produced within a factory environment, can increase production by improving working conditions while enhancing quality and assuring delivery on time. The standardisation of design and construction details will also contribute to the ease and speed of construction. Simplification of the casting, transporting and erection methods will all lead to a superior product that is elegant, durable and of high quality.

A range of options are available for the construction of any particular bridge and there is not a unique solution. This guide is intended to provide both general and particular guidance and advice, while also showing examples and wider references. It should become a guide that summarises the best construction methods for concrete bridge decks and thus promotes the use of concrete in bridges. It should prove to be a reminder of good practice to those experienced in bridge engineering, while at the same time providing less experienced professionals with a wide range of valuable parameters and details, and illustrations from successful projects, which can be used directly or developed further.

Concrete will continue to be used for bridge construction because it is durable and sustainable, by being both a renewable and re-useable material. When carefully designed, specified and constructed, concrete provides a high quality and elegant natural appearance. It can be designed and constructed, with the use of this guide, to be a very economical and competitive product that can be built easily, safely and quickly. Although precasting is often the preferred method of achieving these broad objectives, in-situ concrete does also deliver the same results. The appropriate use of labour, materials and plant to create the best construction method can assure the successful delivery of a wide range of bridge deck structures within tight programmes and across the spectrum of all environmental and site conditions.

This CBDG Technical Guide 14 has thus produced expert and simple guidance for owners, designers and contractors, enabling the best choice of concrete bridge decks to be made at an early stage. It outlines the critical importance of the construction method in this choice, and gives detailed data relating to production rates, programme and cost breakdowns.

Further data will be made available on the CBDG website in late 2015 to keep these costs up to date in any location.

2. Choice of Bridge Deck

The opportunity should be made for an involvement from the whole team (owner, designer and contractor) at the very earliest of stages stage, so that decisions are made with a clear understanding of all the issues and that the owner's priorities are fully understood. The owner should then try to leave as many of the parameters as flexible as possible, such that the designer and contractor can consider all the available construction methods – a strategy that will lead to the optimum solution.

There are three areas of choice that are described in this guide:

- Conceptual choices that will cover areas such as the benefits of concrete, aesthetics, sustainability and durability. This section will often be led by the owner, but input from the designer (and potential contractor) will be very useful.
- General choices that will cover areas such as the layout of the bridge, spans and articulation, joints and bearings, the issues concerning reinforced or prestressed concrete, the possible use of high performance concretes, and the many issues associated with good detailing of the scheme. This section will generally be led by the designer, but input from the owner is vital and some input from the contractor is much preferred.
- Particular choices that will cover areas such as the buildability of the scheme, the balance between in-situ and precast concrete, the various types of bridge and their construction methods, the various types of formwork and falsework, and finally the crucial elements concerning the bridge programme, risk and cost. This section will usually be led by the contractor, but input from the designer is vital and some input from the owner will also be beneficial.

The best construction method for a bridge deck should be determined by a thorough assessment of all these various key parameters. The actual choice of construction method is crucial as the results fundamentally affect the costs, programme and associated risks of the whole project. This is the essence of this guide.

The general parameters of the scheme such as the typical spans, the overall deck area, width and length, the clearance requirements, alignment and the overall aesthetic will start to suggest which construction methods might be appropriate. However, the final choice will then depend on many other particular parameters such as the site access, layout and availability, geotechnical issues, environmental issues and sustainability, construction programme and phasings, labour rates, resource requirements, material quantities and costs, plant supply, traffic management, temporary works layouts, as well as the overall casting, transportation and craneage or erection issues.

Many of these particular parameters are controlled by the need to increase the speed and ease of the construction process and while fast construction is not necessarily an objective in itself, it can be seen that many components of the way in which the best construction methods are chosen are indeed driven by speed. Faster construction also leads to cost savings through reduction in the duration of the overheads associated with the construction and thus any steps to improve the speed will realise far greater cost savings than the immediate operational benefits.

2.1 Conceptual Choice of Bridge Deck

Benefits of Concrete Bridges

Bridge design and construction is a challenging and exciting field, requiring creativity and ingenuity to deliver beautiful, robust and durable structures (Figure 1). More bridges are built worldwide using concrete than any other material and concrete bridges have a clear track record of performance and durability, whilst also having huge versatility of both final form and construction method. Concrete will continue to be used for bridge construction because it is economical, durable, versatile and sustainable. When carefully designed, specified and constructed, concrete also provides a high quality and elegant natural appearance.

Figure 1: Greta Bridge - The Concrete Society's best bridge of the 20th century.

Concrete can be readily used for all bridges – high speed rail, heavy rail, metro systems, highways, aqueducts and footbridges. Recent advances in both concrete material science and concrete bridge construction technologies give owners, designers and contractors better value, reliability and safety than ever before. Concrete is available worldwide, as a locally sourced material for the majority of its constituents, making it the natural choice for all bridge structures. In-situ concrete is therefore easily incorporated in to all bridge components, on its own or as a composite with precast elements. Precasting bridge components in well-controlled factory conditions ensures that they are both precision engineered and quick to erect when delivered to site.

Three key benefits should be considered at this conceptual stage, or the stage where the owner might be considering a scheme – aesthetics, sustainability and durability. This guide will go on to describe the extensive versatility of concrete bridges, with reference to the best choice of bridge type for each location, much of which will be determined by programme, speed of construction and the availability of materials and skills.

Aesthetics

A bridge engineer has twin obligations – to use his client's money wisely and to produce a structure for society that will enhance the built environment. These two elements are the classic balance between form and function. The structural forms that can be achieved with concrete are only limited by the imagination of the designer, but it clearly requires an experienced engineer with good judgement and expertise to control this balance between form and function. Aesthetics is a central feature of the design development but solutions designed to suit the flow of forces in the bridge will tend to have a natural elegance. Bridges often need little more to improve their form, though the collaboration with experienced bridge architects can certainly be a welcome addition, as they can also add a much broader understanding of the social impacts. Nevertheless, a good appreciation of context, scale, lines and balance is still vital for the engineer.

The overall layout of spans and depths should be carefully chosen to create good proportions, with the relative sizes of the masses and the voids being in balance. The structural form of a bridge is an expression of its strength, stability and economy, and the construction method might also be a defining feature. For example, an incrementally launched bridge will be of constant depth, whereas a bridge built in balanced cantilever will tend to have variable depth. Concrete bridges can be shaped to suit the flow of forces and the surroundings, giving enormous scope to the engineer and architect to create elegant bridge structures, which are both dynamic and graceful. The overall feature of the scheme will be determined by the nature and context of the bridge. While a bridge only viewed from distance will need an elegant balance of scale and lines, a bridge viewed at close quarters will need its concrete finishes, surface texture and details to be carefully integrated within its surroundings (Figures 2a & 2b).

Smooth concrete finishes are best for fast construction, but consideration must be given to the aesthetic importance of each element. The soffits and webs of bridge decks generally need no more than a good quality smooth finish, as the visual merits of the scheme will often be governed by the overall balance of spans and depths, and the particular shape of the deck section. Featured shapes and finishes will frequently be used though on piers, abutments and parapets. Occasionally, a particular colour of concrete might also be specified. These unique surface features of concrete eliminate the need for any cladding or painting, thereby reducing any future maintenance requirements. For further details of concrete bridge aesthetics, see CBDG TG 4[1].

Figure 2 (a): Broadmeadow Estuary Bridge - from distance.

Figure 2 (b): Broadmeadow Estuary Bridge - at close quarters.

Sustainability

The design of a bridge has to take a long-term and strategic view. It is essential that design teams develop solutions that minimise the wide range of environmental, economic and social impacts, both during construction and over the whole life of the bridge. Concrete with its long life and minimum maintenance is a good solution to address these issues as it is primarily a locally sourced product (Figure 3).

Figure 3: Typical ready-mix concrete plant.

There are two key issues that need to be addressed – the use of finite natural resources and the emissions caused by the consumption of these resources. With a typical design life of at least 100 years, concrete is the most durable material commonly used to build bridges of any form or size. In environmental terms, it is useful to think of concrete as having three phases in life – creation, use in bridges and final recycling.

The environmental impacts of cement and concrete production have been significantly reduced in the UK, and worldwide, and are set to decrease further as energy and production efficiencies continue to be made[2]. In the UK, CO_2 emissions for cement production are down 40% since 1990 and waste products now account for about 30% of the fuel used. Concrete has a socially responsible production process that can use local and recycled aggregates, as well as cements containing industrial by-products, such as fly ash and ground granulated blast furnace slag (GGBS). The use of such by-products has increased by 50% since 1998. This concrete also has an enhanced durability that makes the bridge less susceptible to chloride ingress and thus reduces the future maintenance commitment.

Concrete should be placed as near to its point of production as possible in order to minimise the need for transport to site, support the local economy and prevent the export of environmental impact to other locations. The UK is highly self-sufficient in this regard and there is generally a ready-mixed concrete plant within 8km of every site, or within the precast factory, and more remote sites can set up their own batching plants. Embodied energy, or the energy consumed, and the CO_2 emissions have both been shown to be at their minimum, during construction and in use, with concrete bridge solutions[3]. Up to 95% of the concrete and steel reinforcement in a concrete bridge can also be recycled once the structure has reached the end of its viable life.

Sustainability is a complex area with environmental, economic and social impacts that are intrinsically woven, but locally sourced, durable concrete made with many recycled materials continues to demonstrate that it provides the best construction material.

Durability

Concrete has been in use since 7,000BC and there is wide evidence to prove that it is a very durable construction material (Figure 4). Most bridges are specified to have an intended working life of at least 100 years and so durability is a primary objective. It is therefore essential to consider the overall layout of the bridge, the detailing of the elements and the specification of the component materials. A significant reduction in the number of joints and bearings, or their elimination, will be a major feature of such considerations, as will the careful specification of concrete types and cover to reinforcement. All external areas of the concrete surface need to be carefully detailed with dedicated routes away from the structure for the flow of salt-laden water (from de-icing), incorporating suitable drips, channels and pipes, where necessary. Refer to CBDG CPS 2[4] for more details. Waterproofing of bridge decks is recognised in the UK as a vital and necessary operation to enhance the longevity and durability of the structure. The most common form of waterproofing is a liquid sprayed system applied in several coats. Refer to CBDG CPS 9[5] for more details.

Figure 4: Maillart's Salginatobel Bridge - opened in 1930.

A number of national and European design standards and specifications set out the requirements for concrete construction, identifying the required cover to reinforcement, cement content, water/cement ratio and cement type depending on the particular site conditions[6, 7 & 8]. Following these recommendations will ensure that the concrete is resistant to carbonation and chloride ingress, providing a full working life. The partial substitution of Portland cement with fly ash or GGBS, for example, results in concretes with high resistance to chlorides from de-icing salts or sea water. Concrete is also very appropriate to use where structures are subjected to other aggressive actions (such as acids) or ground conditions (such as sulfates). Construction methods that also use precast elements will tend to have higher concrete

Figure 5: East Moors Viaduct - stored precast units.

strengths, thus enhancing the long-term performance of the bridge (Figure 5).

The durability of concrete is highly dependent on the attention that is paid to detailing – best practice is described in two notable documents – Highways Agency BD 57[9] and CIRIA C543[10]. Good access to sensitive areas, such as pier tops, abutment shelves, the inside of box girders, bearings and joints, will allow inspection and any maintenance work to be safely carried out. In addition, the choice of the best construction methods must not compromise the durability or maintenance of the structure. The owner should be party to these early discussions to ensure that the finished bridge does not require any additional or earlier maintenance. Well designed and constructed concrete bridges require only minimum maintenance to keep them in good working condition. So, their competitive initial construction costs coupled with reduced inspection and maintenance, ensure a very attractive whole-life cost. High quality, low permeability concretes with the correct covers, low water/cement ratios and the appropriate cementitious material will provide durable bridge structures in all environments. For further details of the testing of concrete bridge durability, see CBDG TG 2[11].

Summary

Using local and recycled resources, teams are able to deliver sustainable concrete solutions for a wide range of bridge applications. Aesthetics, durability, versatility and economy make concrete an excellent material for any bridge project, whatever the size, form or use, delivering the owner a high quality product and good value. With several hundreds of years of history, concrete bridges are an established part of the world landscape. Looking ahead, concrete bridge construction will continue to lead the way, enabling aspirations embraced by the construction industry and society to be fulfilled as part of a sustainable future.

2.2 General Choice of Bridge Deck

Concrete Bridge Layouts

The owner will have described the basic requirements in relation to establishing the best location for the bridge. This choice of location will be governed by the type of crossing that is required (highway, railway or footbridge), and over what sort of obstacles the bridge needs to cross (water, highways, railways or utilities). The alignment of the bridge, and the required loadings that it has to carry, are likely to be determined at this early stage too. Careful thought about the best construction methods must also be accommodated even at this stage, as several good methods might be eliminated through an inappropriate early decision. For example, a launched bridge scheme (Figure 6) might be excluded if the alignment is made too complex. Or, if only one short end of the bridge needs to be widened to carry a slip road, then the costs of the project are likely to be considerably more as the bridge deck will need to be made flexible enough to allow for such a variation. It may be much better to re-consider the alignment and road layout in order to produce a bridge that can be made more uniform and repetitive, and thus become more economical.

In simple terms, it is the deck area and the length of the typical span that determine many of the bridge options. Larger schemes (e.g. with deck areas over 10,000m^2) can accommodate several methods (such as precast segmental techniques) that would be inappropriate for smaller deck areas. The range of construction methods for bridges with typical spans between 50m and 100m (such as in-situ or precast balanced cantilevers) can be quite different to those with spans between 20m and 50m (such as in-situ slabs or beams, or precast beams).

Figure 6: Blackwater Viaduct - straight launched bridge.

The availability of sufficient working access and space can also significantly help to simplify and speed up the construction process. The owner should therefore be aware of all the available construction methods (such as the need for on-site casting and storage areas), as these issues could easily determine the amount of land that needs to be purchased, or temporarily acquired. The opportunity should therefore be made for an involvement from the whole team (owner, designer and contractor) at this early stage, so that decisions are made with a clear understanding of all the issues and that the owner's priorities are fully understood. The owner should try to leave as many of the parameters as flexible as possible, such that the designer and contractor can consider all the available construction methods – this strategy will lead to the optimum solution.

Spans, Articulation and Fixity

Span layouts can often be determined by the obstacles that are being crossed, but it is generally possible to then rationalise the spans to generate either a more typical layout throughout, or a more aesthetically pleasing one, or ideally both. Decisions taken at this stage will fundamentally affect all future components of the scheme and it is therefore imperative that these decisions are taken by the most skilful and experienced engineers in the team, who appreciate the impact upon the overall value of the project, to both the owner and society. Pier locations should be chosen to be clear of water wherever possible to avoid the need for cofferdams, or other marine works, and the restrictive effects on navigation, wildlife, floods or tidal variations. Columns that are positioned well clear (more than about 6m) of highways and railways can also generally be designed without the additional costs of impact forces.

The overall substructure layout will also affect the best choice of bridge type. The wide range of available foundation and pier options are well documented in other publications[12 & 13], and are hugely dependent on the precise and particular geology of the bridge location. The costs and programme for particular substructure options will need to be considered in the overall package of options, which will ultimately allow the most suitable bridge type to be chosen. In areas of difficult foundations, such as over deep water, the bridge tends to be optimised with longer spans over about 80m (Figure 7), whereas in areas of easy foundations, such as over land and good ground, the spans tend to be 20-50m (Figure 8). Intermediate spans of 50-80m tend to be used in poorer ground or over shallow water.

These shorter 20-50m spans are best progressed as in-situ slabs or twin ribs, precast beams, in-situ boxes, precast segmental or incrementally launched boxes, whole span precast units or as the modular precast concrete bridge. The intermediate 50-80m spans are best as in-situ, precast segmental or incrementally launched boxes, whole span precast units or as in-situ balanced cantilever boxes. The longer spans over 80m are best as in-situ or precast balanced cantilever boxes, or as extradosed or cable-stayed schemes. It is common for long bridges with regular spans, for the span to be chosen by the foundation size and type. For example, where a particular pile cap solution works well with 4 No. 1.5m diameter bored piles, or even with a single 2.5m diameter pile, it may be best to select the span to exactly match the capacity of that foundation.

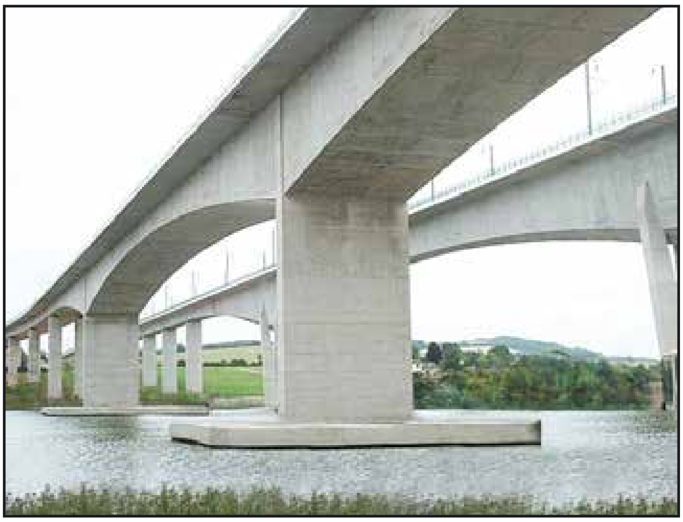

Figure 7: Medway Crossing Viaducts - 152m spans over deep water.

Figure 8: STAR Light Rail Viaducts - 35m spans over land.

Concrete bridges expand and contract with temperature changes, they shorten under creep and shrinkage, and they deflect under applied loads, prestress and temperature gradients. However, bridges also need to be held safely in all directions at all times, including during construction, when subjected to wind, traffic forces, seismic activity or various impact loads. The articulation of a bridge is therefore the measures taken to control its overall position while allowing it to move and deflect. Most bridge decks are generally best fixed transversely at all piers, usually with a guided, sliding bearing that allows longitudinal movement but is rigid transversely. Longitudinally, it is often best to fix the deck upon a central pier, or group of piers – this minimises the differential friction forces that arise from the group of sliding bearings and equalises the movements at each end (Figure 9). Alternatively, the bridge can be fixed at one of the abutments, which does enable all the piers to be kept quite slender. However, this option significantly increases the longitudinal fixing forces (as the fixed bearings have to carry the sum of all the friction forces on all the other bearings) and concentrates them at a location where the vertical reactions are small, which can make it much more difficult to accommodate the fixity.

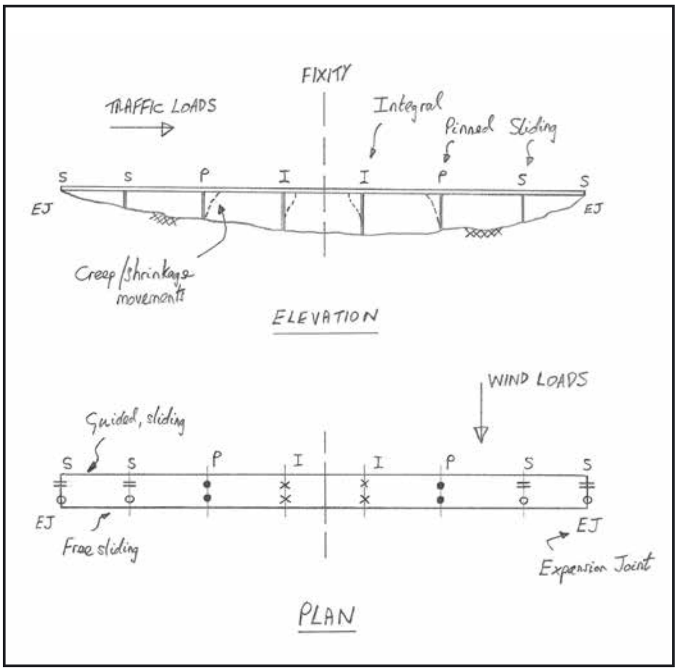

Figure 9: Fixity and bearings.

Joints and Bearings

Bridges are generally best formed as continuous structures with no joints, except at the ends. If the deck is very long, it may be necessary to divide it into several expansion lengths by using intermediate joints. Concrete highway viaducts can easily be over 1km long, without intermediate joints, with the longest in the UK believed to be 1.75km long (Figure 10). This absence of joints also provides a better ride quality and structural performance through the redundancy. So wherever possible, the distance between structural expansion joints on highway bridges should be maximised. The railway environment is different, as more frequent joints in the structure are often preferred so as to eliminate any rail joints, which can be expensive and need regular maintenance. Some construction methods are better suited to forming simple spans, such as when standard or bespoke precast beams are used. But even schemes that are built as a series of simple spans can be subsequently joined together to reduce the number of joints.

Figure 10: A13 Viaduct - 1.75km long with only end joints.

For prestressed concrete bridges, it can be shown that the balance between using either simple or continuous spans is quite close with spans around 25-50m, though continuity generally saves prestress. This better performance of a continuous deck in distributing loads is partly eroded by the secondary effects that arise from continuity, such as differential settlement and temperature. However, the choice of the most appropriate construction method will generally dictate the best solution. For spans over about 50m, concrete bridges should always be continuous. The elimination of joints should always be high in the designer's list of priorities, as historically they have been the source of many bridge maintenance issues. Joints also need to be inspected regularly, requiring good access and space beneath the joint for this purpose. CBDG CPS 5[14] gives details of the various expansion joint options and CBDG TP 6[15] gives details about the formation of sound concrete joints.

It is generally beneficial to also reduce the number of bearings, both to enhance durability and to reduce the maintenance. In areas that are close to the longitudinal fixity, bearings can generally be eliminated and, as long as the piers are flexible or made flexible enough, the deck can be built in to the pier and made integral. Though this detail may appear to be more complex from a construction point of view, it generally also provides a significant additional stability during the temporary phases of the construction, which will be beneficial (Figure 11). Some further distance from the fixity, it will be possible to fix the deck using pinned bearings, and only when the piers are more than 50-100m away from the fixity will it finally be necessary to provide sliding bearings, dependent on the pier height and flexibility. Once bearings are required, pinned bearings are the most economical solution, having the least amount of mechanical components (Figure 12). Sliding bearings are necessarily more complex, requiring a PTFE top to the bearing and a stainless steel plate attached to the deck soffit, both of which work together to form the low-friction sliding surface, which usually has a design friction of 4-5%. Guided, sliding bearings are yet more complex as they also need to carry transverse forces. Any bearings that are chosen should be of the simplest variety, with a strong preference to use rubber pot or elastomeric bearings as opposed to the more mechanical types of bearings. Good access for inspection and maintenance of the bearings must always be provided, including the need to provide space, and adequate strength, for the jacking operations that will be needed to replace the bearings, as bearings (and joints) have a much smaller life (20-30 years) than the life of the bridge.

Figure 11: River Dee Viaduct - built-in central piers.

Figure 12: Broadmeadow Estuary Bridge - pinned bearing.

Integral Bridges

The ultimate development in the ideas to eliminate joints and bearings is to make the bridge integral, with no joints or bearings. As noted above, integral piers are required to be flexible enough to accommodate the movements – this is generally achieved through the height of the pier, but can also be achieved by splitting the pier in to two leaves. This use of integral piers is more complex to design due to the interaction between the deck and the substructure, and between the substructure and the soil, but the benefits for the owner are large. The designer therefore needs to have a good appreciation of all the imposed deformations that might occur due to prestress, creep, shrinkage and temperature in order to deliver a robust solution.

Integral abutments should also be used for smaller bridge lengths – fully integral bridges are generally required to be used for all lengths less than about 60m, but can also be used for lengths up to around 100-120m, depending on the exact levels of prestress, creep, shrinkage and temperature (Figure 13). Often the abutment becomes like a typical pier, in order to attain sufficient flexibility, while the soil is then retained by separate mechanisms, such as reinforced earth. For intermediate cases where a fully integral bridge cannot be achieved, due to longer bridge lengths or high skews (where soil loads will cause deck rotations), it is possible to use semi-integral abutments, where the deck joint is eliminated but a bearing is retained. Further information on the use of integral bridges can be found in CBDG CPS 3[16] and CBDG TG 1[17]. CBDG TG 13[18] then outlines a typical set of integral bridge calculations in accordance with Eurocode 2[8]. Some of the research background to the design of integral abutments is also shown in CBDG TP 2[19] and TP 10[20].

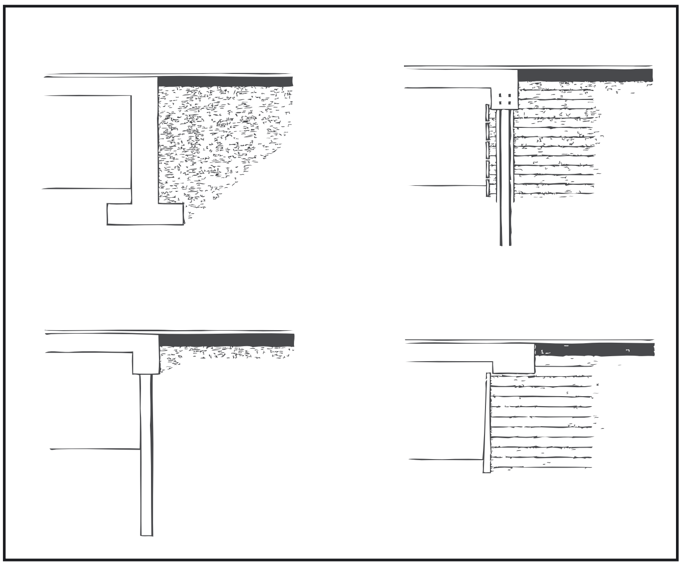

Figure 13: Various types of integral abutment.

Reinforced and Prestressed Concrete

Reinforced concrete is a passive system that relies on the composite action between concrete (which is strong in compression) and reinforcing bars that are strong in tension. In bridges, reinforced concrete would only be used for spans less than about 20-30m. For spans more than 20-30m, prestressing must generally be used. Prestressing is a technique that enhances the capacity of a member that is weak in tension, but strong in compression, to carry loads. It effectively creates a new construction material that is strong in tension. Alternatively, prestressing can be seen as an improvement to the technique of reinforced concrete.

The advantages offered by prestressing are:

- More economical, if well designed and built
- Smaller weight of steel to be handled and fixed
- Reduced steel congestion, leading to easier and quicker concreting
- Greater stiffness and an elastic behaviour
- Generally compressed under permanent loads
- Greater durability due to the absence, or reduced incidence, of cracking
- Active and more efficient system that opposes the applied loads
- Active system can carry a large element of the shear force
- Lighter and more slender members
- Improved appearance

Reinforced concrete can still be used for larger spans than 20-30m but the large deflections, and the increase in these deflections caused by creep, prevent such solutions being realistically sensible. Indeed, it was the extensive research carried out by Eugene Freyssinet in 1910-30 on such topics that allowed him to fully develop the idea of prestressing. Prestressing only really came to the fore though in the 1950s, once high strength prestressing steel had become commercially available (Figure 14). Prestressing steels are required to have a sufficiently high strength (f_{pk} of 1,860 MN/m^2) such that the long-term losses in the prestress force due to relaxation of the steel, and creep and shrinkage of the concrete, are not more than about 10-15% of f_{pk}.

Figure 14: Freyssinet's Changis-St Jean Bridge built in 1951.

As prestressing is an active system, considerable skill and care must be taken in its design. A designer has to more fully understand the range of actions, the effects of creep and shrinkage, the difference between internal and external forces, and between loads and imposed deformations. One cannot simply add more prestressing steel in order to be conservative, as the addition of prestress is just as likely to be detrimental to the section as is its removal. Further discussion on these topics can be seen in the 2012 Milne Medal paper[21].

Footbridges

Most of the issues that are covered in this guide can also be applied to concrete footbridges, although pedestrian loadings (of 5kN/m^2) are less than half those from typical highway traffic (of at least 10kN/m^2). Consideration must also be given to the safe use of the bridge by disabled users, pushchairs or cyclists, which has an impact upon the required gradients (no greater than 1/20 is preferred) and parapet configurations, while the use of stairs and lifts can play a significant role in the scheme too. Aesthetics often play a more major role with footbridges and the flexibility of concrete to be formed into almost any shape can be a real benefit in this regard (Figure 15). In-situ solutions can therefore be used for many of the more expressive footbridges, as the amount of formwork and associated falsework is relatively small, having less impact on the overall economics. Precast solutions are also very effective where the speed and ease of construction is more important, with both standard and bespoke precast elements being appropriate. Such precast elements can be cast either on site or in precast factories, and be made from reinforced, pre-tensioned or post-tensioned concrete. As the bridge is always viewed at close quarters by the pedestrian users, the quality of detail and surface texture is very important. The effects of wind or pedestrian loads on the dynamics of footbridges will need to be assessed, but as concrete solutions are relatively heavy and stiff compared to steel footbridges, the dynamic design tends not to be critical, except for the most slender structures. More details of the particular aspects of concrete footbridge design can be found in the CBDG Footbridges booklet[22] and CPS 1[23].

Figure 15: Garret Hostel Lane Footbridge - formed with in-situ concrete.

Railway Bridges

All the concrete bridge types that are described in this guide can be applied to both highway and railway bridges, although railways do have some additional features, and the obvious main feature is the increase in loading. Light rail or metro systems (Figure 8) actually have loads that are similar to highways, but heavier metros and the normal rail systems can have loads that are 2-3 times more than normal highway traffic. However, the exceptional vehicles for which many major highway bridges are designed (typically, weighing 100-200t) are similar to the heaviest railway locomotives (100-150t). Railway bridges also tend to be designed for higher lateral and longitudinal loads, due to a range of braking, traction, centrifugal and nosing forces, which will significantly affect the substructure design, although the design of the superstructure is usually dominated by the vertical loads. Dynamic effects from railways are also much more dominant than with highways, especially for shorter spans. Loads are typically increased by dynamic factors that can range from 1.0 for long spans (over about 70m) to 2.0 for very short spans (less than 3-4m). Special consideration will need to be given to high speed railways, where the dynamics of both the train and the bridge structure should be assessed. Fatigue should also be considered for all railway bridges, although with the use of well detailed, un-welded reinforcing bars in reinforced concrete, or fully prestressed concrete (where the concrete is always in compression and the prestressing steel has a very low stress range), fatigue is rarely a dominant issue.

As noted earlier, it is generally preferable with most bridges to maximise the distance between structural expansion joints. However, the railway environment can be different, as more frequent joints in the structure are sometimes preferred so as to eliminate any rail joints, which can be expensive and need regular maintenance. In this case, the interaction between the continuous track and the jointed structure will need to be assessed as this can significantly affect the longitudinal loads in the system, especially with track slab (as opposed to ballasted) solutions. All the steel in a railway bridge must also be adequately earthed from the traction power supplies. With new construction, the same rules regarding the speed and programme of the works still apply. Any works around the existing railway though will need to be assessed in a completely different manner, as the speed of construction will become paramount in order to reduce possession times and costs. Many of the launching, sliding and jacking techniques used with these types of activity are discussed in the later sections.

Prestressing for Concrete Bridges

Prestressing is an active system that opposes externally applied loads and actions with a set of internal forces. The designer has to fully understand this range of actions, and the difference between loads and imposed deformations. Only a brief introduction to prestressing can be given here and designers should consult CBDG TN 3[24] and other texts[12 & 13] for more detail.

For the design of all concrete deck sections (beams or boxes), the top slabs are governed by traffic loads and transverse bending effects, the webs by shear and torsion at the supports (but by minimum requirements for concreting at midspan), and the bottom slabs/heels by the layout of the prestressing and by any compressions at the supports (or the minimum thickness for concreting at midspan). Self-weight dominates many bridge designs and the areas of concrete should therefore always be kept to a minimum (Figure 16). It is particularly important to minimise the web concrete in a bridge, as these areas are also inefficient for the prestressing. For most bridge widths up to around 20m, it would generally be best to have only two webs, though with precast beam solutions, the number of webs is necessarily more. However for efficiency, the number of webs should still be minimised by spacing the precast beams as far apart as possible. For the design of box girders, which will generally be used for all spans over 40m, single cells are much preferred as they are far easier to cast than multi-cell boxes. Boxes are very efficient in distributing eccentric traffic loads though some care is needed with the analysis of torsional and distortional warping.

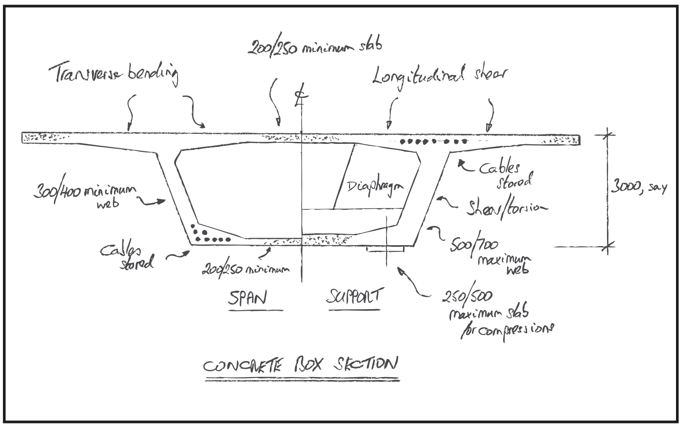

Figure 16: Concrete section sizing.

In order to achieve the sufficiently high covers that are needed for durability, the minimum concrete thickness is about 225-250mm, though 200mm is often seen in less aggressive environments and 160mm can be used for some high strength pre-tensioned beams. The combined analysis of bending and shear within slabs or webs is well described in most codes. However, the haunching of slabs can help with three areas – it aids the flow of concrete during casting, provides an area where internal cables or strands can be located, and it controls the longitudinal shear stresses, allowing a better pattern of reinforcement to be detailed. All these basic section parameters, which are often governed by the practicalities of the construction rather than any detailed analysis, can therefore be sized quickly by an experienced bridge engineer.

Pre-tensioned Bridges

With pre-tensioning, the prestressing steel is stressed first and the concrete member is then cast around this steel (Figure 17). Pre-tensioning is used for all standard, and some bespoke, precast beams. They are produced in a proprietary factory and are described in more detail later in Sections 3.5 and 3.6, suffice to note here that they can be of high-quality and quickly erected on site, with a proven record of durability.

Figure 17: Banagher Precast Concrete - pre-tensioning bed.

Post-tensioned Bridges

With post-tensioning, the concrete member is cast first and the prestressing is then applied afterwards. The range of possible bridge types and construction methods is large, and most concrete bridges over 40m spans (and up to 300m spans) will use post-tensioning. Bridges can be formed in to any shape and the most intricate alignments can be accommodated. The most common strand is a low relaxation superstrand, having a 15.7mm diameter, an area of 150mm^2 and an ultimate strength, f_{pk} of 1,860MN/m^2. The strands are bundled together and typical cables may be formed from twelve to thirty-seven strands, and be designated as 12/15mm or 37/15mm. Each cable sits inside its own duct which, after threading and stressing, is then usually filled with a high-performance cementitious grout. The specification and application of these grouts needs to be very well controlled in order to get a completely filled duct – see TR 72[25], and BS EN 445[26], 446[27] & 447[28].

The prestress is applied to the ends of each cable via a steel anchorage, which is cast in to the concrete. Each strand is then clamped by a set of wedges that locks the strand in to the anchorage. The prestress force is applied to the anchorage with hydraulic jacks, which typically apply loads of 2-8MN, i.e. 200-800t (Figure 18). The prestress can be finely tuned to suit the required forces at every section. So, it is common for post-tensioned bridges to have many sets of cables, each starting and stopping in a variety of locations to suit both the construction method and applied loads. Any inclination of the cables also provides a shear force, which acts against the applied shear forces, providing a significant shear relief, which reduces the amount of reinforcement needed in the webs.

Figure 18: Clackmannanshire Bridge - post-tensioning jack stressing a cable.

There are two types of cable configuration – internal cables that are grouted inside ducts, which are within the concrete and bonded to it, and external cables that are also grouted inside ducts, but which are outside the concrete and not bonded to it. Each type provides a three-layer protection system to the cables using grout (or wax), the duct and the concrete. Internal cables are more compact with smaller cables, anchorages and blisters – often using 12/15mm or 19/15mm cables. They can more closely follow the pattern of moments in the member and thus have a better eccentricity and ULS performance than external cables (Figure 19). In the UK, ducts are required to be made from a continuous, corrugated plastic, whereas elsewhere, away from road de-icing salts in particular, ducts are often formed from corrugated, galvanised steel. These bonded sections tend to be designed as fully compressed under all frequent traffic loads. This is the requirement in EC 2[8] and, as a result, these internally prestressed sections are generally governed by SLS, and ULS will not be critical.

Figure 19: STAR LRTS Viaducts - internal cable ducts at the pier.

External cables are generally larger with a fewer number of anchorages. As they sit in free air, they tend to follow more simple profiles and need deviator blocks at all changes of direction (Figure 20). The cables are housed within continuous HDPE ducts. These large external cables - often using 27/15mm or 37/15mm cables - need large anchorages and deviator blocks, which can contain considerable volumes of concrete and reinforcement. As they sit outside the concrete, external cables have a lower eccentricity than internal cables and being unbonded, their ULS performance is not as good as internal cables. However, they do allow thinner webs and many construction methods (such as span by span precast segmental or whole span precast) work very well using external cables, where it is quicker to install a smaller set of larger cables. They also allow the use of partial prestressing, which is covered below. External cables were first introduced to enable the ducts and cables to be easily inspected, maintained and replaced. However, with the improved grouting technologies introduced by TR 72[25], and its forerunner in 1996, the need for such inspection is significantly reduced. Subject to local regulations, designers should therefore choose between external and internal systems, or a mixture of the two types, on the basis of what is best for the design and construction method.

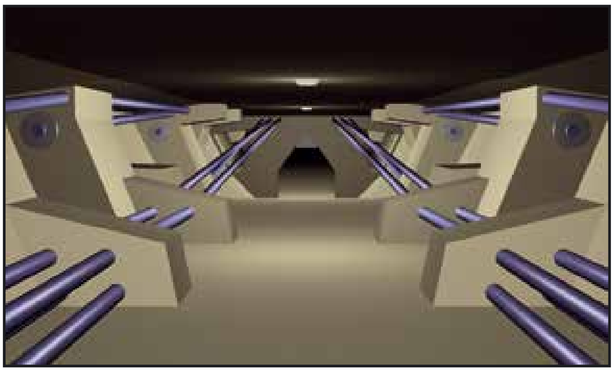

Figure 20: A13 Viaduct - external cable profiles inside the box.

Post-tensioning Details

Single-end stressing is always preferred as it uses less labour and fewer jacks, but the viability depends on the friction losses, especially for internal cables. However, most cables less than about 50m long can be stressed from one end, while over this length, it is generally necessary to stress the cable from both ends. Internal cables can be up to 150m long, whereas external cables can be much longer as they have less friction. Typically, ducts are spaced at two diameters, while the minimum cover to internal ducts is also generally a duct diameter. The alignment of all ducts should follow as smooth a profile as possible to avoid excessive friction losses. Profiles usually consist of straights and radii as these are the easiest to set out. Minimum radii are dependent on the cable size, but vary from 5-10m for internal cables and about half those figures for external. There should also be a minimum length of straight duct immediately behind each anchorage, of 1.0-1.5m. External cables are straight, except at deviator positions, where the radial forces are carried into the body of the section, using struts, ties or beams.

Figure 21: East Moors Viaduct - anchorage blisters inside the box.

Each cable anchorage transmits the huge forces in to the main body of the concrete – these anchorages might be at diaphragms, abutments, pockets or a variety of blisters (Figure 21). The stresses behind these anchorages can be close to the concrete strength and therefore the bursting issues are dominant. Besides the need for any bending or shear steel in these areas, there are three types of additional anchorage zone steel – bursting (or splitting), equilibrium and spalling, all of which are described in CBDG TN 10[29]. These anchorage zones are the most highly stressed areas of the bridge and are often the most heavily congested. It is therefore important to understand all the actions, so that only the correct and co-existent loads are considered, and detail the areas with great care, otherwise they can become unnecessarily congested and prone to poor compaction, whereas well compacted concrete is vital. Smaller, well anchored bars such as H12s and H16s are much more likely to provide better resistance than larger bars. It will generally be necessary to consider the stressing sequence in the area as well, as more critical conditions than the long-term might be found.

Where cables are anchored along the length of the bridge, as opposed to an end face, there are additional effects at these blisters. The same issues of bursting, equilibrium and spalling still apply, but the designer should also take account of any corbel action using a strut and tie analogy, especially for external blisters. Blisters, which are generally only found in box girders, are best placed at the intersection of a web and slab, i.e. where there is sufficient rigidity of the node in both directions to carry the overall moments. Prestressing cables can also be coupled, though the more common practice is to lap cables using blisters – this is generally a more reliable and economic method. If couplers are used, then ideally no more than a third of the cables should be coupled at any one location, though EC 2[8] allows a figure of 50%.

Partially Prestressed Bridges

As noted above, partial prestressing is possible when external cables are used. As the cables are protected within the envelope of the concrete, the concrete section can be allowed to crack, as this cracking would have no detrimental effect on the cables. The designer thus has the option to consider a full range of prestressing, from full compression to none, i.e. just reinforced concrete. Further discussion on this topic can be seen in the 2012 Milne Medal paper[21], where it is concluded that a high level of prestressing is likely to provide the better set of results. High levels of prestressing provide all the benefits described earlier, whereas low levels of prestressing are not really suitable for spans over about 30m, primarily due to the much higher deflections and ongoing levels of creep (Figure 22).

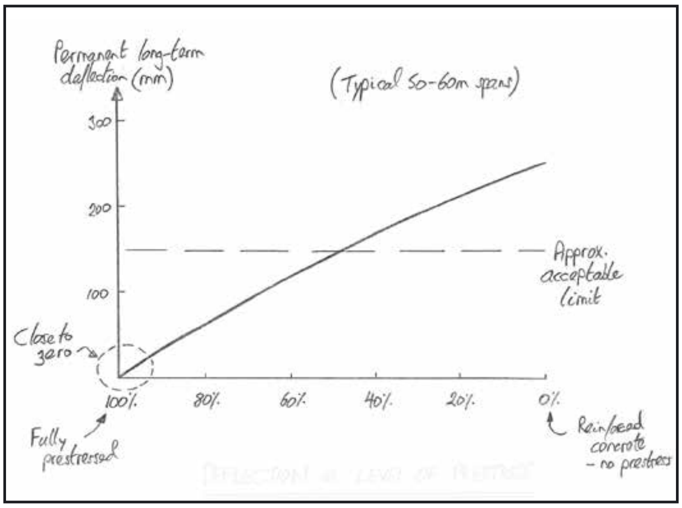

Figure 22: Permanent deflections vs level of prestress.

High Performance Concretes

Various high performance concretes (such as the high strength, lightweight or self-compacting concretes described below) can be used for concrete bridges, to make them either quicker and easier to build, or more economic. The specification for high performance concretes needs to identify the required concrete strength, cover to the reinforcement, cement content, water/cement ratio and cement type, all of which will depend on the particular site and environmental conditions. Working to these specifications will ensure that the concrete is best suited to its location in the bridge, as well as being resistant to carbonation and chloride ingress, in order to provide a long and low maintenance working life. The choice of cement and admixture type will also have an impact on the speed of construction because of the rate of gain of strength, which therefore has an influence on some of the construction methods. Many of these topics are also discussed in CBDG TG 5[30].

High Strength Concretes

High strength concretes (HSC), typically with higher cement contents and lower water/cement ratios (less than about 0.40) than normal strength concretes (NSC), can offer many advantages for bridges by allowing the use of shallower, thinner, lighter and more durable sections, where higher compressive and shear stresses can be adopted (Figure 23). It is thus possible to use longer spans or to have higher load-carrying capacity without increasing member sizes. Higher early strengths will also speed the construction process and allow the earlier removal of falsework or application of prestressing. The durability of the section is also considerably improved and the low permeability of HSC results in lower maintenance costs and longer service lives.

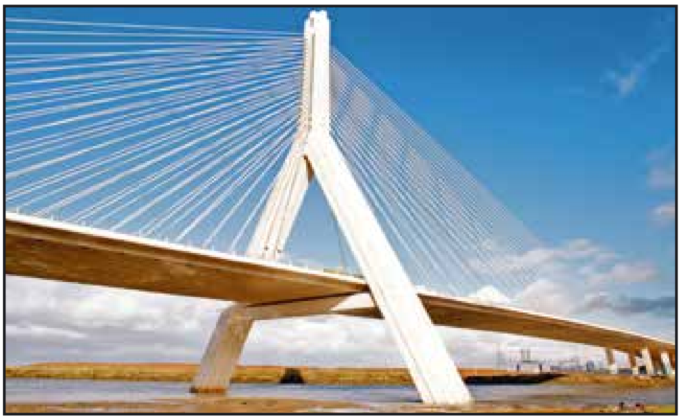

Figure 23: Flintshire Bridge - with 70MPa cube HSC deck.

Characteristic cylinder strengths of 40-60MN/m^2 (cubes of 50-75MN/m^2) are the norm for prestressed concrete schemes, though strengths up to 60-80MN/m^2 are becoming more common for some types of precast decks, mainly through the use of water-reducing admixtures. Once the cylinder strength is in this 60-80MN/m^2 range (cubes of 75-100MN/m^2), the concretes are generally referred to as HSC. Most codes of practice around the world cover these HSC.

Fly ash is used extensively in HSC as the pozzolanic activity in the concrete takes place over a longer period than with Portland cement, contributing to higher ultimate compressive strengths. GGBS is also used widely for longer term strength, improved durability and reduced heat of hydration effects. In all cases, high range water reducers are likely to be used to maintain consistence without increasing the water/cement ratio. Additionally, all the aggregates should be strong and durable, and are typically crushed rock. Concrete Society TR 74[31] refers to the use of these various components. All HSC need good quality control of the production and placing of the concrete, as well as proper curing and testing. As the water/cement ratio of these mixes is lower than with NSC, continuous external moisture input is needed over the first 7 days after placing the concrete to avoid self-desiccation, i.e. where there is not enough water to fulfil the hydration potential of the cementitious components. Various wet curing methods are possible, including covering the surfaces with wet mats or other absorbent materials.

HSC have been used in bridges widely over the last 20 years to enable shallower sections, fewer members, lighter sections (with less prestressing), or more durable bridges with a longer life, particularly in aggressive environments. Cost savings have resulted from both a reduced initial and whole life cost. High strength bridge concretes are covered in CBDG TG 6[32] (with an extensive reference to other documents), while for further details can also be seen in CBDG TN 9[33].

Lightweight Concretes

Lightweight aggregate concretes (LWC) have been used widely and successfully in bridge construction for more than 80 years. The decisions to use LWC were generally because of the economic advantages, mainly associated with reductions in the self-weight loads giving rise to savings in reinforcement and prestressing, as well as in the substructure costs. The use of LWC can often bring a competitive advantage to a wide range of bridge types (where the total material savings across the bridge more than offset the increased cost of the lightweight material). Typical savings on the whole bridge might be small for short-medium span bridges, but savings can reach 5-10% for longer spans, especially with spans over 100m (Figure 24). LWC can therefore be competitive for these longer spans where the greater effects on the self-weight can reduce the prestressing by more than 15%.

Figure 24: Raftsundet Bridge - 298m span with 65MPa cube LWC.

LWC are defined as having an oven dry density of 800-2,000kg/m^3, compared to 2,000-2,600kg/m^3 for normal weight concretes (NWC). However, to achieve the required concrete strengths for bridges, only the coarse aggregate component of the mix is made from lightweight aggregates, giving a realistic range of densities of 1,600-2,000kg/m^3. Lightweight aggregates are made from pelletised GGBS and fly ash, and expanded clay, slate or shale, many of which are known by their trade names, such as Lytag®, Liapor® and Leca®. Most codes of practice around the world cover these LWC. Bridges containing LWC have been used widely and have been shown to be as durable as NWC, with no difference in maintenance costs. Bridges with LWC are fully described in CBDG TG 8[34], which also has an extensive reference list, while a further summary is given in CBDG TN 9[33].

Self-compacting Concretes

Self-compacting concretes (SCC) must flow under their own weight and fill the formwork completely, producing a dense and uniform concrete without segregating or the need for compaction. They are not simply high workability concretes, as these still need to be compacted. The properties of the hardened concrete can cover the whole range of required strength and durability. As the material will flow without segregation from one end of the pour to the other, the need for temporary access and plant is significantly reduced. The rate of placing needs to be controlled to allow the entrapped air to escape and so may not be faster than normal concrete, but as it is continuous the completion of the overall concreting operation may be quicker. With the absence of vibrators, the major benefits are quieter worksites and the avoidance of vibration related injuries.

There is not a particular concrete mix that works in all cases, but to enable self-compaction without segregation, the paste and mortar volumes must be carefully balanced. The cementitious content is typically greater than with normal concrete and can include GGBS or fly ash additions, along with limestone powder, to act as a fine filler. High range water reducers are used to impart fluidity and control water content. Viscosity-modifying admixtures can be added to control segregation but ideally, with the availability of appropriate constituents, this addition should be kept to a minimum, especially if visual concrete is required. As all these fine particles make the microstructure of SCC more dense, the strength and durability of the hardened concrete is generally increased, when compared to traditional concrete having the same water/cement ratio. The formwork for SCC needs to withstand higher pressures than with traditional mixes and, depending on the method of placing, the formwork will probably need to be designed for the full hydrostatic pressure (Figure 25).

Figure 25: Whitecleave Viaduct - pier replacement with SCC.

All the evidence to date suggests that SCC have the same long-term properties as traditional concretes of the same strength and water/cement ratio. However, SCC are generally of a higher quality, with fewer voids and a denser microstructure. SCC may be more expensive than traditional mixes, but this deficit can be offset by the reduced labour requirement. Faster bridge deck construction times are also possible due to the increased workability and ease of flow around reinforcement. The economics of SCC are best displayed when they have been incorporated right at the start of the design process, taking full advantage of all the possible material, labour and plant savings. A fuller summary of all these issues can be seen in CBDG TG 7[35] and Concrete Society TR 62[36], with a briefer summary in CBDG TN 9[33], and SCC can be specified through BS EN 206[6].

Concrete Bridge Detailing

All details need to consider buildability, durability and maintainability as well as safety and aesthetic issues[9 & 10]. The weather is the main source of concern for most external details, with water, often laden with de-icing salt, able to access almost everywhere. Every surface must therefore be detailed on the basis that it will get wet – this requires a positive drainage and drip system for all near-horizontal surfaces. To protect details within the concrete, the characteristics of the concrete must be specified, which will depend on particular site conditions. Working to these specifications will ensure that the concrete is best suited to its location, in order to provide a low maintenance working life.

Good reinforcement detailing is covered by many documents and indeed modern codes[8 & 37] tend to outline key areas of recommended detailing. This section will only therefore cover some of the particular concrete bridge issues. The minimum bar size is usually H12, though H10s can be used in some nominal areas, whereas structural reinforcement should generally consist of H16s or H20s. In heavily loaded areas, these bars might become H25s or H32s. H40 bars would usually only be used in large beams or columns, or in pads/pilecaps. H50 bars should not generally be specified, as they are too heavy to fix. The best bar pitch is generally 150mm, possibly 125mm in more heavily loaded areas, as 100mm is too close to accommodate good placing of the concrete around laps, while 200mm may be too far apart for adequate control of cracking. An old rule of thumb for minimum steel is *If in a fix, use half inch at six*, which in today's parlance is H12s at 150, and still a wise rule. The requirements to limit early thermal cracking are also generally covered by this rule for most thin sections. Sections that are more than about 500mm thick will need slightly more steel, with H16s at 150 being typical. This is the minimum steel needed within the surface zone to prevent yielding and limit crack widths. Another excellent rule of thumb is to never use bars that are more than 1/10 of the section depth, i.e. do not use H32s in a 200mm slab – the maximum bar size should be 20mm.

EC 2[8] incorporates a variable angle truss analogy for shear design that allows engineers to select any angle between 22 and 45 degrees. For thick (or lowly stressed) webs, where concrete crushing is not critical, the optimum solution is to minimise the area of shear reinforcement by using a low angle, but no lower than 22 degrees. However, for most bridges where self-weight is crucial and therefore where the thinnest webs are used, the concrete crushing is critical and the best method is to use a high angle, i.e. the traditional 45 degrees. The most complex areas in bridges can all be analysed using struts and ties. Not only is the concept simple, but it ideally suits the linear pattern within which reinforcement is fixed. Finite element (FE) analyses have their role in some circumstances, and can help the designer select the best struts and ties, but they can also suggest a greater degree of precision than is really the case. Reinforced concrete is neither homogeneous nor a linearly elastic material – cracking produces a material that is generally much better represented by the struts and reinforcement ties of this simple method. EC 2 also points the designer in this sensible direction and Schlaich & Schäfer[38] have an excellent summary. For other major areas of detailing, the reader should take adequate reference from other sources, such as CBDG TN 10[29].

Summary

It is very important that the best bridge layout is chosen at an early stage, while the greatest benefits are still available to the owner. This guide will help designers select the scheme that provides this highest value. However, the design team must employ the skills of the most experienced bridge engineers at this early stage as, once an inappropriate solution has been chosen, it will be difficult to optimise it later. The key factor is to get on the right path in the first place – this process requires a team with a thorough understanding of bridge design, prestressing and the various construction methods that are available. Of all the available materials to a bridge engineer, prestressing is the most challenging as it is an active, not passive, system. One cannot simply add more prestressing steel in order to be conservative, as the addition of prestress is just as likely to be detrimental to the section as is its removal. The designer must therefore calculate all the effects along all sections of the member, and then design the prestress to counter them at all locations. This process needs a determined effort from skilful designers and, all the while, they must be considering the critical construction issues, as they affect all their decisions. The careful detailing of concrete bridges ensures that the construction process is safe, easy and quick, and the bridge is durable and easily maintained for its entire life. Many details require the designer to only consider the correct co-existent effects, which needs a good understanding of the principles of reinforced and prestressed concrete. As with most design and detailing, the drawing of sketches and the preparation of 3D models will help the designer identify all the relevant issues and create good solutions.

2.3 Particular Choice of Bridge Deck

Buildability - precast versus in-situ

Buildability and the various construction methods available for all types of concrete bridges are covered in the later sections, but the particular issues around the use of precast or in-situ construction are outlined here.

The general parameters of the scheme such as the typical spans, the overall deck area, width and length, the clearance requirements, alignment and the overall aesthetic will start to suggest which bridge types and which construction methods might be appropriate (Table 1). However, the final choice will then depend on many other particular parameters such as the site access, layout and availability, geotechnical issues, environmental issues, construction programme and phasings, labour rates, resource requirements, material quantities and costs, plant supply, traffic management, temporary works layouts, as well as the overall casting, transportation and craneage or erection issues. The owner should try to leave many of these parameters as flexible as possible, such that the designer and contractor can consider as many of the available construction methods as is possible.

Many of these particular parameters are controlled by the need to increase the speed and ease of the construction process and while fast construction is not necessarily an objective in itself, it can generally be seen that the best construction methods are indeed driven by speed. Although precasting is often the preferred method of achieving these speed objectives, in-situ concrete can also deliver the same results (Figure 26). In practice, a combination of the two (in-situ piers and precast decks) is typical. The appropriate use of labour, materials and plant to create the best construction method can assure the successful delivery of a wide range of bridge deck structures within tight programmes and across the spectrum of all environmental and site conditions.

Precasting and factory production methods can significantly improve the safety regime by shifting the works to a more regular and controlled series of operations, with a workforce who have become familiar with the production process. Precasting of elements can also significantly reduce risks and improve rates of production. The repetition created by a standardisation of details and dimensions helps to reduce construction time (Figure 27). Bridge components that are manufactured away from the construction site, in an efficient factory environment, can be made to very high standards and without any concerns about adverse weather (Figure 28). The quality of the concrete can be tightly controlled and the formwork, reinforcement and prestressing can be prepared and positioned to extremely high tolerances. After it has been poured, the concrete can be cured effectively to maximise its performance, durability and appearance. Importantly, precast concrete can be stored and delivered to site at precisely the right time in the construction programme. On larger projects, a precasting facility may be established on site, or near to the site.

Figure 27: Kingsway Canal Bridge - standard precast beams.

Figure 26: River Dee Viaduct - in-situ balanced cantilevering.

Figure 28: Banagher Precast Concrete factory and yard.

Table 1: Concrete Bridge Types vs Span.

Bridge Type	Span (m) 10 to 20	20 to 30	30 to 40	40 to 50	50 to 60	60 to 70	70 to 80	80 to 90	90 to 100	100 to 150	150 to 200	200 to 250	250 to 300
In-Situ Flat Slabs	Most competitive range in UK												
In-Situ Voided Slabs	Typical range	Most competitive range in UK	Typical range										
In-Situ Twin Ribs	Typical range	Most competitive range in UK	Most competitive range in UK	Typical range									
Standard Precast Arches/Portals	Most competitive range in UK	Typical range											
Standard Precast Beams	Most competitive range in UK	Most competitive range in UK	Most competitive range in UK	Typical range									
Bespoke Precast Beams		Typical range	Most competitive range in UK	Most competitive range in UK	Typical range								
In-Situ Span by Span Boxes			Typical range	Most competitive range in UK	Most competitive range in UK	Typical range	Typical range						
Modular Precast System	Typical range	Most competitive range in UK	Most competitive range in UK	Typical range									
Precast Segmental Span by Span		Typical range	Most competitive range in UK	Most competitive range in UK	Typical range								
Incremental Launching		Typical range	Most competitive range in UK	Most competitive range in UK	Most competitive range in UK	Most competitive range in UK	Typical range						
Whole Span Precast			Typical range	Typical range	Typical range								
In-Situ Balanced Cantilevering				Typical range	Most competitive range in UK	Most competitive range in UK	Most competitive range in UK	Most competitive range in UK	Most competitive range in UK	Most competitive range in UK	Most competitive range in UK	Most competitive range in UK	Typical range
Precast Segmental Balanced Cantilevering		Typical range	Most competitive range in UK	Most competitive range in UK	Most competitive range in UK	Most competitive range in UK	Most competitive range in UK	Most competitive range in UK	Most competitive range in UK	Most competitive range in UK	Typical range		
Bespoke Arches/Frames					Typical range	Typical range	Typical range	Most competitive range in UK	Most competitive range in UK	Most competitive range in UK	Most competitive range in UK	Typical range	Typical range
Stressed Ribbons		Typical range	Typical range	Most competitive range in UK	Most competitive range in UK	Most competitive range in UK	Most competitive range in UK	Most competitive range in UK	Most competitive range in UK	Typical range			
Extradosed										Typical range	Most competitive range in UK	Most competitive range in UK	Typical range
Cable-Stayed										Typical range	Typical range	Most competitive range in UK	Most competitive range in UK

Typical range
Most competitive range in UK

(All dependent on total deck area, alignment, depth and local conditions)

Precast elements, which can vary from several tonnes to several thousand tonnes, are much quicker and easier to erect too, though more sophisticated erection methods will generally be needed. These methods might use large mobile or site cranes, lifting frames or shear legs, gantries (some of which can become self-launching and very sophisticated pieces of mechanical/electrical engineering), falsework towers and a range of girders (Figure 29). Precasting therefore requires a greater degree of capital investment, with not only more complex erection methods, but also casting and storage areas, transportation, and more equipment than is needed for in-situ works. Precasting thus tends to need greater planning and more care in its execution. Besides the bridge deck components, it is very common to now see the precasting of parapet edge beams, which allows a greater degree of control to be applied to these areas, which are often on the critical path as well as being very close to high levels of road de-icing salts.

Figure 29: Limerick Southern Ring Road - precast beam lifting.

Having described all the benefits of precasting, it should be re-iterated that in-situ construction is still also very valid, able to produce high quality bridge decks in the right circumstances, as can be seen in the later sections.

Concrete Bridges Types

There are several types of concrete bridge deck, each of which should be used in different circumstances. The two key parameters used in selecting a bridge type are the construction method and the typical span, though many other particular parameters come in to play, as noted above. Table 1 above shows a layout of Bridge Types vs Span, which gives a broad outline of the options. The bridge types may be split into in-situ and precast options:

In-situ

- In-situ solid or voided slab – cast on a scaffold system or a series of beams/girders
- In-situ twin rib – cast on scaffold/beams or using travelling gantries
- In-situ span by span box girder – cast on scaffold/beams or using travelling gantries
- In-situ balanced cantilever – short box sections cast using a travelling formwork system.

Precast

- Standard precast beam – inverted T/Y or U beams erected by crane
- Bespoke precast beam – T, I or U beams erected by crane or using a gantry system
- Precast segmental box girder – short segments erected with cranes or gantries
- Whole span precast box girder – erected span by span with gantries
- Incrementally launched box girder – erected using sliding equipment
- Modular precast – short shell segments erected on scaffold/beams or launched into place.

Further details of all these bridge types will be given in the later sections. The basic cross-sections of each type are shown in:

- Figure 30a - reinforced or post-tensioned solid or voided slab
- Figure 30b - post-tensioned twin rib
- Figure 31 - typical post-tensioned box girder for either in-situ or precast options
- Figure 32a - standard pre-tensioned inverted T or Y beam, with a composite deck slab
- Figure 32b - bespoke pre-tensioned U beam, with a composite deck slab
- Figure 32c - bespoke post-tensioned I beam
- Figure 33 - modular precast shell with a post-tensioned and composite infill.

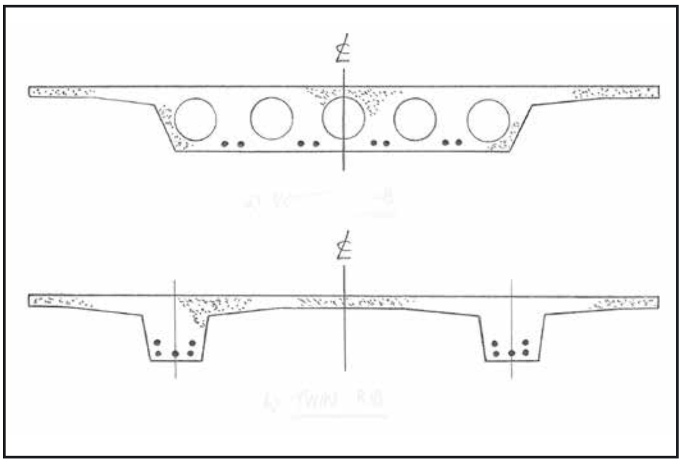

Figure 30: In-situ voided slab and twin rib.

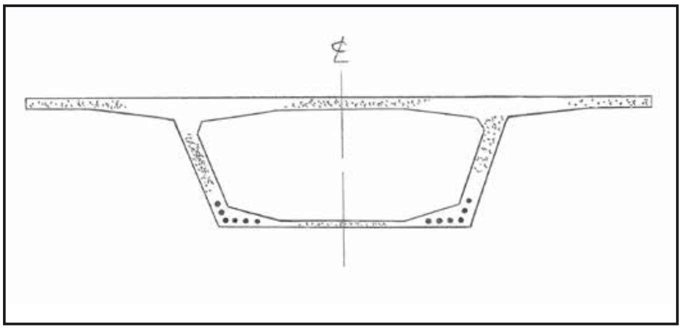

Figure 31: In-situ or precast box girder.

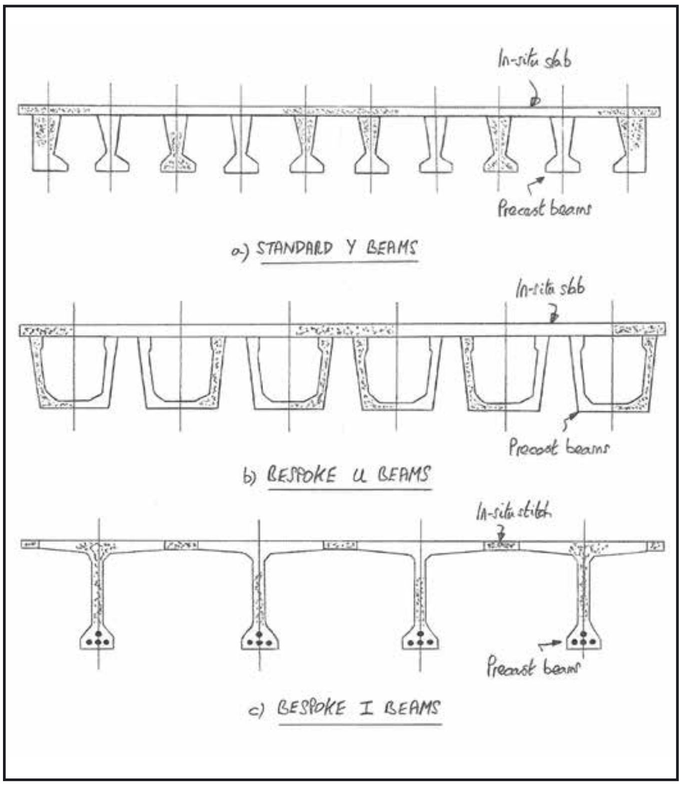

Figure 32: Standard and bespoke precast beams.

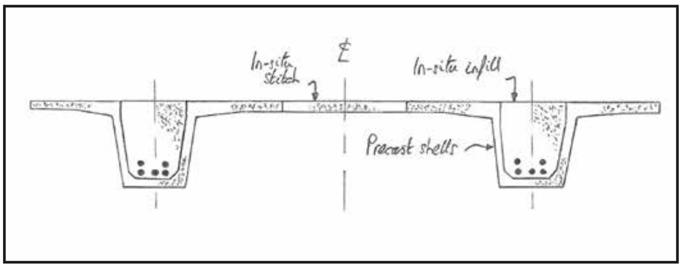

Figure 33: Modular precast shells with in-situ infill.

Selection of Bridge Type

It is often the construction method that determines the actual design solution, as no bridge can really be designed without knowing how it will be built. The construction method influences the forces in the bridge deck, as well as shaping the cross-section and many of its details. It is also determined by the site constraints, with the overall programme and the speed of the actual construction method playing a key part in the breakdown of cost. Ultimately, it is the optimum cost solution that will be built, but a skilful team should ensure that this solution is also the same scheme that delivers best value to the owner.

Figure 34: Banagher Precast Concrete - casting.

The deck construction process can be split in to three broad areas – casting, transportation and erection. Casting relates to the formwork and mould issues (and to the falsework for in-situ schemes) (Figure 34). Casting needs to consider the amount of land that is made available for casting areas and storage of any units. Transportation relates to the precast options, all of which involve the movement of units from the casting area to the erection area. This will involve the use of low-loaders, straddle-carriers, wheeled-bogies or rail systems (Figure 35). Erection entails the use of mobile or site cranes, or various falseworks, to move and then support the precast units (Figure 36). These falseworks will be in the form of scaffolds, beams, girders or trusses that need to travel from span to span as the construction evolves. This movement can be via a dismantling and re-erection process, or by using gantry systems that travel forward. The bridge and all its falsework must remain stable during all these operations, which will often need several other items of temporary works to ensure that stability is not compromised or that the permanent works are not adversely affected.

Figure 35: Afon Hydfron Bridge - transportation.

Figure 36: Limerick Southern Ring Road - erection.

Access for all these items of construction plant is important for both buildability and the speed of construction, with the ease and degree of access being crucial to the way in which the project is phased and programmed. The programme will also need to take account of utility diversions or installations, and any traffic management, which can be either on the bridge, over it or underneath it. The particular supply of materials, labour and plant will vary from site to site, and in relation to the remoteness of the site. The arrangements with particular sub-contractors or suppliers can also be vital, as they may be involved with considerable elements of the bridge, i.e. not only the concrete and reinforcement supply, but also the supply and use of prestressing, specialist formwork and moulds, specialist items of falsework (such as gantries, girders and props) and cranes. Precast manufacturers will also play a fundamental role as they could be involved with almost any of the various precast options.

Programme Issues

Many of the choices about which bridge deck to use are controlled by the need to increase the speed and ease of the construction process. Faster construction also leads to cost savings through reduction in the duration of the overheads and thus any steps to improve the speed will also generate greater cost savings than the overall operational benefits. Alternatively, faster construction may be driven by the need to minimise disruption to traffic or users and, in extreme cases, more expensive construction methods might be adopted in order to realise such benefits, e.g. within the railway environment, where possessions are very costly. Many of these topics are discussed in more detail in CBDG TG 5[30].

Design decisions must be made with buildability in mind and thus the involvement of construction team members during the design process, such as in design and construct contracts, will yield significant benefits. The resulting details will reflect the contractor's requirements, while safety issues can be better recognised and the cost implications of decisions can be readily assessed. Sufficient time must be allowed for designers, contractors, sub-contractors and suppliers to adequately design, plan and execute the scheme in relation to any restrictions. The owner will be an essential part of this process and will have an active part in the discussions to resolve any issues with third parties. Simplicity is a key element for efficiency - simple and standardised detailing should allow more rapid and easier construction.

Reinforcement rationalisation should eliminate unnecessary variation by simplifying, reducing complexity and taking advantage of the opportunities provided by prefabrication. The team should identify typical reinforcement arrangements that will be suitable for many elements. Though this process may lead to some over-design, there will be subsequent economies in terms of the ease and speed of fixing the reinforcement. Prefabricated cages can be made on site, in timber or steel jigs, to allow the precise positioning of every bar. Cages can be produced in a factory environment, with repetitive and safe operations, and then lifted straight in to the mould (Figure 37). Welded cages are rarely used in bridge decks due to the fatigue issues, though some welding can help to stiffen the cage. The careful integration of prestressing anchorages and ducts within the cage is crucial. Such areas can become congested and each bar is best designed and detailed, by sketches or 3-D models, to ensure that they can all be placed, with speed and ease (Figure 38).

Figure 37: Clackmannanshire Bridge - reinforcement cage assembly.

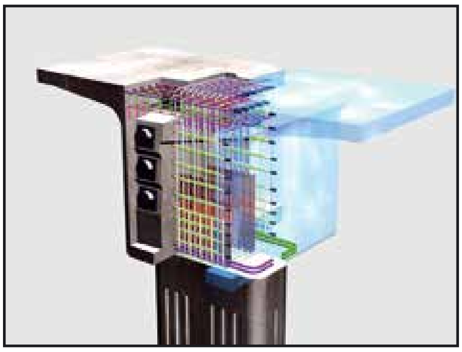

Figure 38: 3D reinforcement model.

Connections between precast units and in-situ concrete, or between in-situ concrete pours, will require lengths of reinforcing bar projecting from the elements, which then need to be lapped. The detailing of these *starter* bars needs as much care as other congested areas, as they can form both a hazard and a hindrance to site operations. The temptation for operatives to bend any high-yield steel bars out of the way must be avoided, in order to prevent unacceptable stresses in these bars. Mild steel *bend-out* bars can still be used in some countries, but it is more common nowadays in Europe to use couplers. Couplers can play a major role in allowing fixing operations to be safe, easy and rapid, though they can be expensive and should only be used when all the implications are understood. Various types of coupler are available, though the most common are threaded, requiring the ends of both bars to be machined. Some couplers can have a relatively poor fatigue performance and should only be used in areas close to repeated traffic loads after careful consideration.

Road or lane closures, or railway possessions can significantly affect the speed of construction. On the railway, or waterway, the usual method is to close the route for the duration of the works, whereas on a highway, it is more common to divert traffic. Such closures or diversions have to be arranged many months in advance, and so the role of the owner is again crucial. Railway possessions may need 12 months' notice, or more, whereas highway diversions may need only 2 months' notice, though on major routes this may be closer to 6-12 months. The phasing of the works to suit these diversions or closures should be carefully considered at an early stage, as otherwise several methods might become impractical. A single box across the whole carriageway would not be possible, for example, if the highway needed to be built in two phases, and an alternative beam section might be preferred.

This guide has been prepared by examining typical production rates for all concrete bridge types. These have been based on comparisons to multiple sources of data from bridge schemes worldwide. Table 2 shows a summary of the typical production rates (in m/week) for each bridge type. In order to examine the overall programme, it is also necessary to include mobilisation, substructure, finishes and a learning curve for the production. Learning curves generally add around 25% to the production - this could vary from 10-15% for projects with many cycles to over 50% for projects with limited cycles. One of the benefits of precast solutions is the ability to cast the deck before, or at the same time as, the substructure. Only the deck erection needs to wait for the substructure to be finished, or partly finished. So for precast schemes, there is also the need to assess the casting rates (with a learning curve too) – the balance between the casting and erection rates then determines the amount of storage needed for the precast units, or vice versa. The typical production rates vary from 5-10m/week for the relatively slow balanced cantilever method (which can be accelerated by using multiple sets of travellers) to 100m/week, or more, for the sophisticated whole span precast system.

The time required to precast beams or segments, and to then cure them effectively, will start during the substructure works. The typical production rates noted above just refer to the erection process, which occurs after the required amount of substructure is ready, or in accordance with the overall balance of casting and erection rates. This balance between the casting and erection rates will then determine the amount of storage required. A large difference between the

Table 2: Concrete Bridge Production Rates.

Bridge Type	Erection Method	Typical Production Rate (m/week)
Whole span precast	Gantry	100
Precast segmental	Gantry	50
Precast segmental	Crane	30
Incremental launching	Launched	25
In-situ span by span boxes	Gantry	25
In-situ twin ribs	Gantry	25
Bespoke precast I beams	Gantry	25
Bespoke precast U beams	Crane	25
Standard precast Y beams	Crane	20
Modular precast	Launched	20
Modular precast	Scaffolding	15
In-situ span by span boxes	Scaffolding	10
In-situ twin ribs	Scaffolding	10
In-situ slabs	Scaffolding	10
In-situ balanced cantilever	Travellers	5 to 10

rates will require the majority of the beams or segments to be stored. However, when the two rates are similar, the storage can be kept to the absolute minimum, with the beams or segments always being delivered to site just in time. Table 3 shows two typical precast segmental programmes – with a crane-erected and gantry-erected comparison, showing the differing amounts of storage that are then required. It also shows the time needed to procure moulds, casting sheds and gantries, or other major items of erection equipment.

Risk Issues

The whole team need to ensure that the project falls within the health and safety regime of the particular site, though best practices should always be used in all locations. Whatever decisions are made on the various construction methods, their adoption must never compromise site safety. Besides the usual factors related to working with concrete, there will be other factors related to the construction method, such as working next to traffic, stability of temporary works, or transportation and erection of heavy elements, including working at night or in adverse weather conditions. Factory methods that form part of many techniques can significantly improve the safety regime by shifting the works to a more regular and controlled series of operations, with a workforce who have become familiar with the process. Many of the methods also reduce the need to work at height, by using cranes or other heavy lifting equipment. Launching techniques, in particular, require limited numbers of men to work at height, as the majority of activities take place behind an abutment (Figure 39).

Figure 39: Blackwater Viaduct - launching.

To address these issues, the owner should adopt a formal approach to health and safety, and risk management, and share all this information with the designer and contractor, who will also use it throughout their considerations. Health and safety risk assessments need to consider the residual risks related to construction, operation, maintenance and demolition of the bridge. In the UK, all these issues are contained within the CDM regulations. But commercial risk assessments should also be considered, where factors are applied to both the programme and costs in order to get greater surety of safety, quality, delivery and final price.

Cost Issues

The deck quantities should always be checked against historic data for typical bridges. It is easy to calculate the effective thickness of the deck, defined as the total concrete volume divided by the total deck area, i.e. it is the average thickness of concrete in the deck, not its depth. Charts exist in a number of publications[12, 13 & 39], which show a reasonably linear relationship between effective thickness and typical span. For typical highway (or light rail/metro) bridges, the effective thickness (in mm) is approximately 350 + 4.5L, where L is the typical span (in m). So, for spans between about 30m and 60m, the effective thickness of an efficient box or beam section should be 500-600mm. Great care needs to be exercised with such simple rules, but in the hands of experienced bridge engineers, it is a useful means of checking the quantities. The figure can easily vary by +/- 100mm, depending on local conditions and bridge types. Heavy or high-speed rail bridges, or bridges with unusual traffic loads, will have a greater effective thickness. The quantities of prestressing and reinforcement can be expressed in kg/m^3, i.e. the total tonnage divided by the total deck concrete volume. The prestressing rate is generally independent of span and is around 45kg/m^3, with a typical range of +/-10kg/m^3. This figure equates to fully prestressed highway bridge decks – it will be less for partially prestressed decks and more for more heavily loaded decks. This figure directly relates to the average axial prestress of the section, which is generally 4-7MN/m^2. The reinforcement rate also tends to be independent of span, with values of 170-200 kg/m^3 for fully prestressed decks with internal cables (or 200-230 kg/m^3 for external cables). The rates will be 120-170kg/m^3 for sections with a higher effective thickness. These rates increase for partially prestressed decks, where the longitudinal reinforcement is also used to carry loads. Once there is no prestress, and the section becomes reinforced concrete, the rates will be 200-300 kg/m^3, or more.

Once the quantities are confirmed, it is possible to calculate the costs of the bridge deck. The concrete, reinforcement and prestressing rates that should be used are the gross rates that are inclusive of all elements, i.e. to include material, supply, and the labour for the placing or fixing – this includes all the ducts, anchorages, jacking and grouting for the prestressing. The rates in the UK in 2014 have a range of figures:

- Concrete £100-160/m^3
- Reinforcement £850-1,100/t
- Prestressing £2,250-3,000/t

Table 3: Typical Precast Concrete Bridge Programme.

Option 1 1,200m long deck - crane erection

Item	Duration (months)	3	6	9	12	15	18	21	24
Substructure	Mobilisation								
	Piling and pile caps								
	Piers								
Deck Casting	Yard/mould procurement								
	Casting								
Deck Erection	Crane operation								
	Segment storage			100	100	100	100		
Finishes									

400 segments 2 moulds
Casting 5 per week per mould, say plus 25% learning curve = 50 weeks 12 months, say
Erecting 30m per week, say plus 25% learning curve = 50 weeks 12 months, say

Note - erection rate ~ casting rate and therefore low levels of segment storage required = about 100 segments

Option 2 1,200m long deck - gantry erection

Item	Duration (months)	3	6	9	12	15	18	21	24
Substructure	Mobilisation								
	Piling and pile caps								
	Piers								
Deck Casting	Yard/mould procurement								
	Casting								
Deck Erection	Gantry procurement								
	Gantry operation								
	Segment storage			100	200	300	200		
Finishes									

400 segments 2 moulds
Casting 5 per week per mould, say plus 25% learning curve = 50 weeks 12 months, say
Erecting 60m per week, say plus 25% learning curve = 25 weeks 6 months, say

Note - erection rate < casting rate and therefore high levels of segment storage required = about 300 segments (maximum)

For this technical guide, the following figures are used, as being the most typical for concrete bridges in the UK:

- Concrete — £100-160/m^3 as Table 4
- Reinforcement — £900/t
- Prestressing — £2,500/t for post-tensioning (£2,250/t for pre-tensioning)

Table 4 shows a simple range of typical concrete cost rates that are dependent on the ease of placing the concrete, i.e. that vary for simple or complex pours, small or large pours, and the height at which the concrete is placed.

However, the main difficulty with concrete bridge decks is the pricing of all the works necessary to get the concrete into place, i.e. the combined cost of the formwork and falsework. The difficulty arises because there are a large number of different construction methods available, each one of which needs to be priced separately. Such a combined formwork/ falsework rate needs to be calculated using the breakdown of all the elements below:

- Casting – moulds/formworks, precast factory/storage, falseworks, labour, cranes/gantries
- Transport – vehicles, labour, cranes
- Erection – falseworks, beams/girders, towers, jacks, labour, cranes/gantries

The typical range of these combined formwork/falsework costs is currently £50-150/m^2 of the total formwork area. It is because there is such a wide range in these costs and a lack of available data, that the CBDG has produced this guide, the bulk of which defines the details, programmes and formwork/falsework costs for a range of fifteen different concrete bridge decks. These cover all the options that have been described above. Each option has been priced from extensive comparisons to multiple sources of data from bridge schemes worldwide that had been collated by Benaim, and with the substantial assistance of the chief estimators and temporary works managers at Bam Nuttall. The options are shown as a 15m wide deck with a length dependent on the minimum desirable length for each of the particular construction methods. The total formwork/falsework price for each scheme has then been converted back into typical formwork/falsework rates, which can be applied to the total formwork area. The rates are then shown as they might be applied to a 50m, 150m, 600m, 1,200m or 5,000m long bridge, allowing teams to pick the most suitable rate for their project. So, in conjunction with the concrete, reinforcement and prestressing rates, teams will now be able to price the full range of suitable concrete bridge decks, for any size of scheme. For detailed pricing, a thorough programme and cost exercise would still need to be carried out, but these broad rates will allow teams to consider all the options at an early stage. Often in the UK, concrete schemes have been too readily dismissed, or not considered, as teams did not have any reliable cost information. All these rates can be adjusted pro rata over time or into different locations, to suit the prevailing conditions and local rates in each particular market – a series of indices/factors will be made available on the CBDG website in late 2015 to assist in the process. The breakdown of the combined formwork/falsework costs also allows teams to re-assess these figures in their own markets.

Table 5a shows the 15 different bridge types that have been considered together with their typical spans, production rates and range of bridge deck lengths. Table 5b then shows the assumed level of the major quantities for each of the different bridge types. The results of the extensive costing exercise are then summarised within each of the following sections (Sections 3.1 to 3.10) that fully describe each of the 15 different bridge types – see Tables 6 to 15b (Appendix). A summary of all the key output data in Tables 6 to 15b is shown in Table 5c.

In order to make comparisons with other schemes, especially lighter steel-composite bridges, the substructure costs should also be included. Rates for these items are well defined and there is no need to discuss them further here. In general though, the differences in substructure costs between concrete and steel-composite decks are not as large as might be thought. Even if the self-weight of a steel-composite deck is close to half that of concrete, the combined differences at foundation level (including finishes, eccentric traffic loads, lateral loads and substructure loads) are usually only 15-20%. As the substructure might represent about 30% of the total bridge cost, the effects of the reduced weight of the steel scheme are then only around 5%, which certainly needs to be accommodated but is not dominant.

Finally, if a real cost estimate is needed, rather than just a comparison in order to select a solution, the costs need to include all the finishes and be factored for preliminaries, overheads and profit. Such factors might add another 30-50%. It is then useful to check the overall cost of the bridge per m^2 of deck area. These overall costs/m^2 vary reasonably linearly with typical span, but are very dependent on bridge types and local conditions. Very roughly, total bridge costs in £/m^2 are currently about 1,000 + 15L, where L is the typical span (in m). These figures apply up to spans of 100-150m and need to be treated with great caution as the variation could easily be +/- 25%, or more. Above spans of this size, the costs become closer to 2,000 + 7L.

Table 4: Concrete Rates.

Concrete Rates (£/m^3)	On the ground		At height	
	Simple pour	Complex pour	Simple pour	Complex pour
Small pour <50m^3	120	140	140	160
Large pour >50m^3	100	120	120	140

Table 5a: Concrete Bridge Summary Data.

Bridge Type	Erection Method	Average Erection Rate (m/week)	Span (m)	Main Length (m)	Overall Deck Programme (weeks)	Other Lengths (m)					Overall Deck Cost Summaries	Notes
In-situ slabs	Scaffolding	10	15	150	20	50		600			Table 6	
In-situ twin ribs	Scaffolding	10	30	150	20	50		600			Table 7a	
In-situ twin ribs	Gantry	25	30	600	30				1200		Table 7b	gantry pays for itself on this project
In-situ span by span boxes	Scaffolding	10	50	150	20	50		600	1200		Table 8a	
In-situ span by span boxes	Gantry	25	50	600	30				1200	5000	Table 8b	gantry pays for itself on this project
In-situ balanced cantilever	Travellers	2 by 7	50	600	55		150		1200		Table 9	2 pairs of travellers pay for themselves on this project
Standard precast Y beams	Crane	20	30	150	10	50		600	1200		Table 10	mould and casting yard costs amortised over several projects of this size
Bespoke precast U beams	Crane	25	40	150	8	50		600	1200		Table 11a	mould and casting yard costs amortised over several projects of this size
Bespoke precast I beams	Gantry	25	40	600	30				1200	5000	Table 11b	1 mould/gantry pays for itself on this project
Precast segmental	Crane	30	50	600	25				1200	5000	Table 12a	1 mould/casting yard pays for itself on this project
Precast segmental	Gantry	50	50	1200	30					5000	Table 12b	2 moulds/casting yard and gantry pay for themselves on this project
Whole span precast	Gantry	100	40	5000	65						Table 13	1 mould/casting yard and gantry pay for themselves on this project
Incremental launching	Launched	25	40	600	30		150		1200		Table 14	1 mould/launching kit pays for itself on this project
Modular precast	Scaffolding	15	30	150	15	50		600			Table 15a	mould and casting yard costs amortised over several projects of this size
Modular precast	Launched	20	30	150	10	50		600			Table 15b	mould, casting yard and launching kit costs amortised over several projects of this size

All bridge sections with 15m width and constant spans
6m clear height off good ground
Main Length is the length used to provide a detailed cost breakdown of the scheme - it is also close to a minimum optimum length
Other Lengths are the lengths used to cover a full range of arrangements by making suitable adjustments to the detailed cost breakdown

Table 5b: Concrete Bridge Quantity Data.

Bridge Type	Erection Method	Span (m)	Depth (m)	Span/Depth ratio	Concrete rate (m^3/m)	Effective thickness (m)	Total formwork perimeter (m)	Rebar rate (kg/m^3)	Prestress rate (kg/m^3)	Overall Deck Cost Summaries
In-situ slabs	Scaffolding	15	0.8	19	9.5	0.63	16	250	0	Table 6
In-situ twin ribs	Scaffolding	30	2.0	15	9.5	0.63	22	150	40	Table 7a
In-situ twin ribs	Gantry	30	2.0	15	9.5	0.63	22	150	40	Table 7b
In-situ span by span boxes	Scaffolding	50	2.8	18	9.0	0.60	35	200	45	Table 8a
In-situ span by span boxes	Gantry	50	2.8	18	9.0	0.60	35	200	45	Table 8b
In-situ balanced cantilever	Travellers	50	2.8	18	9.0	0.60	35	200	45	Table 9
Standard precast Y beams	Crane	30	1.8	17	9.5	0.63	57	125	55	Table 10
Bespoke precast U beams	Crane	40	2.5	16	9.5	0.63	70	125	55	Table 11a
Bespoke precast I beams	Gantry	40	2.5	16	7.5	0.50	38	175	50	Table 11b
Precast segmental	Crane	50	2.8	18	8.5	0.57	35	200	50	Table 12a
Precast segmental	Gantry	50	2.8	18	8.5	0.57	35	200	50	Table 12b
Whole span precast	Gantry	40	2.5	16	8.0	0.53	34	200	45	Table 13
Incremental launching	Launched	40	2.5	16	8.5	0.57	34	200	45	Table 14
Modular precast	Scaffolding	30	2.0	15	10.5	0.70	36	175	40	Table 15a
Modular precast	Launched	30	2.0	15	10.5	0.70	36	175	40	Table 15b

All bridge sections with 15m width and constant spans

Table 5c: Concrete Bridge Summary Cost Data.

TOTAL DECK COST PER TOTAL DECK PLAN AREA (£/m²)*								
Bridge Type	**Erection Method**	**Span (m)**	**Deck Length (m)**					**Overall Deck**
			50	**150**	**600**	**1200**	**5000**	**Cost Summaries**
In-situ slabs	Scaffolding	15	380	370	340			Table 6
In-situ twin ribs	Scaffolding	30	440	430	390			Table 7a
In-situ twin ribs	Gantry	30			380	310		Table 7b
In-situ span by span boxes	Scaffolding	50	510	500	460	460		Table 8a
In-situ span by span boxes	Gantry	50			550	420	420	Table 8b
In-situ balanced cantilever	Travellers	50		650	520	500		Table 9
Standard precast Y beams	Crane	30	510	450	430	420		Table 10
Bespoke precast U beams	Crane	40	520	450	420	410		Table 11a
Bespoke precast I beams	Gantry	40			400	330	330	Table 11b
Precast segmental	Crane	50			510	460	430	Table 12a
Precast segmental	Gantry	50				500	430	Table 12b
Whole span precast	Gantry	40					340	Table 13
Incremental launching	Launched	40		850	460	390		Table 14
Modular precast	Scaffolding	30	440	420	410			Table 15a
Modular precast	Launched	30	480	430	400			Table 15b

TOTAL FORMWORK/FALSEWORK COST PER TOTAL FORMWORK AREA (£/m²)*								
Bridge Type	**Erection Method**	**Span (m)**	**Deck Length (m)**					**Overall Deck**
			50	**150**	**600**	**1200**	**5000**	**Cost Summaries**
In-situ slabs	Scaffolding	15	150	140	120			Table 6
In-situ twin ribs	Scaffolding	30	150	140	110			Table 7a
In-situ twin ribs	Gantry	30			110	70		Table 7b
In-situ span by span boxes	Scaffolding	50	110	100	90	90		Table 8a
In-situ span by span boxes	Gantry	50			120	70	70	Table 8b
In-situ balanced cantilever	Travellers	50		160	110	100		Table 9
Standard precast Y beams	Crane	30	80	60	50	50		Table 10
Bespoke precast U beams	Crane	40	60	50	40	40		Table 11a
Bespoke precast I beams	Gantry	40			80	60	60	Table 11b
Precast segmental	Crane	50			120	90	80	Table 12a
Precast segmental	Gantry	50				110	80	Table 12b
Whole span precast	Gantry	40					60	Table 13
Incremental launching	Launched	40		270	100	70		Table 14
Modular precast	Scaffolding	30	70	60	60			Table 15a
Modular precast	Launched	30	90	70	60			Table 15b
* Cost data from Summary Tables rounded to the nearest 10.								

Formwork Types

For in-situ construction, where the bridge deck is cast in its final position, the casting and erection process takes place at the same time. Formwork, or shuttering, is needed to create a mould. This formwork is then supported by falsework, generally off the ground, until the bridge has sufficient strength to be self-supporting.

For precast construction, there are the three distinct phases of casting, transportation and erection. Formwork is again needed to create the required concrete form – this formwork, or mould, generally sits directly on the ground and thus needs no major falsework support. Casting either takes place in a proprietary precast factory or in a precast yard on site. Completed units are either moved to a storage area, left in place until required for transporting, or transported to the site. When the bridge site is ready to receive the precast units, they need to be transported from storage to the construction head – this may be a short distance, or many kilometres, away. The precast units then need to be erected into their final bridge form, which needs a falsework system. All these various falsework systems are described below.

Figure 40: Incarville Viaduct - in-situ casting gantry.

Timber formwork panels tend to be 10-40m long, and are thus best suited to the in-situ casting of short to medium span bridges. The form-face material is typically phenolic film-faced plywood (medium or high density overlay), which can be used up to 50 times before needing to be refurbished and/or re-faced. So, in-situ solid slab, voided slab, twin rib or box girder bridges are often cast in timber forms, which are then supported on a scaffold falsework or a series of beams and props. As they are often being cast span by span, the common configuration is to cast a span plus a short cantilever in to the next span (of 0.2 to 0.25 of the span) – this ensures that the as-built moments in the deck are close to the final moments, thus reducing the impact of creep on the moments. Once a large enough length of deck exists, it becomes economic to mechanise the process by using a gantry falsework system, which spans from pier to pier, or from the previously built deck to the next pier. Such gantries would then move themselves forward from span to span (Figure 40). The formwork for these 20-40m long pours would usually then become steel, as large steel forms can accommodate the casting of around 20-100 units before needing to be refurbished or re-faced. The only in-situ construction method that uses short lengths of concrete pour is balanced cantilevering, which can be used for spans anywhere from 40m up to over 300m. Here, the bridge is formed from short in-situ segments, or units, each 3-5m long and cast in a travelling formwork system, which generally has timber forms though they can be steel too, depending on the number of uses (Figure 41).

Figure 41: Medway Crossing Viaducts - short timber forms.

Figure 42: Clackmannanshire Bridge - long steel forms.

For precast units, the formwork is invariably steel, as the mould is used many times. Long, steel moulds (around 10-50m long for beams) can cast 20-100 units before needing to be refurbished, whereas short, steel moulds (3-5m long for segments) can cast 50-300 units. So, standard and bespoke precast beam, and whole span precast, bridges tend to be cast in long, steel moulds. Incrementally launched bridges, which are effectively precast, are also generally cast in long, steel moulds (Figure 42). Precast segmental and modular precast bridges are usually match-cast in short, steel moulds. Match-casting involves casting each new segment between a fixed bulkhead and the previously cast segment, which ensures a precise fit at every joint and thus creates the desired alignment. In the UK, formwork and falsework should be designed in accordance with BS 5975[40], and The Concrete Society document, *Formwork – a guide to good practice*[41], should also be considered, along with its formwork and falsework checklists[42 & 43].

As the formwork is simple, slab and voided slab bridges are very easy to cast, though care needs to be taken to ensure that any void formers are firmly held in place. In reality, void formers tend to cost as much as the concrete that they replace, but they are used in deeper members both to reduce self-weight and to increase the efficiency of the section with respect to the prestressing. Ribbed, beam and modular bridges are also relatively easy to cast as they have no internal forms. Box girder sections are usually used with spans over around 40m as they are particularly efficient in carrying eccentric traffic loads. However, boxes are more difficult to cast due to the general inaccessibility of the bottom slab and the need to operate the internal formwork that creates the cell of the box (Figure 43). These issues can be resolved by casting the box in shorter lengths than the span, e.g. by using in-situ balanced cantilevering, precast segmental construction or incremental launching, all of which are explained in more detail in the later sections. Multi-cell boxes are particularly difficult to cast, as the cells are often too small to allow the easy placing and stripping of the internal formwork, and should therefore be avoided wherever possible. All moulds need to operate smoothly to allow the forms to be struck and moved with ease, allowing them to be re-positioned quickly and safely. Depending on the scale of the project, these operations may be aided by jacking systems, electrical winches or hydraulic arms and pumps.

Figure 43: Clackmannanshire Bridge - internal steel formwork.

Precasting facilities, either in a bespoke factory or in a yard set up on the site, will comprise the formwork and its foundations, and also a range of other options, which might include a shed or sheltered area to protect the casting operations, areas to fix and store the reinforcement cages, a batching plant, light cranes to move 1-5t around and heavy cranes or gantries to move the precast units around. Such lifting and moving equipment might need to accommodate precast units weighing from 5-50t, though larger units could weigh up to 200t and whole span precast units could weigh up to 1,000t, or more. The precasting facility also needs to have sufficient land for the areas needed to store the units. If the casting and erection rates are very different, then the majority of the units will need to be kept in storage, needing a large storage capacity. However, if the casting and erection rates are similar, then the storage requirements are much less. For incrementally launched bridges, the units are poured in lengths of around 15-30m, generally in a casting area behind one of the abutments. The bridge is then extruded pour by pour, as it is then pushed or pulled out over the piers.

Plain concrete finishes, as defined in BS EN 13670[44], are best for fast construction, but consideration must be given to the aesthetic importance of each element. Bridge decks formed from either timber or steel forms generally need no more than a good quality plain finish, as the visual merits of the scheme will tend to be governed by the balance of spans, depths and type of cross-section. Featured shapes, textures and finishes (termed *Special* in BS EN 13670) will frequently be used on piers, abutments and parapets, which then require greater attention to detail and the concrete placing process.

Permanent Formwork

Permanent formwork is used to speed construction by reducing the need for falsework. Particular economies can be achieved when the formwork becomes an integral part of the completed bridge structure. Permanent formwork is also used in locations where it would be difficult to remove conventional formwork, and so it is particularly beneficial in situations where additional possession times would be required, such as over live roads or railways.

Two types of non-participating permanent formwork are available, each with a range of flat or corrugated profiles to suit all configurations. Glass fibre reinforced concrete (GRC) panels are widely used as permanent soffit formwork to span around 1m between closely-spaced precast concrete beams (Figure 44), while glass fibre reinforced plastic (GRP) panels are also available with spans up to 4m between supports. Joints between the panels, made with mortar, tape or sealants, are required to prevent the leakage of grout from the subsequent concrete pours. See CBDG CPS 12[45] for further details.
The modular precast bridge, developed by Benaim for the CBDG, is also effectively a permanent formwork system, having short, precast shell segments that provide a permanent and participating structural formwork for the in-situ infill concrete (Figure 45). In a similar way, precast

units can also be used to form the exposed face of a wall or column. In this case, high quality concrete (using white cement or pigments in the mix, for example) can be used to give the required appearance with lower quality concrete used for the infill material.

Figure 44: GRC formwork panel.

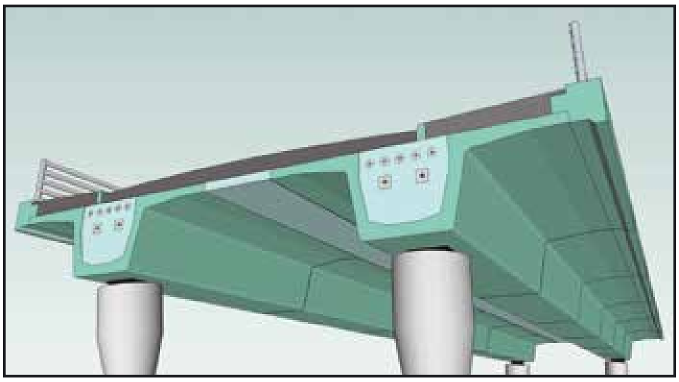

Figure 45: Modular Precast Bridge - with permanent, participating formwork.

Specialist Formwork and Finishes

Besides the use of plywood or steel forms to produce a good quality plain concrete finish, it is also possible to produce either particular shapes or special finishes. Piers are often designed to accommodate some considerable aesthetic statement and their shape can readily be chosen to both respect the load paths and the surroundings within which the pier sits. As several, or many, piers are often cast from the same formwork, and as this formwork is easily supported off the ground, it is generally possible to create quite elaborate pier shapes for relatively little additional cost. Abutments and parapet edge beams can also be shaped to a certain extent, though their geometries are often more heavily constrained than is the case with piers. Piers, abutment walls and parapet edge beams are all often improved by the use of a featured finish to the concrete. A theme can be carried through the whole scheme by using the same finish on all, or some, of these elements. Two excellent Concrete Society documents describe the use of these visual concretes[46 & 47].

It is possible to increase the density and reduce the porosity of the concrete cover zone by the use of controlled permeability formwork (see CBDG CPS 10[48]). This system comprises thermally bonded permeable liners that consist of filter and drain elements, attached in tension to the internal face of the formwork. During concreting, entrapped air and excess water in the mix, which would otherwise become trapped at the surface causing blemishes, can instead pass through the liner. The liner therefore creates a uniform surface and a concrete cover zone that has significantly enhanced durability (Figure 46).

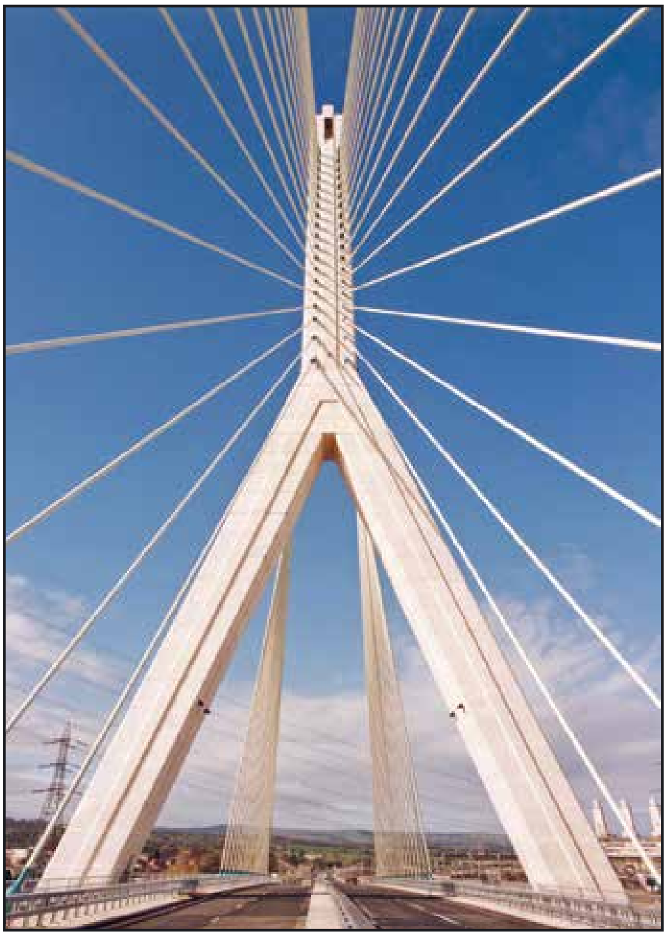

Figure 46: Flintshire Bridge - controlled permeability formwork towers.

Falsework Types

In-situ solid slab, voided slab, twin rib or box girder bridges are often supported by falsework that comprises a scaffold birdcage (Figure 47), with a suitably firm foundation, or a series of beams/girders and props/towers, which move from span to span as the construction evolves. Once a large enough length of deck exists, it becomes economic to mechanise this process by using a gantry falsework system, which spans from pier to pier, or from the previously built deck to the next pier. These falseworks can be built from proprietary equipment or from purpose-made steelwork, and they move themselves forward as the construction progresses. Such gantries may be placed either above the deck or beneath it, depending on the clearance and operational issues, many of which will be discussed in more detail in Sections 3.2 to 3.10. Individual travelling frames can also be used to cast in-situ elements in the balanced cantilever method. Here, the bridge is formed from short in-situ segments, each 3-5m long and cast in a travelling formwork system that is supported by the falsework frames. All these pieces of equipment combine the formwork and falsework into one mechanised item. These machines need to be operated with due regard to safe, quick and easy handling throughout each cycle of striking the formwork/ falsework, moving it forward and re-positioning it correctly for the next in-situ concrete pour.

Figure 47: Scaffolding birdcage.

Transportation of major items generally only relates to the various precast options, all of which involve the movement of units from the casting to the erection area. This will involve the use of low-loaders, straddle-carriers, wheeled-bogies or rail systems, some of which may be proprietary vehicles and some of which may be purpose-made.

The erection of precast elements entails the use of cranes and/or various falsework to support the precast units. Standard precast beams and some bespoke precast beams (weighing 5-80t) are erected using a range of 100-800t mobile or crawler cranes, in either single or tandem formation. The heaviest beams (weighing 80-120t) might use the biggest 1,200t cranes, which are becoming more available in most major countries. The location of each crane position will need to be prepared for the outrigger loads, and some ground improvement might be required in poor conditions. Precast segmental and modular precast schemes (with segments weighing 25-100t) can also be erected by crane, as long as a firm foundation exists throughout the key areas of the site. These precast segments can then be joined together in their final position, with either span by span (supported on an under-slung gantry as in Figure 48) or balanced cantilever construction (where the balanced cantilever is held stable with falsework towers).

Figure 48: Stanstead Abbotts Viaduct - falsework girder and towers.

The heavier bespoke precast beams (weighing 100-200t) will tend to be erected by a gantry. Such gantries need to lift the beam either from the ground, or from the already completed deck, move it forward, and sideways, in order to lower it into its correct position. These gantries will span from pier to pier, and will usually be fitted with front noses and rear tails to allow them to launch forward to the next pier. Gantries for the erection of whole span precast units (each weighing up to 1,000t, or more) will be of a similar format, though much larger in order to accommodate the heavier whole span units. For long marine viaducts that use whole span precasting, it is common to use massive marine shear legs to lift the whole span. Such shear legs can lift several thousand tonnes.

For precast segmental construction, where good crane access is not available throughout the site, the segments can be erected in balanced cantilever with a pair of shear legs (or lifting frames) at each end of the cantilever. However, the balanced cantilever is not always actually in balance and needs to be held stable with falsework towers. Once the total deck area is over about 20,000m^2, gantries can be used, which can erect segments span by span (and be either overhead or under-slung), or in balanced cantilever (where they also tend to provide the stability to the balanced cantilever) (Figure 49). These gantries all need to operate quickly, easily and safely. Depending on the scale of the project, these operations may be aided by jacking systems, winches or hydraulics, though any increase in the complexity of the machine will need a corresponding increase in the control systems to manage it successfully. Incrementally launched bridge decks use various items of falsework to get the bridge into its final position. These items will include slide tracks, launching bearings and noses, as well as jacks to push the deck or prestressing strands to pull it (Figure 50). Modular precast schemes, using short shell segments, infilled with in-situ concrete in to 20-40m lengths, can also be launched in to place in a similar manner.

Figure 49: A13 Viaduct - precast segmental gantry.

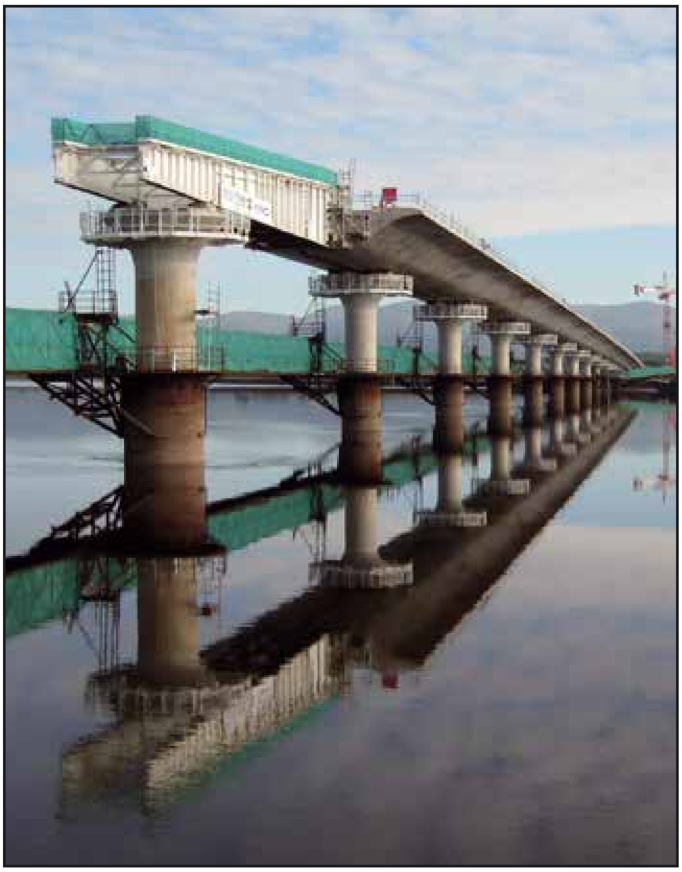

Figure 50: Clackmannanshire Bridge - launching nose and bearings.

The bridge and all its falsework must remain stable during all these various lifting, moving and sliding operations, which will often need several other items of temporary works to ensure stability in all directions. Temporary prestressing bars are frequently used to clamp concrete elements together or falsework items to the concrete, providing a safe, quick and easy method of generating stability. The common prestressing bars are 26.5, 32, 36 or 40mm in diameter, with either a fine or coarse thread. The coarse-threaded bars are particularly useful on site as they can be installed, stressed and then re-used many times. They are stressed to about 70% of their ultimate strength (f_{pk} of about 1,030 MN/m^2), which generates high clamping forces (of 30-90t per bar), though care needs to be taken with short, coarse-threaded bars where the loss of extension as the nut beds down into the thread could be significant. The advantages of using prestressing bars in many of these falsework items are that the connection is then held rigid and the force in the bar stays constant, even under applied loads that have a variable tension (Figure 51) – this is a good example of prestressing, as it shows that the concrete carries the tension, not the prestressing bar. Similarly, bars are used with lifting beams to move precast units, where the clamping action ensures a safer and more rigid lifting process. Bars tend not to be used as part of the permanent works on economic grounds, as their f_{pk} is nearly half that of strand for about the same price, and being rigid, they are much less able to accommodate the moment variations seen within bridges.

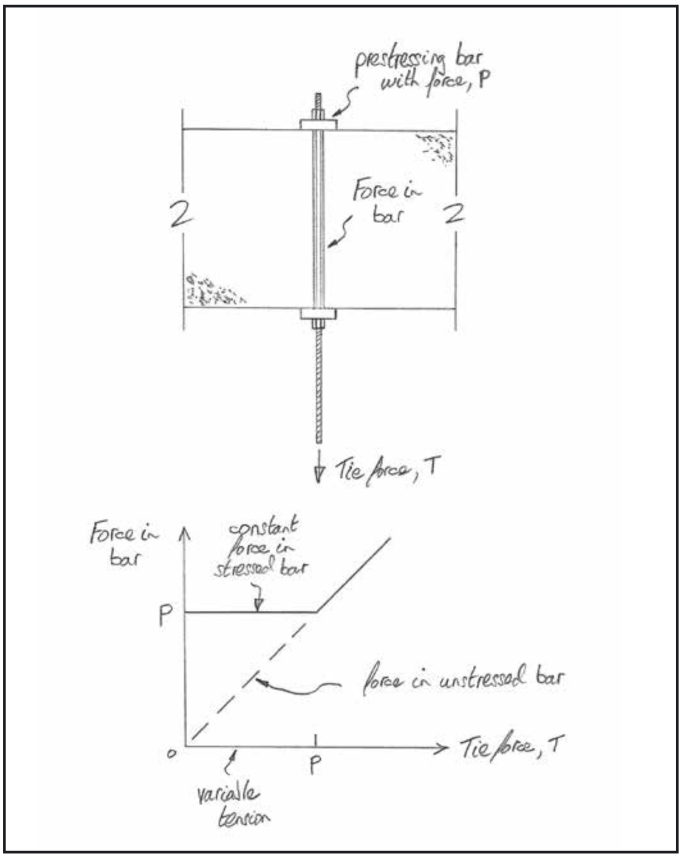

Figure 51: Temporary prestressing bar forces.

Summary

Construction methods have been shown to play a huge role in the selection of the most appropriate bridge types, with the detailed assessment of the programme having a major influence on the final costs. Concrete is used for the majority of bridges worldwide as its competitive initial construction costs are coupled with low levels of inspection and maintenance, ensuring a very attractive whole-life cost for the owner. The proper understanding of how the formwork and falsework varies for each construction method is very important in determining the best bridge deck for any particular site. The *fib* Bulletin 48[49] concerning *Formwork and falsework for heavy construction* also gives further details of many of these items described above.

3. Construction Methods for Each Bridge Deck Type

Bridge Types

There are several types of concrete bridge deck, each of which should be used in different circumstances. The two key parameters used in selecting a bridge type are the construction method and the typical span, though many other particular parameters come in to play. Table 1 showed a layout of Bridge Types vs Span, which gives a broad outline of the options. The bridge types may be split into these 15 different in-situ and precast options:

In-situ

- In-situ solid or voided slab – cast on a scaffold system or a series of beams/girders
- In-situ twin rib – cast on scaffold/beams or using travelling gantries
- In-situ span by span box girder – cast on scaffold/beams or using travelling gantries
- In-situ balanced cantilever – short box sections cast using a travelling formwork system

Precast

- Standard precast beam – inverted T/Y or U beams erected by crane
- Bespoke precast beam – T, I or U beams erected by crane or using a gantry system
- Precast segmental box girder – short segments erected with cranes or gantries
- Whole span precast box girder – erected span by span with gantries
- Incrementally launched box girder – erected using sliding equipment
- Modular precast – short shell segments erected on scaffold/beams or launched into place

Extensive details are given in the following sections for all these bridge types, including a summary, detailed description, and breakdown of programme and costs.

Details are also given in the later sections for all these further bridge types, including a summary and detailed description:

- Arches – standard precast arches/portals and precast or in-situ bespoke arches
- Frames – precast or in-situ beam bridges supported by inclined legs
- Tunnels – standard precast box culverts and bespoke in-situ cut-and-cover tunnels
- Jacked portals and boxes – whole spans that are slid or rolled into place
- Cable-stayed bridges – erected in balanced cantilever
- Extradosed bridges – erected in balanced cantilever
- Stressed ribbons – erected on steel catenaries and prestressed

Construction Methods – In-situ

These in-situ options (Figures 30 & 31) tend mainly to be used on projects where the speed of construction is not crucial, or where the lower costs of the in-situ works justify a slightly longer programme. Table 2 showed that in-situ bridges cast on scaffolding get produced at a rate of about 10m/week, which is about half the rate that can be achieved with many precast solutions. Once there is sufficient length of bridge to justify some capital investment in travelling gantries though, this rate can easily be increased to 25m/week, which is similar to all other methods, except the most specialised ones.

In-situ slab and twin rib solutions therefore tend to be used on smaller projects with modest spans in the range 10-40m. In these situations, it will not be possible to justify the use of the more sophisticated precast solutions, as these methods will need considerable investment in specialist equipment. However, precast beam solutions will generally be perfectly valid and the actual choice between precast and in-situ will primarily depend on the assessment of programme and costs.

For longer spans of 40-80m, box girder solutions are generally required. In-situ box girder bridges cast on scaffolding or on gantries can be used, though the casting of long lengths of box can be quite slow, needing the box section to be cast in two or three phases, i.e. bottom slab, followed by webs, followed by top slab; or bottom slab and webs, followed by top slab. These casting issues are often resolved by casting the box in shorter lengths than the span, e.g. by using in-situ balanced cantilevering or by using some of the precast solutions. With in-situ balanced cantilevering, the bridge is formed from short in-situ units, or segments, each 3-5m long and cast in a travelling formwork system. The production rates for this technique are quite slow at 5-10m/week for each pair of travelling forms, but this rate can be accelerated to 10-20m/week by using multiple sets of forms. So, whereas in-situ boxes cast on scaffolding or gantries tend only to be used for spans of 40-80m, in-situ balanced cantilevering can be used from 40m up to 300m. The longest concrete beam bridges in the world have all been built by this method, with the Stolma Bridge in Norway holding the current record span of 301m (Figure 52). Once the spans get above about 150m, all precast solutions generate units that are too heavy for transportation, and thus the only viable option for beam bridges becomes in-situ.

Figure 52: Stolma Bridge - 301m main span.

Construction Methods - Precast

These options (Figures 31, 32 & 33) are all used on projects where speed of construction is crucial, or where the capital investment needed for precasting is justified by a shorter programme or an easier construction process. Table 2 showed that various precast bridges are produced at a rate of 20-25m/week, which is about twice the rate that can be achieved with most in-situ solutions. Once there is sufficient length of bridge to justify further capital investment, this rate can be increased to 50-100m/week. The CBDG Technical Guide No. 5 on fast construction also gives general guidance on many of these in-situ or precast production issues[30].

Construction Methods - Summary

Each of the following detailed sections has a description, programme summary and cost summary for the 15 different bridge types considered. The programme summary is shown for the relevant bridge deck lengths, ignoring site mobilisation, substructure and finishes works. The cost summary is also shown for each relevant deck length, with a detailed breakdown given in Tables 6 to 15b. Tables 5a and 5b summarised the various assumptions regarding the spans, production rates, major quantities, and casting/erection equipment. As seen in Tables 6 to 15b, the combined formwork/falsework rates are calculated using the breakdown of all the elements below:

- Casting – moulds/formworks, precast factory/storage, falseworks, labour, cranes/gantries
- Transport – vehicles, labour, cranes
- Erection – falseworks, beams/girders, towers, jacks, labour, cranes/gantries

The total formwork area should include all the external and internal sections of formwork, especially for the box and precast shell solutions, and should also include all formed areas of both the precast and in-situ sections, excluding any free, unformed surfaces, of course.

3.1 In-situ Slab Bridges

Summary	Simple cross-sections cast span by span with simple falsework
Key deck features	Very flexible solution for any small site; any alignment; simple aesthetic
Typical spans	5-20m for solid slabs; 20-40m for voided slabs
Best method for	Small spans with good access
Typical production rate	10m/week
Typical formwork/falsework costs	£120-150/m^2

Description

In-situ slab bridges have very simple cross-sections that are easily cast (Figure 53). Typical spans range from 5-20m for solid slabs and from 20-40m for voided slabs. Prestressing is generally used with spans over 20-30m. Span to depth ratios for highway bridges are typically 18-24, depending on whether the bridge spans are simple or continuous. This type of bridge deck represents a very flexible solution for any site, with a clean aesthetic, which is best suited to low sites over land with good access.

Spans are usually constructed using plywood formwork and simple falsework systems, based on scaffolding or proprietary props, often just sat on sleepers, concrete blocks or blinding concrete (Figure 47). The system is relatively sensitive to ground conditions and once the simple methods noted above are no longer adequate, then further ground improvements may be needed. Beams are used to span over openings for traffic through the site, or over live carriageways, though more substantial girders and piers with proper foundations will need to be used for bigger openings. As these bridges are often cast span by span, the common configuration is to cast a span plus a short cantilever in to the next span (of 0.2 to 0.25 of the span) – this ensures that the as-built moments in the deck are close to the final moments. With smaller spans, it would be possible to cast several spans at the same time, all in one continuous pour. Timber forms of this size can be used 10-50 times before needing to be refurbished.

With the larger spans, voids should also be incorporated, both to reduce the self-weight and to increase the efficiency of the section. These voids are generally made from polystyrene formers, which need to be held rigidly in place, with care taken to ensure that the concrete flows around them. Because of these issues, the cost of these void formers can often be more than that of the concrete that they replace, but the benefits in reducing the amount of prestressing justify their use.

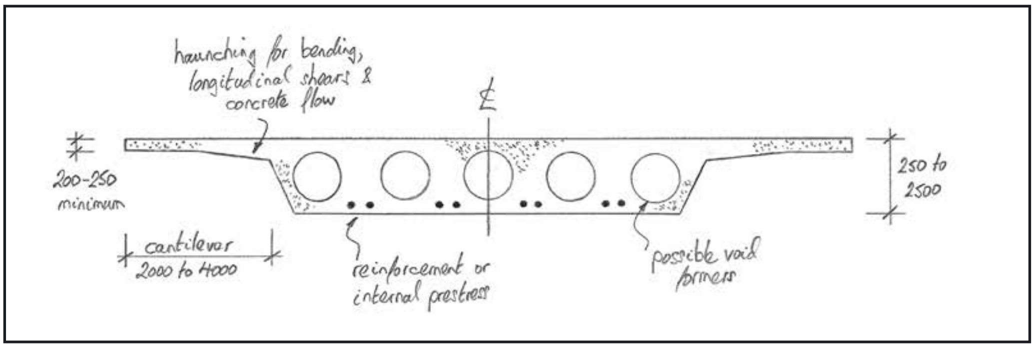

Figure 53: In-situ slab section.

The flat soffit of the deck makes the formwork, fixing and concreting very simple, but the deck is relatively uneconomical in terms of concrete volume and main reinforcement or prestressing tonnage. Overall, bridges of this nature have very low construction costs, as long as there is good access.

Formwork/Falsework Costs – Scaffold/Beams

Typical production rates – 2-4 weeks per span, i.e. about 10m per week.

Table 6 shows the breakdown of deck costs for 50m, 150m and 600m deck lengths with 15m spans.

Deck length (m) = 50m

- Formwork/falsework rate per total formwork area (£/m^2) = 150
- Total deck rate per total deck plan area (£/m^2) = 380

Deck length (m) = 150m

- Formwork/falsework rate per total formwork area (£/m^2) = 140
- Total deck rate per total deck plan area (£/m^2) = 370

Deck length (m) = 600m

- Formwork/falsework rate per total formwork area (£/m^2) = 120
- Total deck rate per total deck plan area (£/m^2) = 340

Commentary on total deck rates and typical formwork/falsework rates

Given the caveat that this assessment has only considered the assumed aspects of this guide, i.e. it has used short spans of 15m, a 15m constant deck width and has taken the deck to be 6m clear from good ground with good access, we can see that in-situ slabs are extremely cost effective. However, 15-30m spans may be too small for some projects and the cost of scaffolding would increase for taller piers and/or deck construction over water, traffic or more difficult ground. These issues tend to render in-situ slab bridges less useful for anything other than the shortest decks.

3.2 In-situ Twin Rib Bridges

Summary	Simple cross-sections cast span by span with simple falsework or on gantries
Key deck features	Flexible solution for any site; slightly deeper sections; min. deck area of 10,000m^2 for gantry use; simple aesthetic
Typical spans	20-50m
Best method for	Small to medium spans with good access; any site once gantries are used
Typical production rate	10m/week on scaffold/beams; 25m/week on gantries
Typical formwork/ falsework costs	£70-150/m^2

Description

In-situ twin rib bridges have a more efficient section than flat slabs but they maintain a simple external profile that is easy to cast (Figure 54). Typical spans range from 20-50m and prestressing is generally always used. Span to depth ratios for highway bridges are typically 14-18. Even though they need a slightly deeper section, twin rib bridges still represent a flexible solution for any site, with a good aesthetic (Figure 55). If a scaffold system is being used as the falsework, then they are best suited to low sites over land with good access, but once a travelling gantry system is used, they are suited to all sites, even with poor access.

Twin rib bridges can accommodate deck widths up to about 20m, beyond which additional ribs can be incorporated. Transversely, they rely on the interaction between the transverse stiffness of the deck slab and the torsional stiffness of the ribs to carry eccentric traffic loads. Though not as efficient as a box girder in this regard, they still perform well in spreading load between the ribs. No diaphragms between the ribs are needed in the span to help with this behaviour. Diaphragms might be needed in some pier locations where the lateral loads are high, due to wind, traffic loads or seismic effects, but adding them will generate significant additional torsions in the rib, which is undesirable. Diaphragms are also a nuisance for the construction process as they prevent the

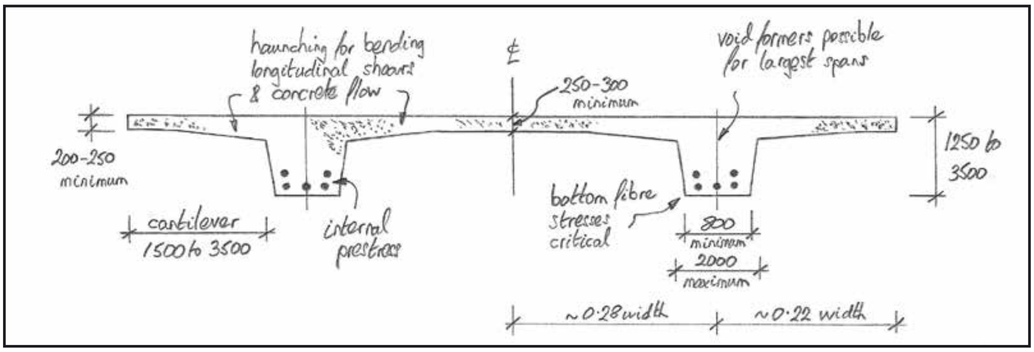

Figure 54: In-situ twin rib section.

easy use of the soffit forms, and thus they should preferably only be used at the ends of the bridge. The ribs are sized for shear, bottom fibre compressions at the supports and to provide torsional stiffness – they will generally be at least 800mm wide, but they may be 1.5-2.0m wide. The ribs are best spaced across the width such that there is no permanent torsion on the rib – this will split the width approximately in the ratios 0.22:0.56:0.22. The soffit of each rib is generally the critical area for the design, both at SLS and ULS, and care should be taken in the case when the whole of the rib is critical in sagging throughout the whole span (as a result of the low bottom modulus and high prestressing secondary moments).

Figure 55: South Holland Bridge - in-situ twin rib.

As with in-situ slab bridges, twin ribs are usually cast span by span in one continuous pour, with the common configuration being to cast a span plus a short cantilever in to the next span (of 0.2 to 0.25 of the span). For shorter lengths of bridge, the falsework would be the same as used for slab bridges, i.e. scaffolding or scaffolding/beams (Figure 47). Once a large enough area of deck exists (over 10,000m^2), it becomes economic to mechanise the process by using a gantry falsework system, which spans from pier to pier, or from the previously built deck to the next pier. The formwork for these 20-50m long pours would usually then become steel, as this can accommodate the casting of 20-100 units. These gantries can be either overhead or under-slung, and be as mechanised as the project allows, although quite simple gantries are possible too (Figure 40). Gantries need to support spans that weigh 500-1,500t and as such the gantries themselves might weigh 100-300t.

The simple soffit of the deck makes the formwork, fixing and concreting easy. The deck is more economical than a slab in terms of concrete, though it is still relatively expensive in terms of prestressing, due to the eccentric load distribution and section efficiency both being worse than with a box section. Overall, bridges of this nature still have relatively low construction costs, depending on the degree of access.

Formwork/Falsework Costs – Scaffold/Beams

Typical production rates – 2-4 weeks per span, i.e. about 10m per week.

Table 7a shows the breakdown of deck costs for 50m, 150m and 600m deck lengths with 30m spans.

Deck length (m) = 50m

- Formwork/falsework rate per total formwork area (£/m^2) = 150
- Total deck rate per total deck plan area (£/m^2) = 440

Deck length (m) = 150m

- Formwork/falsework rate per total formwork area (£/m^2) = 140
- Total deck rate per total deck plan area (£/m^2) = 430

Deck length (m) = 600m

- Formwork/falsework rate per total formwork area (£/m^2) = 110
- Total deck rate per total deck plan area (£/m^2) = 390

Formwork/Falsework Costs – Gantries

(allowing for the cost of the gantry)

Typical production rates – 1-2 weeks per span for highly mechanised gantries, i.e. about 25m per week.

Table 7b shows the breakdown of deck costs for 600m and 1,200m deck lengths with 30m spans.

Deck length (m) = 600m

- Formwork/falsework rate per total formwork area (£/m^2) = 110
- Total deck rate per total deck plan area (£/m^2) = 380

Deck length (m) = 1,200m

- Formwork/falsework rate per total formwork area (£/m^2) = 70
- Total deck rate per total deck plan area (£/m^2) = 310

Commentary on total deck rates and typical formwork/falsework rates

Given the caveat that this assessment has only considered the assumed aspects of this guide, i.e. it has used short spans of 30m, a 15m constant deck width and has taken the deck to be 6m clear from good ground, we can see that in-situ twin ribs are very cost effective, either on scaffolding where possible, or even on gantries (for decks over 600m long). They have been used extensively in Europe, but are rarely seen in the UK. For all the reasons noted, they should become much more common, although spans only go up to 30-50m.

3.3 In-situ Span by Span Box Bridges

Summary	Box cross-sections cast with simple falsework or on gantries
Key deck features	Min. depth of 2m; min. deck area of 10-20,000m^2 for gantry use; regular alignments; clean aesthetic
Typical spans	30-80m
Best method for	Medium spans with good access; any site once gantries are used
Typical production rate	10m/week on scaffold/beams; 25m/week on gantries
Typical formwork/ falsework costs	£70-120/m^2.

Description

In-situ box girder bridges have a very efficient section but the inside shape of the box does cause some issues with the casting process. Typical spans range from 30-80m and prestressing is always used. Span to depth ratios for highway bridges are typically 16-22. Even though they have a more complex cross-section (Figure 56), box girder bridges represent a good solution for many sites, with a clean aesthetic. If a scaffold system is being used as the falsework, then they are best suited to low sites over land, but once a travelling gantry system is being used, they are suited to all sites.

The minimum slab thicknesses are 200-250mm. The top slab is primarily governed by transverse bending effects from the traffic, and therefore the slab thickness increases over the webs. The webs would generally be positioned at about ¼ points of the deck width. Typical rules of thumb for a highway bridge would show a top slab thickness over the webs of (cantilever length)/8 or (box width)/16-18, both of which generate about the same figure. This greater thickness helps the flow of concrete during casting, and is also a good means to create an area at the top of the webs where internal cables can be located. This haunching of the slab also controls longitudinal shears. The variable depth of the top slab therefore serves multiple purposes, though the longitudinal compressions in the top slab at midspan rarely govern this thickness, as the deck width is invariably sufficient to control these stresses.

Ideally for easy casting, the webs of the box should be vertical, though inclined webs are much more elegant. Such shapes also reduce the width of the bottom slab, which is beneficial in self-weight as it rarely needs to be as wide as the

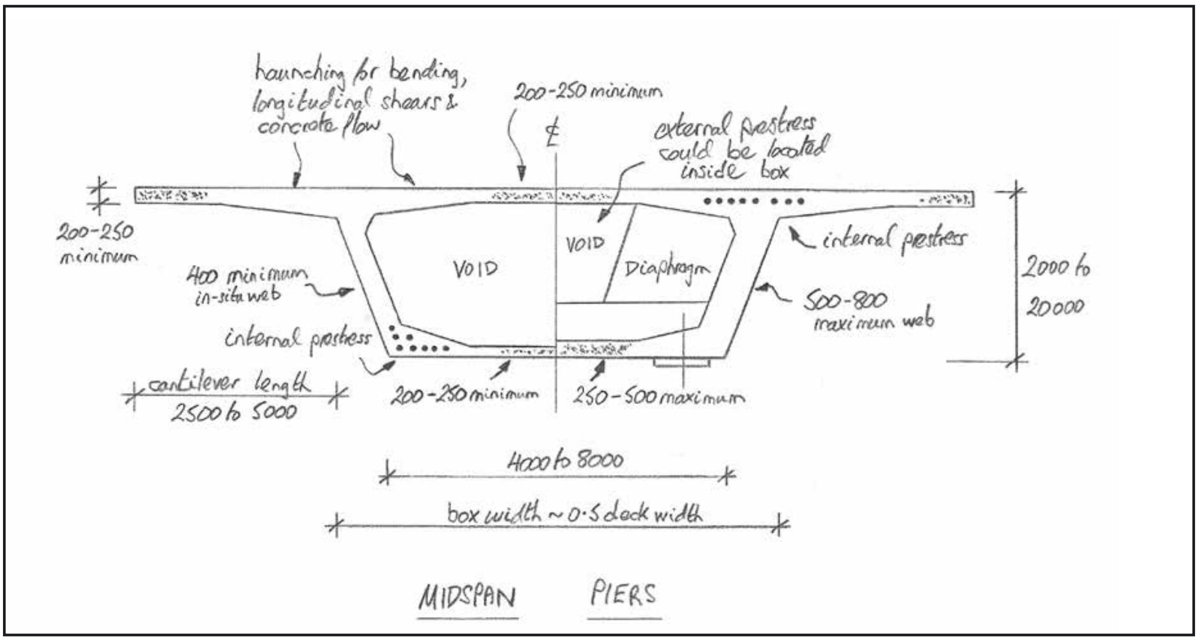

Figure 56: In-situ box section.

top of the box. The minimum web thickness for an in-situ box is about 400mm for concreting purposes and the use of internal vibrators. The web thickness is then governed by shear and torsion at the pier locations, where the typical thickness increases to 500-800mm. The only requirement for the bottom slab at midspan is to close the torsion box – the slab is therefore best kept narrow and as slender as the codes allow. It should still be thickened where it connects to the web to help the flow of concrete during casting and to provide a location where internal cables might be located. At the pier locations, the bottom slab may need to be thickened to carry the longitudinal compressions, though it rarely needs to be more than about 500mm thick, except for the biggest spans. Diaphragms are only ever needed at pier locations and should generally never be used in the span, as the distortional behaviour of a concrete box is rigid enough.

The easiest form to create is a single-cell box, which can accommodate widths up to about 20m. Boxes generally need internal access for both maintenance and stressing operations – they should therefore be at least 2m deep, which determines the minimum span of about 30m. Multi-cell boxes, though possible in some locations, should be avoided wherever possible as they are awkward to construct, with too many pours and difficulties in operating the many internal shutters, unless each cell is made at least 4m wide. They also tend to have too much web and bottom slab, making them inefficient in self-weight and prestressing.

Figure 57: In-situ box girder on scaffolding.

As with in-situ slabs and twin ribs, these boxes are usually cast span by span, with the common configuration being to cast a span plus a short cantilever in to the next span (of 0.2 to 0.25 of the span). For shorter lengths of bridge, timber forms supported on scaffolding would again be used (Figures 47 and 57). Beams are used to span over openings for traffic through the site, or over live carriageways, though more substantial girders and piers with proper foundations will need to be used for bigger openings. Once a large enough area of deck exists (over 10-20,000m^2), it becomes economic to mechanise the process by using a gantry falsework system, which spans from pier to pier, or from the previously built deck to the next pier (Figure 58). The formwork for these 30-80m long pours would usually then become steel, as this can accommodate the casting of 20-100 units. These gantries can be either overhead or under-slung, and be as mechanised as the project allows, although quite simple gantries are possible too. Gantries need to support spans that weigh 1,000-2,500t and as such the gantries themselves might weigh 300-600t. Such bridges are common overseas, but quite rare in the UK, as the box section has to be cast in two or three phases, generally bottom slab and webs, followed by top slab. However, it is quite difficult to move the long lengths of internal shutter that form the inside of the box, which can make the operations slower.

Figure 58: Tajo Viaduct - in-situ box with gantry.

The deck is very economical in terms of concrete and prestressing, due to the excellent eccentric load distribution and section efficiency. Overall though, the box section makes the formwork, fixing and concreting more complex, which will be reflected in higher construction costs than ribs and slabs.

Formwork/Falsework Costs – Scaffold/Beams

Typical production rates – 4-8 weeks per span, i.e. about 10m per week.

Table 8a shows the breakdown of deck costs for 50m, 150m, 600m and 1,200m deck lengths with 50m spans.

Deck length (m) = 50m

- Formwork/falsework rate per total formwork area (£/m^2) = 110
- Total deck rate per total deck plan area (£/m^2) = 510

Deck length (m) = 150m

- Formwork/falsework rate per total formwork area (£/m^2) = 100
- Total deck rate per total deck plan area (£/m^2) = 500

Deck length (m) = 600m

- Formwork/falsework rate per total formwork area (£/m^2) = 90
- Total deck rate per total deck plan area (£/m^2) = 460

Deck length (m) = 1,200m

- Formwork/falsework rate per total formwork area (£/m^2) = 90
- Total deck rate per total deck plan area (£/m^2) = 460

Formwork/Falsework Costs – Gantries

(allowing for the cost of the gantry).

Typical production rates – 1-3 weeks per span for highly mechanised gantries, i.e. about 25m per week.

Table 8b shows the breakdown of deck costs for 600m, 1,200m and 5,000m deck lengths with 50m spans.

Deck length (m) = 600m

- Formwork/falsework rate per total formwork area (£/m^2) = 120
- Total deck rate per total deck plan area (£/m^2) = 550

Deck length (m) = 1,200m

- Formwork/falsework rate per total formwork area (£/m^2) = 70
- Total deck rate per total deck plan area (£/m^2) = 420

Deck length (m) = 5,000m

- Formwork/falsework rate per total formwork area (£/m^2) = 70
- Total deck rate per total deck plan area (£/m^2) = 420

Commentary on total deck rates and typical formwork/falsework rates

Once spans are over 40-50m, one of the box solutions will be required, which rules out the various slab, rib and beam solutions. However, given the caveat that this assessment has only considered the assumed aspects of this guide, i.e. it has used medium spans of 50m, a 15m constant deck width and has taken the deck to be 6m clear from good ground with good access, we can see that for shorter deck lengths, in-situ boxes on scaffolding are the best option. However, the cost of scaffolding would increase for taller piers and/or deck construction over water, traffic or more difficult ground. With deck lengths over 600-1,200m, and where the alignment does not allow launching, the use of gantries to cast in-situ boxes is the best solution, as long as the alignment is gentle enough to accommodate this method. As with twin ribs, these gantry schemes are used extensively overseas, but are not often seen in the UK.

3.4 In-situ Balanced Cantilever Bridges

Summary	Box cross-sections cast in balanced cantilever with short travelling gantries
Key deck features	Min. depth of 2.5m; min. deck area of 5,000m^2 or length of 300m; ideally needs constant width; good aesthetic
Typical spans	Most common 60-100m; range 40-300m
Best method for	Medium to long spans at any site with poor access; often used over valleys or water
Typical production rate	5-10m/week; can be accelerated using multiple pairs of travellers
Typical formwork/ falsework costs	£110-150/m^2

Description

The issues related to casting long lengths of box are resolved in this method by casting the bridge in short lengths. Typical spans range from 60-100m, but the system can accommodate any span from 40-300m (Figures 7, 11, 24 & 52). The spans are always continuous, by definition, and prestressing is always used. Span to depth ratios for highway bridges are typically 18-20 for constant depth schemes. However, variable depth is very common and would generally be a necessity for all spans over about 60m (Figure 59). In this case, span to depth ratios for highway bridges are typically 12-18 at the pier locations and 25-45 at midspan, and the variation in depth can use either linear or parabolic haunches.

Figure 59: River Taw Bridge - variable depth.

Each box section is cast within a travelling formwork/ falsework frame, or traveller, which needs a minimum deck area of about 5,000m^2 to justify its procurement. Ideally, to simplify the formwork, the bridge should be of constant width. The aesthetics are very good, particularly with variable depth girders and inclined webs. The method is best suited to all sites, especially ones with poor access from below. In-situ balanced cantilever bridges are used extensively worldwide and are ideally suited to the typical crossings of a river with five or more spans - locations where the cost of conventional falsework can be prohibitive.

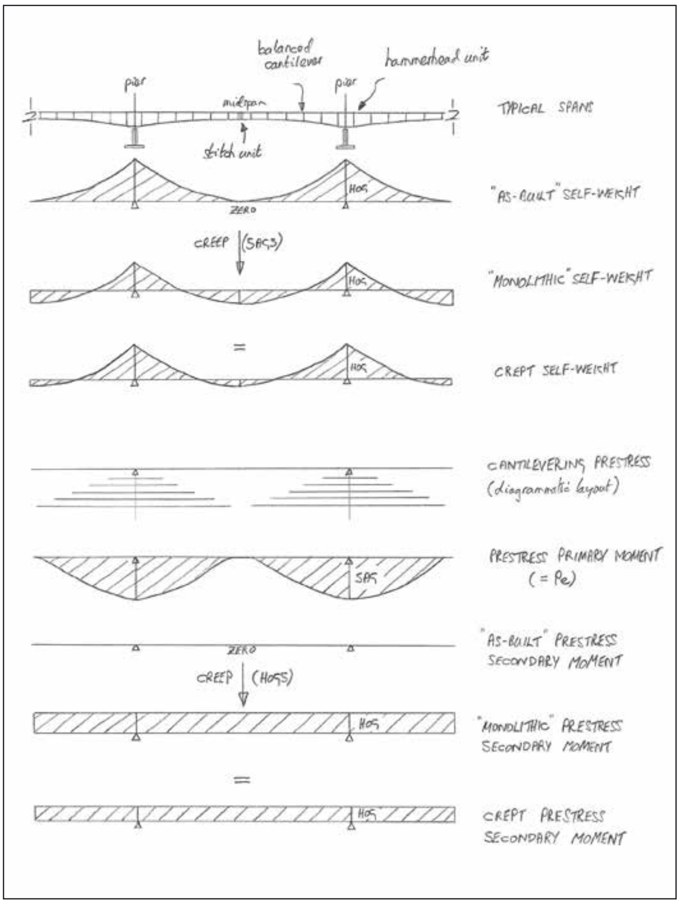

Figure 60: Creep of moments.

The sizing of the box girder is as described in the last section on in-situ box girders (Figure 56). The bridge is again best developed as a single-cell box, with each 3-5m long unit poured in one complete operation. The maximum box width is also about 20m but the minimum box depth is now 2.5m to allow easy use of the internal formwork. Ideally, the webs of the box should be vertical as this allows better use of the side shutters with a constant width bottom slab. Inclined webs are much more elegant though and are often used, even though the bottom slab formwork then has to accommodate a variation in width. As each new pair of units is cast, the balanced cantilever grows, until it reaches the midspan of each adjacent span. The self-weight of the bridge is thus primarily produced while the bridge is statically determinate – significant creep of these *as-built* moments then occurs as the bridge creeps toward moments that would have existed if it had been built in one phase, i.e. *monolithic* moments. There will also be significant creep of the prestressing secondary moments. Fortunately, the creep of the self-weight and the secondary prestressing moments is in the opposite direction, negating the need for too much precision in the calculation of the creep factor (Figure 60), unless the spans are very large.

Each pair of units is cast either side of the pier location to create a balanced cantilever (Figures 26, 41 & 61) – typically, on a weekly cycle. The unit formwork is generally supported from an overhead traveller that is attached to the end of the last unit. Formwork is generally plywood as each traveller will cast 10-50 units. Each traveller can weigh 30-60t, supporting concrete units that might weigh 75-250t. Underslung travellers, which keep the top of the deck clear, are also used as they allow the unit reinforcement cage to be pre-fabricated and lifted in as a whole piece. This allows the casting cycle to be reduced to less than a week, though at the cost of a more expensive traveller. In most cases, the pair of units is cast on a Friday, left to cure over the weekend, allowing the deck to be prestressed on the Monday, and the travellers to be moved forward that afternoon. Cantilevering prestress is applied to each balanced pair until the whole cantilever is complete. It is also possible to stress within 12-15 hours, by pouring late in the afternoon and stressing first thing in the morning, which suits the casting of a pair of units every 3-4 days (possibly, with some night working). Enlarged anchor plates or precast end blocks can also be used, if necessary, to enable these early stressing operations.

Figure 61: River Dee Viaduct - balanced cantilever pair.

The whole construction cycle tends to be operated by a composite gang of labour who do all the traveller operations, rebar fixing, stressing and grouting, with additional labour used for the weekly concreting phase. As each traveller is a mechanised piece of formwork/falsework, it needs to be operated with a careful sequence of striking, moving, fixing and casting. There are many operations in each cycle, which require a thorough set of checking and signing-off procedures to ensure its safe use. Construction starts from the top of a pier with a 4-15m long hammerhead unit that is cast on a falsework system that sits on the permanent foundations or is supported off the piers (Figure 62). Alternatively, the hammerhead units are often cast monolithically with the piers. This unit then forms the initial platform for the travellers (Figure 63), while temporary props or packs are used to provide stability to the balanced cantilever until further continuity of the spans is achieved. Once two cantilevers meet at midspan, a stitch unit is poured to close the span. The same travellers are used to form this stitch unit, though additional falsework is also required to hold the cantilever ends stable against temperature movements during the pour. The stitch is then initially stressed within 12-15 hours, by pouring late in the afternoon and stressing first thing the following morning. Once continuity is made and the stitch concrete is up to full strength, further prestressing cables are added and stressed across each span to make the bridge continuous. Similarly, end span units are cast, in cantilever or on props, to reach the abutments, thus completing the whole bridge length.

Figure 62: River Taw Bridge - hammerhead unit cast on scaffolding.

Figure 63: River Taw Bridge - hammerhead unit with travellers.

Even though the typical production rate is two balanced units per week, the hammerhead unit can take 4-6 weeks, which generates an overall period of 10-16 weeks per span, i.e. 5-10m per week. Construction can be accelerated though by using multiple pairs of travellers and starting work at several piers at the same time, thus increasing the production rate to 10-20m/week, if needed. The main advantage of in-situ balanced cantilever construction is the use of a bespoke travelling formwork system that is used many times on a regular production-line cycle, obviating the need for falsework from the ground. The deck is also very economical in terms of concrete and prestressing and thus, in-situ balanced cantilevering should deliver very competitive construction costs in certain locations.

Formwork/Falsework Costs - Travellers

Typical production rates – 2 units traveller-erected per week plus 4-6 weeks per pierhead (or hammerhead) unit, i.e. 10-16 weeks per span, which is 5-10m per week.

Table 9 shows the breakdown of deck costs for 150m, 600m and 1,200m deck lengths with 50m spans.

Deck length (m) = 150m

- Formwork/falsework rate per total formwork area (£/m^2) = 160
- Total deck rate per total deck plan area (£/m^2) = 650
- The 150m deck length shown here is a little too short for in-situ balanced cantilevering, but is shown for completion of the charts and figures, allowing some interpolation of the results.

Deck length (m) = 600m

- Formwork/falsework rate per total formwork area (£/m^2) = 110
- Total deck rate per total deck plan area (£/m^2) = 520

Deck length (m) = 1,200m

- Formwork/falsework rate per total formwork area (£/m^2) = 100
- Total deck rate per total deck plan area (£/m^2) = 500

Commentary on total deck rates and typical formwork/falsework rates

Once spans are over 40-50m, one of the box solutions will be required, which rules out the various slab, rib and beam solutions. However, given the caveat that this assessment has only considered the assumed aspects of this guide, i.e. it has used medium spans of 50m, a 15m constant deck width and has taken the deck to be 6m clear from good ground with good access, we can see that in-situ balanced cantilevering on the surface appears rarely to be cost effective. However, on closer examination, it can be seen that it is effective, in the right circumstances. For deck lengths of 150-600m, where launching or scaffolding are not possible or sensible, it becomes not only the best box option, but the only one. While for deck lengths of 600-1,200m, also where launching or scaffolding are not possible, it becomes comparable to in-situ boxes on gantries or crane-erected precast segmental solutions. Once spans are closer to 100m, and/or where the bridge deck crosses either a deep valley or difficult water/ground conditions, it would become very competitive.

3.5 Standard Precast Beam Bridges

Summary	Standard factory-cast beams erected by cranes
Key deck features	Flexible solution for any site; slightly deeper sections; straight beams
Typical spans	5-40m
Best method for	Small to medium spans with good access
Typical production rate	20m/week
Typical formwork/ falsework costs	£50-80/m^2

Description

These bridges utilise standard precast sections, which are cast in proprietary factories off site and then erected by cranes. They are ideal for small to medium spans, ranging from 5-40m. The precast beams are pre-tensioned and are generally straight. Span to depth ratios for highway bridges are typically 15-18, as the spans are often simply supported. The spans can also be made continuous after erection, in which case the ratio is closer to 20. This type of bridge represents a very flexible solution that is good for any site, though it is best suited to low sites with good access.

With pre-tensioning, the prestressing steel is stressed first and the concrete member is then cast around this steel (Figures 17 & 34). It has the advantage that as the prestressing is embedded in the concrete, there is no need for any grouting. The prestressing consists of individual strands, each made up from seven spirally-wound steel wires. The most common strand is a low relaxation superstrand, having a 15.7mm diameter, an area of 150mm^2 and an ultimate strength, f_{pk} of 1,860MN/m^2. As the strands are generally straight, the system usually only allows straight beams to be produced. Standard precast, pre-tensioned concrete beams have been used for years in many countries, and various shapes and depths are produced (Figure 64). Typical beams weigh 5-60t and can be readily transported by low-loader to site (Figure 35), where they are generally erected by crawler or mobile cranes (Figures 29 & 36). Some transportation restrictions may apply with beam lengths beyond about 30m, but beams up to 40m can generally be accommodated on the road network. Depending on the ground conditions, some hardstandings for the crane outriggers may also be required and, in extreme, it might be necessary to pile the relevant area.

Smaller beams (SBB or solid M, MY, T or TY beams) are placed adjacent to each other, transverse reinforcement passed through preformed holes, and the space between the beams filled with concrete to form a solid slab, with typical spans varying from 5-25m. Wide box beams are used in the same way, but require significantly less in-fill concrete, giving a lighter cross-section. Larger beams (M, TY, Y, SY or U beams) are spaced further apart, permanent formwork (precast, GRP or GRC planks – Figure 44) is placed between the beams and an in-situ deck slab is cast over the top. Typical spans in this case vary from 15-35m, though up to 40m is possible. The prestress and self-weight loads are carried on the precast beam and all other loads (finishes and traffic loads) are carried on the composite section, i.e. including the top slab. There will be some creep as all the permanent stresses re-distribute on to the composite section, but it tends not to be critical. These bonded sections tend to be designed as fully compressed under all frequent traffic loads. This is the requirement in EC 2[8] and, as a result, these pre-tensioned sections are generally governed by SLS, and ULS will not be critical.

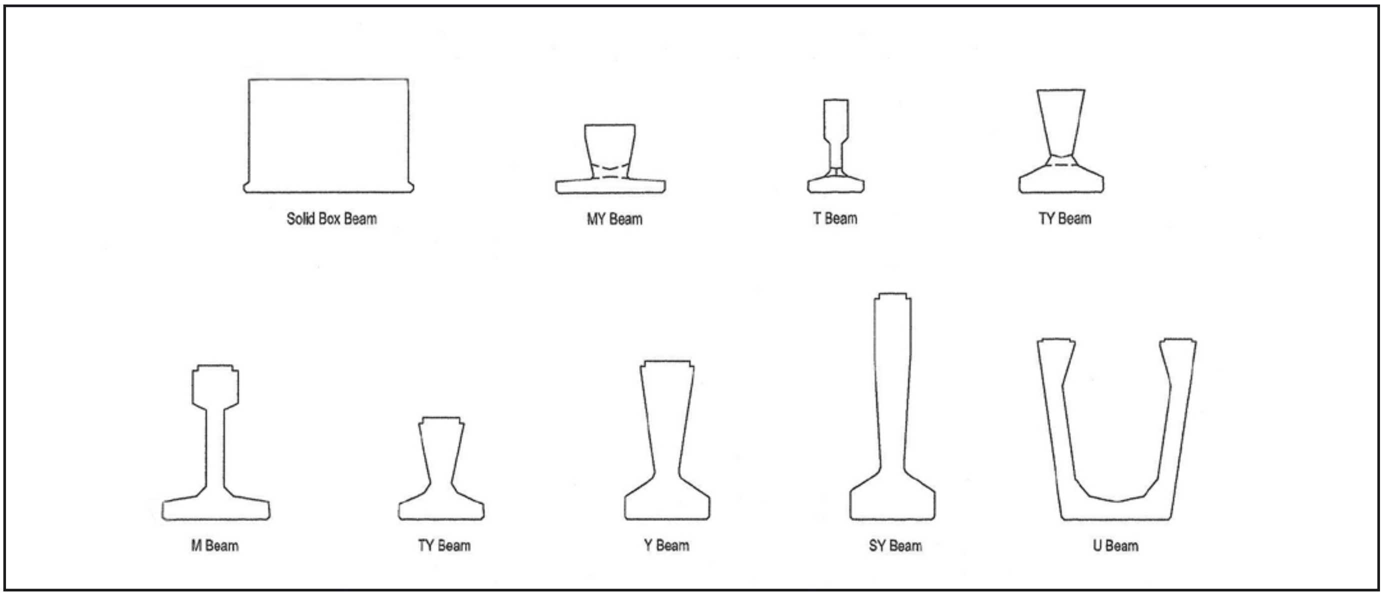

Figure 64: Standard precast beams.

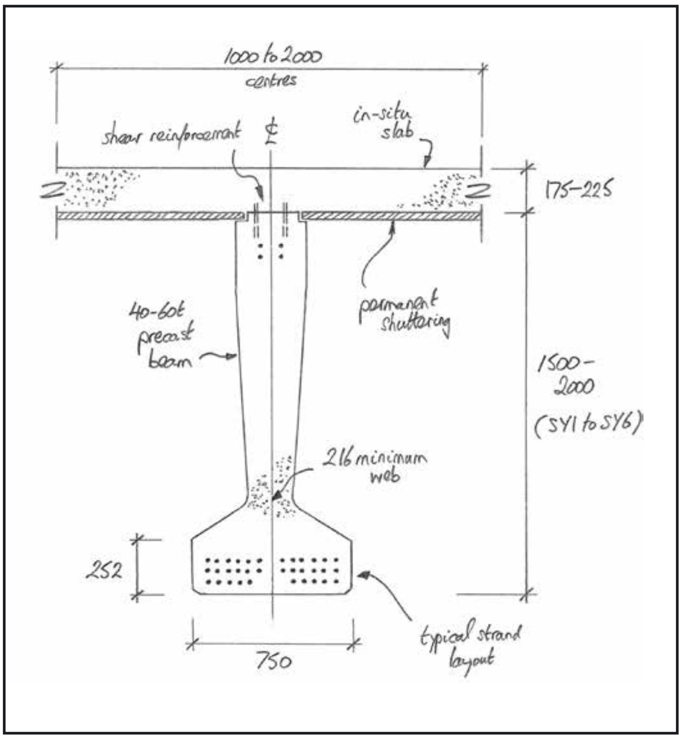

Figure 65: Standard precast SY beam.

The top surface of the beams is suitably prepared and has projecting reinforcement so that the slab and beams act together. For the beam and slab decks, the preferred arrangement in the UK is with Y, SY or U beams, spaced 1-2m apart with a top slab that is about 160mm thick, though this thickness increases to 175-225mm for SY beams (Figure 65). Beams should be made as deep, and spaced as far apart, as possible – to maximise the efficiency of the prestressing. Many other countries have their own set of very similar precast beams. The beams are produced in steel moulds with minimum web thicknesses of 160-200mm. The prestress is applied to the ends of the member by bond action between the strand and the concrete, resulting in a length over which the force is transmitted (of 500-1,000mm). De-bonding of some of the strands is often used at the ends of the beams, so as not to either overstress the bottom fibre or put tension in to the top fibre. Alternatively, further strands or reinforcement can be added to the top of the beam to control these effects.

The strands are generally treated in the same way as reinforcement as regards cover and spacing, though EC 2[8] quotes an extra cover of 10mm. Typically, the cover is 50mm and the spacing of the strands is 40-50mm. The analysis of stresses in the end zones of pre-tensioned members is not really covered in the codes, but the basic principles of bursting, equilibrium and spalling still apply. However, the strands are more evenly spread out than post-tensioning anchorages and the transmission length applies the loads more gradually. So, the effects are much less pronounced than with post-tensioning. Some pre-tensioned beams that are used in integral bridges do have a fairly uniform distribution of strands, resulting in no particular issues within these end zones. However, most beams would tend to have the majority of strands placed within the lower heel or flange, which will generate equilibrium effects, which will try to split the web horizontally. A summary of the two most common calculation methods can be found in CBDG TN 10[29]. As with post-tensioning, small well anchored bars such as H12s are likely to be the best type of reinforcement.

With pre-tensioned, asymmetric edge beams (Figure 66), it is important for the designer to place the centroid of the strands at the lateral centroid of the section, i.e. on the Y-Y axis, not on the centre of the heel. This will significantly minimise any lateral deflections (and additional lateral stresses) that would otherwise occur. For any beam longer than about 30m, or which is slender or heavily prestressed, a proper principal axes calculation (for the self-weight and the prestressing loads) should be carried out to determine the optimum position. CBDG TN 10[29] gives further details.

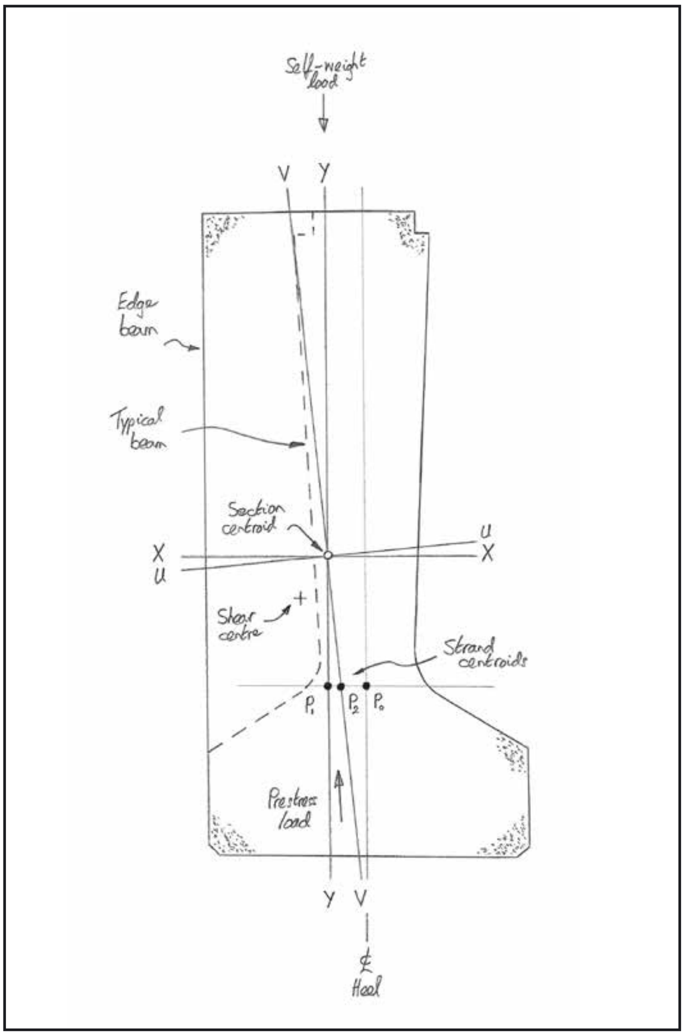

Figure 66: Assymetric edge beam analysis.

Beams are erected as simple spans (Figure 27), but are often then made continuous (or integral) to avoid the need for expansion joints (or bearings). In this case, an in-situ stitch is formed between the ends of the beams, making the structure monolithic. The hogging moment tensions from the finishes and traffic loads are then carried in the top slab reinforcement. Some bottom reinforcement is also required at the piers as the creep of the prestressing secondary moment will induce a sagging effect. This continuity is often provided by lapping of the projecting lengths of prestressing strand, though reinforcement could also be used. See CBDG CPS 4[50] for further details, and CBDG TG 13[18] for a set of integral bridge calculations to EC 2[8].

Standard precast beams, produced in a factory, can therefore be of high-quality, with a proven record of durability. These precast beams can be quickly erected on site and are therefore particularly useful when bridging over live roads, railways and waterways, where the interruptions to the traffic must be minimised. The precasting of beams in a well-controlled factory environment, and the simple casting of the deck slab, make this solution very effective. Construction can also be started at several locations at the same time, if needed to further reduce the programme. Overall, bridges of this nature have low construction costs, as long as there is good access for crane erection.

Formwork/Falsework Costs – Cranes

Typical production rates – 12 standard beams crane-erected per day plus 1 span per week for the in-situ deck, i.e. about 20m per week.

Table 10 shows the breakdown of deck costs for 50m, 150m, 600m and 1,200m deck lengths with 30m spans.

Precast beams are often supplied to site at an all-up cost, i.e. with the mould, casting cranes and yard, casting labour, storage and transport costs added to the concrete, reinforcement and prestressing material costs to give a price per beam or per m^3. The casting data figures in Table 10 have been verified against this breakdown, confirming that reinforced concrete sections can be delivered to site for about £400-600/m^3, while prestressed concrete sections are £500-700/m^3. All the further site costs to lift and place the beams, and to form the top slab and diaphragms, including further concrete, reinforcement, formwork, labour and craneage, are then in addition.

Deck length (m) = 50m

- Formwork/falsework rate per total formwork area (£/m^2) = 80
- Total deck rate per total deck plan area (£/m^2) = 510

Deck length (m) = 150m

- Formwork/falsework rate per total formwork area (£/m^2) = 60
- Total deck rate per total deck plan area (£/m^2) = 450

Deck length (m) = 600m

- Formwork/falsework rate per total formwork area (£/m^2) = 50
- Total deck rate per total deck plan area (£/m^2) = 430

Deck length (m) = 1,200m

- Formwork/falsework rate per total formwork area (£/m^2) = 50
- Total deck rate per total deck plan area (£/m^2) = 420

Commentary on total deck rates and typical formwork/falsework rates

Given the caveat that this assessment has only considered the assumed aspects of this guide, i.e. it has used short spans of 30m, a 15m constant deck width and has taken the deck to be 6m clear from good ground with good access for the crane erection, we can see that, as expected, the various standard precast Y or SY beams are very competitive as long as there is good access for crane erection. They are used extensively worldwide, although spans only go up to 35-40m.

3.6 Bespoke Precast Beam Bridges

Summary	Large precast beams erected by cranes or gantries
Key deck features	Flexible solution for larger spans; slightly deeper sections; min. deck area of 5-10,000m^2 for gantry use; straight beams
Typical spans	30-60m
Best method for	Medium spans with good access; any site once gantries are used
Typical production rate	25m/week with cranes or gantries
Typical formwork/ falsework costs	£40-80/m^2

Description

These bridges utilise bespoke precast sections, which are cast either off or on site, and are then erected by crane or gantry. They are ideal for medium spans, ranging from 30-60m. The precast beams can be either pre-tensioned (Figure 17) or post-tensioned, but either way, they are generally straight. Span to depth ratios are also typically 15-18 when the spans are simple, and closer to 20 with continuity. This type of bridge represents a good solution for bigger spans, and with crane erection, it is best suited to low sites with good access. Once gantries are used on the larger sites though, it suits any location. With fewer webs, the sections are more efficient and have a better aesthetic than standard precast beams.

These beam and slab decks use U, I or T beams, spaced 2-4m apart with a top slab that is at least 200mm thick (Figure 67). These bespoke beams tend to have more top/bottom flanges than standard beams, making them more efficient and stable, while maintaining a section that is simple to cast, i.e. without any internal shutters. With post-tensioned beams, a significant shear relief is obtained from the inclined cables, allowing thinner webs to be used. The beams are generally produced in steel moulds with minimum web thicknesses of 175-250mm, depending on whether external or internal vibrators are used (Figure 34). Beams can be 2-4m deep and weigh 60-200t. If cast on site, then further facilities will be required such as a casting shed and lifting equipment to move the beams to the storage area, and on to the bridge. The beams can be erected as simple spans, in the same way as standard beams, with an in-situ reinforced concrete stitch formed, if required, between the ends of the beams to make them continuous. They can also be made with only the top slab being continuous, while the beam itself stays simply-supported - this arrangement with 4-8 spans linked together keeps the simplicity of the support areas, while producing a uniform running surface with fewer expansion joints. The beams can also be erected in balanced cantilever, with an in-situ, post-tensioned concrete stitch formed between the beam ends – effectively, a concrete version of a steel-composite girder solution (Figure 68).

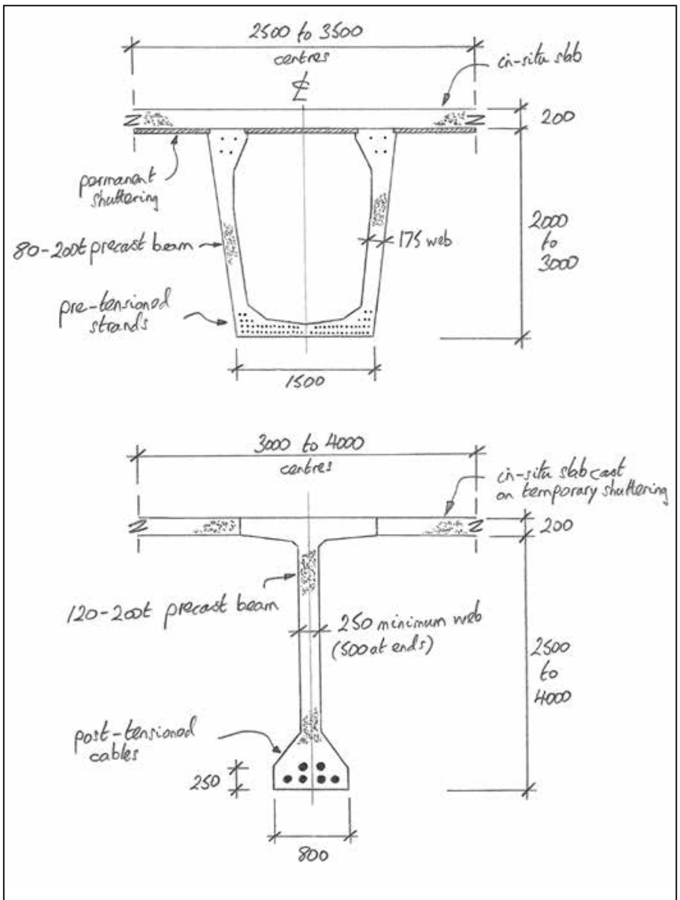

Figure 67: Two bespoke precast beam types.

Cranes can accommodate beams up to around 150t (Figures 29 & 36), but in the range 100-200t, gantries would normally be required (Figure 68). However, gantries can normally only be justified once the deck area is more than about 10,000m^2.

The gantries can be quite simple though, enabling their use on smaller deck areas (of closer to 5,000m^2, say), especially if the precast supplier or contractor has amortised the cost of the gantry over several projects. Such gantries, which may themselves weigh 100-200t, need to lift the beams either from the ground, or from the already completed deck, in order to lower them into their correct position. These gantries would be supported on the previously built deck and the existing piers. The in-situ deck slab is cast in the same way as with standard beams (Figure 44), or by using temporary formwork. Large precast concrete slabs can also be used as permanent, participating shuttering, often wide enough to form the whole deck width. Holes or slots are then required in the precast slab to allow the shear connection to be made to the precast beams.

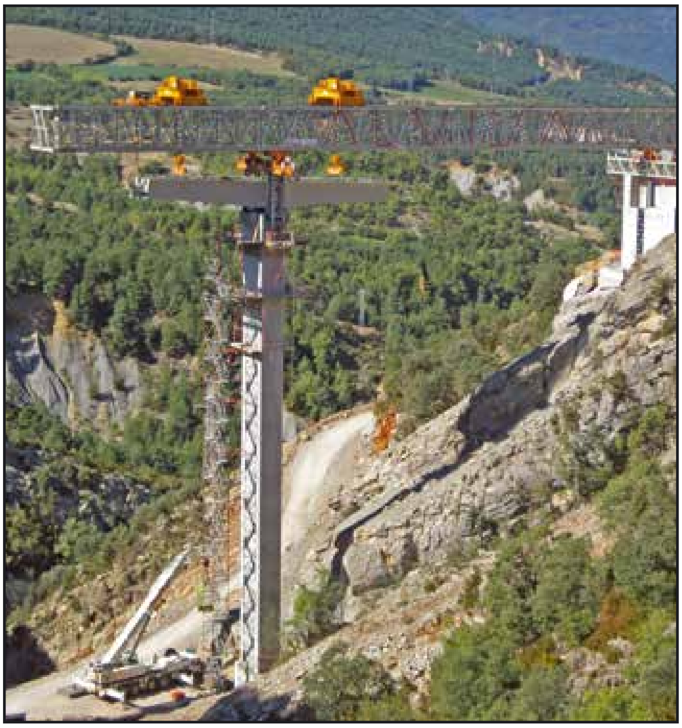

Figure 68: Egea Bridge - gantry-erected bespoke beams.

The precasting of these bespoke beams and the simple casting of the deck slab, also make this solution very effective, and the deck is more economical than standard beams in terms of materials. Overall, bridges of this nature have low construction costs, depending on the degree of access and the amount of temporary works needed.

Formwork/Falsework Costs – Cranes

Typical production rates – 4 bespoke beams crane-erected per day plus 1 span every 1-2 weeks for the in-situ deck, i.e. about 25m per week.

Table 11a shows the breakdown of deck costs for 50m, 150m, 600m and 1,200m deck lengths with 40m spans.

Deck length (m) = 50m

- Formwork/falsework rate per total formwork area (£/m^2) = 60
- Total deck rate per total deck plan area (£/m^2) = 520

Deck length (m) = 150m

- Formwork/falsework rate per total formwork area (£/m^2) = 50
- Total deck rate per total deck plan area (£/m^2) = 450

Deck length (m) = 600m

- Formwork/falsework rate per total formwork area (£/m^2) = 40
- Total deck rate per total deck plan area (£/m^2) = 420

Deck length (m) = 1,200m

- Formwork/falsework rate per total formwork area (£/m^2) = 40
- Total deck rate per total deck plan area (£/m^2) = 410

Formwork/Falsework Costs – Gantries

(allowing for the cost of the gantry)

Typical production rates – 4 bespoke beams gantry-erected per day plus 1 span every 1-2 weeks for the in-situ deck, i.e. about 25m per week.

Table 11b shows the breakdown of deck costs for 600m, 1,200m and 5,000m deck lengths with 40m spans.

Deck length (m) = 600m

- Formwork/falsework rate per total formwork area (£/m^2) = 80
- Total deck rate per total deck plan area (£/m^2) = 400

Deck length (m) = 1,200m

- Formwork/falsework rate per total formwork area (£/m^2) = 60
- Total deck rate per total deck plan area (£/m^2) = 330

Deck length (m) = 5,000m

- Formwork/falsework rate per total formwork area (£/m^2) = 60
- Total deck rate per total deck plan area (£/m^2) = 330

Commentary on total deck rates and typical formwork/falsework rates

Given the caveat that this assessment has only considered the assumed aspects of this guide, i.e. it has used medium spans of 40m, a 15m constant deck width and has taken the deck to be 6m clear from good ground with good access, we can see that the bespoke pre-tensioned U beams are all very competitive as long as there is good access for crane erection. For deck lengths over about 600m, gantry erection becomes effective, obviating the need for any access. Gantry-erected post-tensioned I beams are extremely cost effective for these larger deck lengths – they have been used extensively overseas, for some very long bridges as well, where they can compete with the exceptionally low costs of the whole span precast system. They have not been used in the UK – probably due to the need for gantry erection, which is seen as more complex. The aesthetic of these larger I beams is perhaps also seen in the UK to be less good, but it is certainly no worse than steel-composite decks. Spans are also able to go up to 50-60m.

3.7 Precast Segmental Bridges

Summary	Precast box cross-sections erected span by span or in balanced cantilever with cranes or gantries
Key deck features	Flexible solution for any large site; min. depth of 2m; min. deck area of 10,000m^2; any alignment; good aesthetic
Typical spans	30-60m for span by span; 30-200m for balanced cantilever
Best method for	Medium to long spans with good access; any site once gantries are used
Typical production rate	30m/week with cranes; 50m/week with gantries
Typical formwork/ falsework costs	£80-120/m^2

Description

These bridges use short box sections, which are cast in a factory on site and are erected either by crane or gantry. They are ideal for medium to long spans, from 30-200m. The segments are post-tensioned and can accommodate any alignment or variation in depth. Span to depth ratios for highway bridges are typically 16-22. For variable depth schemes (spans over about 60m), these ratios become 12-18 at the piers and 25-40 at midspan. This type of bridge represents an excellent solution for large schemes, with deck areas more than 10,000m^2, where the investment in moulds, casting areas and erection equipment is justified. The aesthetics are very good, especially with variable depth girders and inclined webs (Figures 8 & 10). With crane erection, the method is best suited to low sites with good access, but once gantries are used, it suits any large site, particularly in urban areas where the cost of conventional falsework can be prohibitive.

The sizing of the box is as described for in-situ boxes in the last section (Figure 56), although the minimum web thickness is now 300mm, as there is more control of concreting in the precast factory and external vibrators on the mould are generally used. The best section is a single-cell box, with each 2-5m long segment poured in one operation, typically on a daily cycle, although more complex or larger segments can take 2-3 days. The maximum box width is 20m and ideally, the webs of the box should be vertical as this allows the use of a simpler mould with a constant width bottom slab. Inclined webs are much more elegant though and are often used. Production rates can be very high with cranes able to erect 2-4 segments per day and gantries at least 4-6 segments per day. Overall, the typical production rates are 30-50m/week, which is very fast and one of the major benefits of the method. Further details are shown in CBDG CPS 15[51] and TP 9[52].

The casting area should generally be located on the site in a purpose-built shed. The layout of the yard should be carefully chosen to accommodate the reinforcement fixing, the moulds, the casting and the storage areas. Segments are poured in purpose-made steel moulds, each able to cast 200-300 segments. Segment lengths vary from 2-5m, though around 3m is usual, and widths can be tailored to suit the site. Typical weights are 25-75t, with segments closer to the piers, or those with large blisters/deviators, being around 100-150t. These highly mechanised steel moulds accommodate all variations in section size and depth, all the geometric changes between successive segments, and all the internal arrangements for cable anchorages and deviators (Figures 20 & 21). Transitions in both the slab and web thicknesses can also be accommodated. However, it is beneficial to keep variations between segments to the minimum, both to simplify the mould and to minimise the operations each day. The more basic pier segments are often cast in separate moulds, getting them off the critical path and recognising that there are often fewer pier segments to produce. Such moulds might then be made in timber, enabling 20-50 pier segments to be cast.

Figure 69: A13 Viaduct - one of four bespoke moulds.

All segments are match-cast against each other in the same sequence that they will be erected and thus the geometry of the bridge is determined at the time of casting. Each new segment is cast between a fixed bulkhead and the previously cast segment, with the three-dimensional alignment being incorporated by small angular changes between these two match-cast segments (Figures 19 & 69). The casting process becomes like a production line, with many activities taken off the critical path so as to guarantee the daily cycle. Reinforcement is fixed in timber jigs, which match the shape of the segment, and the cage, including all prestressing ducts and anchorages, is then lifted into the mould as a single piece. Segments are stored in a dedicated area, before being transported to the bridge (Figures 5 & 70). The amount of storage is dependent on the relative rates of casting and erecting, and the deck programme can be tuned to suit varying numbers of moulds or erection equipment. Segments are moved out of the casting shed and into storage with cranes or lifting frames/gantries, before being transported to the bridge using low-loaders, straddle-carriers, wheeled-bogies or rail systems (Figure 71).

Figure 70: A13 Viaduct - segments in storage.

Figure 71: STAR LRTS Viaducts - straddle-carrier and low-loader.

The erection methods depend on the available access to the site. Two main types of construction are widely used - span by span and balanced cantilever. Span by span is used for 30-60m spans, with segments positioned on a gantry, while balanced cantilever is used for 30-200m spans, with segments erected by crane, shear legs or gantry. If ground conditions permit, or subject to some ground improvement, the simplest solution is to erect all the segments using cranes (Figure 72). Alternatively, for balanced cantilever construction, it is possible to install just the pier and one or two adjacent segments by crane, and to then erect the remainder using shear legs or lifting beams positioned on the cantilever tips. Sophisticated gantries then become economic for larger structures, with a total deck area of over 20,000m^2. Gantries are supported on the previously built deck and the next pier location, and launch themselves forward to the next position. Span by span techniques can use either overhead gantries from which the segments are suspended or under-slung gantries upon which the segments rest (Figure 48). Span by span gantries can weigh 200-600t, supporting 600-2,500t of deck. In balanced cantilever construction, segments are erected sequentially either side of a pier segment, so that the overall cantilever is never more than one segment out of balance, i.e. the same way as with in-situ balanced cantilevering. The gantries can also be designed to erect all the pier segments, with the balanced cantilever held stable by falsework at the pier or by the gantry (Figure 49). These balanced cantilever gantries can weigh 150-350t, moving individual 50-100t segments into position.

Figure 72: A13 Viaduct - crane-erected pier segment.

As was described earlier for the similar in-situ method, the construction concludes with midspan stitches, end span units and continuity prestressing. The end spans can be supported on separate falsework or props – scaffolding, proprietary trestles, or fabricated supports can all be used. Creep of the self-weight and secondary prestressing moments also then occurs in any configuration where the *as-built* moments are not the same as the *monolithic* moments - see Figure 60. As there is no reinforcement across the joints, shear keys are provided at the ends of each segment. They combine with temporary bar prestressing to hold the segments secure until the permanent prestressing is installed. Thin layers of epoxy resin (around 1mm thick after temporary stressing) are often applied to the joint surfaces; mainly acting as a weather seal, as in global regions away from road de-icing salts, precast segmental schemes can be progressed using dry joints. The segments will always fit perfectly as they were all match-cast against each other in the casting area. Either way, it is common practice in all countries to design the joints as fully compressed under all SLS load combinations. In the UK currently, precast segmental schemes must use external cables, in order to ensure the three-layer protection system required by TR 72[25]. This moratorium is likely to be relaxed once proprietary duct coupler systems have been accepted, giving a protection system at the joint of the epoxy resin, continuous plastic duct and a high-performance grout.

The main advantage of precast segmental construction is the use of segments that have been produced on a regular cycle in controlled, factory conditions, and which are then quickly erected in a variety of sophisticated ways. The deck is very economical in terms of materials due to the excellent eccentric load distribution and section efficiency of the box, and thus at large sites, precast segmental schemes should deliver some of the most competitive construction costs.

Formwork/Falsework Costs - Cranes

Typical production rates – 2-4 segments crane-erected per day plus 2 days per pier segment, i.e. 1-2 weeks per span, i.e. about 30m per week.

Table 12a shows the breakdown of deck costs for 600m, 1,200m and 5,000m deck lengths with 50m spans.

Deck length (m) = 600m

- Formwork/falsework rate per total formwork area (£/m^2) = 120
- Total deck rate per total deck plan area (£/m^2) = 510

Deck length (m) = 1,200m

- Formwork/falsework rate per total formwork area (£/m^2) = 90
- Total deck rate per total deck plan area (£/m^2) = 460

Deck length (m) = 5,000m

- Formwork/falsework rate per total formwork area (£/m^2) = 80
- Total deck rate per total deck plan area (£/m^2) = 430

Formwork/Falsework Costs - Gantries

(allowing for the cost of the gantry)

Typical production rates – 4-6 segments gantry-erected per day plus 2 days per pier segment, i.e. 1 week per span, i.e. about 50m per week.

Table 12b shows the breakdown of deck costs for 1,200m and 5,000m deck lengths with 50m spans.

Deck length (m) = 1,200m

- Formwork/falsework rate per total formwork area (£/m^2) = 110
- Total deck rate per total deck plan area (£/m^2) = 500

Deck length (m) = 5,000m

- Formwork/falsework rate per total formwork area (£/m^2) = 80
- Total deck rate per total deck plan area (£/m^2) = 430

Commentary on total deck rates and typical formwork/falsework rates

Once spans are over 40-50m, one of the box solutions will be required, which rules out the various slab, rib and beam solutions. However, given the caveat that this assessment has only considered the assumed aspects of this guide though, i.e. it has used medium spans of 50m, a 15m constant deck width and has taken the deck to be 6m clear from good ground with good access for cranes, we can see that precast segmental construction is only really competitive with deck lengths over about 1,200m, as expected. However, with crane-erected deck lengths from 600-1,200m, where scaffolding or launching are not possible or feasible, it can still be competitive with in-situ balanced cantilevering or in-situ boxes cast on gantries, especially if the deck alignment is particularly complex.

3.8 Whole Span Precast Bridges

Summary	Precast boxes erected span by span with gantries or marine shear legs
Key deck features	Min. depth of 2m; min. deck area of 50,000m^2 or length of 5km; straight spans; good aesthetic
Typical spans	30-60m
Best method for	Medium spans at any very long site with poor access; often used over long sea crossings
Typical production rate	100m/week
Typical formwork/ falsework costs	~ £60/m^2

Description

These bridges use precast whole span boxes, cast in a factory on site, and erected by gantry or marine shear legs. They are ideal for medium spans, typically from 30-60m, and are effectively a special form of precast segmental construction. As they are commonly simply-supported, span to depth ratios for highway bridges are typically 16-18. This system is an excellent solution for the very longest schemes, with deck areas more than 50-100,000m^2, i.e. bridges at least 5km long, ideally 10-20km long. They are best suited to new railway lines or marine causeways, where the scale of the project can justify the huge investments required and where the very fastest production rates are needed.

The sizing of the box section is as described above for the precast segmental system (Figure 56). Most of the casting, transportation and erection issues noted for the precast segmental method also apply to whole span units, except that typical units weigh 600-2,000t, not 50-100t! The span units are usually straight and of constant width, to suit the minimal curvatures on these linear crossings. Steel moulds are used to cast the whole span, generally in one single pour. Alternatively, the bottom slab and webs can be cast first followed by the top slab. Either way, a whole span can usually be cast every two days. Many moulds might be required, needing a massive casting yard, shed and storage area next to the site. Although post-tensioning is the most common technique, it is also possible to pre-tension the unit in the factory and to then apply further post-tensioning once the unit has been put into storage or erected. Gantries in the casting area are used to take the units out of the mould and into storage, and the units are then usually taken along the completed bridge deck on wheeled bogies or rail systems. Alternatively, the precast units can be slid or lifted on to marine barges, for transport by water to the sea/river crossing locations. Erection of the whole span is then carried out by a sophisticated overhead gantry (Figure 73), massive marine shear legs or by using tidal actions to lower the units from marine barges down on to the piers. Gantries might weigh 200-400t in order to lift the 600-2,000t whole span units.

Figure 73: Taiwan HSRL Viaducts - whole span precast gantry.

Typically, a span is erected every 1-2 days, giving production rates of at least 100m/week, which is the fastest achievable by any method. The spans can be left simply-supported, though it is common with highway schemes to create some continuity in the top slab, while still keeping the main box determinate. 4-8 spans can be joined together in this way, thus eliminating joints and providing a better running surface.

The use of whole span precast units, which have been produced in controlled, factory conditions, and which are then erected extremely quickly, should deliver the most competitive construction costs at the very longest bridge sites.

Formwork/Falsework Costs - Gantries

(allowing for the cost of the gantry)

Typical production rates – 1 span gantry-erected per 1-2 days, i.e. 2-3 spans per week, i.e. about 100m per week.

Table 13 shows the breakdown of deck costs for a 5,000m deck length with 40m spans.

Deck length (m) = 5,000m

- Formwork/falsework rate per total formwork area (£/m^2) = 60
- Total deck rate per total deck plan area (£/m^2) = 340

Commentary on total deck rates and typical formwork/falsework rates

Once spans are over 40-50m, one of the box solutions will be required, which rules out the various slab, rib and beam solutions. However, given the caveat that this assessment has only considered the assumed aspects of this guide, i.e. it has used medium spans of 40m, a 15m constant deck width and has taken the deck to be 6m clear from good ground, we can see that the whole span precast system is one of the best options for very long decks, but really needs decks well over 5km long, which are only seen in the rarest of cases.

3.9 Incrementally Launched Bridges

Summary	Box cross-sections cast on site and launched into place using launching noses and jacks
Key deck features	Min. depth of 2m; min. deck area of 5,000m^2 or length of 300m; needs constant alignment and depth; good aesthetic
Typical spans	30-80m
Best method for	Medium spans at any constant curvature site with poor access; often used over valleys or water
Typical production rate	25m/week
Typical formwork/ falsework costs	£70-150/m^2

Description

These box bridges are generally cast on site behind one of the abutments, and are then pushed or pulled out into their final position. They are ideal for constant depth, medium spans, typically 30-80m, which are straight or have a constant curvature, in both plan and elevation. Span to depth ratios for highway bridges are typically 15-18 in order to control the amount of prestressing needed during the launching, although the use of midspan props can allow much shallower decks also to be launched. Bridges should be at least 300m long with deck areas of at least 5,000m^2, and maximum lengths of over 1,000m are possible. The aesthetics are good, especially when inclined webs are also used, and these bridges are best suited to any linear site where the cost of traditional falsework would be prohibitive (Figures 2a, 2b & 6). They are often used for high-speed railways, where the constant curvature and slightly deeper section depths are well-suited to the requirements of the track.

The sizing of the box is as described previously for in-situ boxes (Figure 56), but the web thickness is kept to at least 400mm, as every section will experience high shears during the launch. The section is again best developed as a single-cell box (for widths up to about 20m), but the webs should be positioned so that their centroidal intersection with the bottom slab is directly above the temporary bearing locations, to ensure there are no moments in the section during the launch. Further details are shown in CBDG CPS 13[53] and TP 9[52]. The typical span for launching is 40-50m, with maximum spans of about 80m, although such spans will need temporary props during the launch. The main series of spans should, wherever possible, be of equal length. By definition, an incrementally launched bridge must always be of constant depth, and must have an alignment that is straight or of constant curvature, in both plan and elevation. Ideally, the deck should also be of constant width, although some minor variations in depth or width are possible at the ends of the bridge. The length of each unit to be cast is chosen to suit the particular span arrangement, i.e. by using either half or third span lengths, with the main construction joints ideally placed away from the points of maximum moment. Typically, each 15-30m long unit is poured in 2-3 phases on a weekly cycle, although it is possible to cast whole 40-50m spans on a two-weekly cycle (Figure 42). In either case, the typical production rates are about 25m/week.

Plywood formwork could be used for smaller decks, but over about 5,000m^2, steel moulds should be used. Generally, the bottom slab and webs are cast first followed by the top slab. The typical weekly casting cycle begins on Monday with the stressing and launching of the unit, followed on the Tuesday and Wednesday with the fixing and casting of the bottom slab and webs, followed on the Thursday and Friday with the fixing and casting of the top slab. The unit is then cured over the weekend ready for stressing again the following Monday. The casting area can be covered for weather protection and should be serviced by a tower or gantry crane. The foundations for the casting area would generally be piled, as they need to be rigid enough to show virtually no movement during casting.

Runway beams generally sit beneath each web of the box and these must be cast to exactly the correct line and level. This alignment control is vital in that once the unit is cast, its shape cannot be changed. It is not possible to include any precambers for the bridge, but this is not important for these relatively deep, medium span prestressed structures. The casting process is also run as a production line, with most activities taken off the critical path to guarantee the weekly cycle. The reinforcement is pre-assembled in jigs that match the mould dimensions, and the prefabricated cage, including all prestressing cable ducts, deviators and anchorages, is then lifted into the mould as a single piece, or a series of large pieces (Figure 37).

In order to limit the moments in the deck during the launch, a nose is attached to the front of the bridge. This usually consists of a twin-plate girder with a length of about 70% of a typical construction span (Figures 39 & 50). It typically weighs 50-75t and should be attached to the front of the deck with prestressing bars that lap back in to the launching prestress. Spans longer than about 60m should be propped during the launch to avoid excessive launching prestress. The bridge slides over temporary launching bearings both in the casting area and at every pier, and the total weight being launched can be 4,000-40,000t, which will require longitudinal forces of 200-2,000t, depending on the deck gradients. The deck can be pulled forward using prestressing strands or pushed forward with long-stroke jacks (Figure 74), or using lift-and-push jacks. As each section of the deck passes over every location, there are full moment reversals almost everywhere in the bridge, and the launching prestress is thus installed as a central force, having only an axial stress. This launching prestress is generally kept in place for the long-term, but is augmented by further continuity prestress once the launch is completed. The rates of prestress are therefore higher than with normal boxes, due to this relatively inefficient launching prestress. A range of different post-tensioning options can be used, with both internal and external cables. The classic post-tensioning solution is to use small internal prestress for the launching cables and larger internal (or external) prestress for the continuity cables. Alternatively, external cables could be used throughout, allowing the use of partial prestressing. This option offers significant savings in the prestressing tonnage, while only increasing the reinforcement tonnage by a modest amount – effectively, the passive longitudinal reinforcement in the deck becomes active and is used structurally. The extreme version of this scenario is to launch the deck over temporary props as a reinforced concrete structure and to then install the external prestressing from end to end on completion of the launch – this technique has been used successfully on two major launched bridges in Ireland (Figures 2a, 2b & 6).

Incrementally launched bridges, using units that have been produced on a regular cycle in controlled, factory-like conditions, are slid into place with no traditional falsework. The deck is economical in terms of materials, and thus at sites with a suitable alignment, launched bridges should deliver very competitive construction costs.

Figure 74: Clackmannanshire Bridge - pushing jacks.

Formwork/Falsework Costs - Launching

(allowing for the cost of the launching equipment)

Typical production rates – 1-3 weeks per span, i.e. about 25m per week.

Table 14 shows the breakdown of deck costs for 150m, 600m and 1,200m deck lengths with 40m spans.

Deck length (m) = 150m

- Formwork/falsework rate per total formwork area (£/m^2) = 270
- Total deck rate per total deck plan area (£/m^2) = 850
- The 150m deck length shown here is too short for incremental launching, but is shown for completion of the charts and figures, allowing some interpolation of the results.

Deck length (m) = 600m

- Formwork/falsework rate per total formwork area (£/m^2) = 100
- Total deck rate per total deck plan area (£/m^2) = 460

Deck length (m) = 1,200m

- Formwork/falsework rate per total formwork area (£/m^2) = 70
- Total deck rate per total deck plan area (£/m^2) = 390

Commentary on total deck rates and typical formwork/falsework rates

Once spans are over 40-50m, one of the box solutions will be required, which rules out the various slab, rib and beam solutions. However, given the caveat that this assessment has only considered the assumed aspects of this guide, i.e. it has used medium spans of 40m, a 15m constant deck width and has taken the deck to be 6m clear from good ground, we can see that with deck lengths over about 600m incremental launching should be used wherever the deck alignment is suitable. For shorter deck lengths, in-situ boxes on scaffolding are clearly the best option (although scaffolding may not always be possible or may become less cost effective as piers get taller or the ground conditions get worse), but launching is still competitive (although launching does not start being truly competitive until deck lengths are over about 300m).

3.10 Modular Precast Bridges

Summary	Standard, simple precast shells, infilled with in-situ concrete and erected span by span with falsework or by launching
Key deck features	Flexible solution for any site; slightly deeper sections; any alignment; simple aesthetic
Typical spans	15-50m
Best method for	Small to medium spans with good access; any regular alignment site once launching is used
Typical production rate	15m/week on scaffold/beams; 20m/week launched
Typical formwork/ falsework costs	£60-90/m^2

Description

These modular precast bridges were developed by Benaim for the CBDG in order to create a solution that could be used at any site with small to medium spans, typically 15-50m. They are essentially an in-situ twin rib deck cast inside structurally participating, precast shell formwork. They have span to depth ratios of 14-18 and can be erected by several methods. This system takes the best features of in-situ and precast segmental construction, without using box sections or needing to make considerable investments in casting and erection equipment. The actual investments would be amortised over several projects, thus making the solution viable for any bridge, even with a single span – in the same way that precast beams can be used at any small site. Further details of this innovative method can be seen in CBDG TG 11[54] and CBDG TP 9[52].

The solution was developed into a modular system to suit any site from the use of similar precast shells on two recent bridges in Ireland – an innovative solution using well-proven construction technologies. The system consists of 2-3m long precast U-shells, cast in factories off site, that are 4-6m wide and 1-3m deep, allowing a whole range of lengths, spans, widths and alignments to be accommodated (Figures 75 & 76). Transverse stitches in the top slab then allow each shell unit to be connected to its adjacent unit – forming a precast twin rib section. Permanent post-tensioning cables are then placed inside the shells and an in-situ concrete core is cast to complete the rib (Figures 45 and 77). As the cables sit within continuous ducts within the in-situ concrete core, the full three-layer protection required under TR 72[25] is provided. The system was initially developed using match-cast units, but it can also be used with non-match-cast units, which are easier to cast in a less complex mould. The thin joints between the shells are then sealed, with the majority of the section still consisting of solid, monolithic concrete, which is post-tensioned and fully participating in the structural performance. Simple steel moulds are used to form the precast U-shells, which also have a central transverse rib for stability and temporary prestressing. The shells weigh 10-20t and are easily transported to site for assembly. The construction methods can be varied to suit specific bridges sites and demands of the project programme, but suggested methods include piecemeal erection on scaffold/beams or gantries, or launching, or lifting of whole pre-assembled ribs using cranes (the *span-lift* method), all of which produce typical production rates of 15-20m/week. The whole system can also be made fully integral with bankseat abutments and fully monolithic with intermediate piers. A railway version is also available, which for the typical spans seen in most UK situations (10-15m weighing 100-200t) can be slid, or lifted into place with large mobile cranes or transporters.

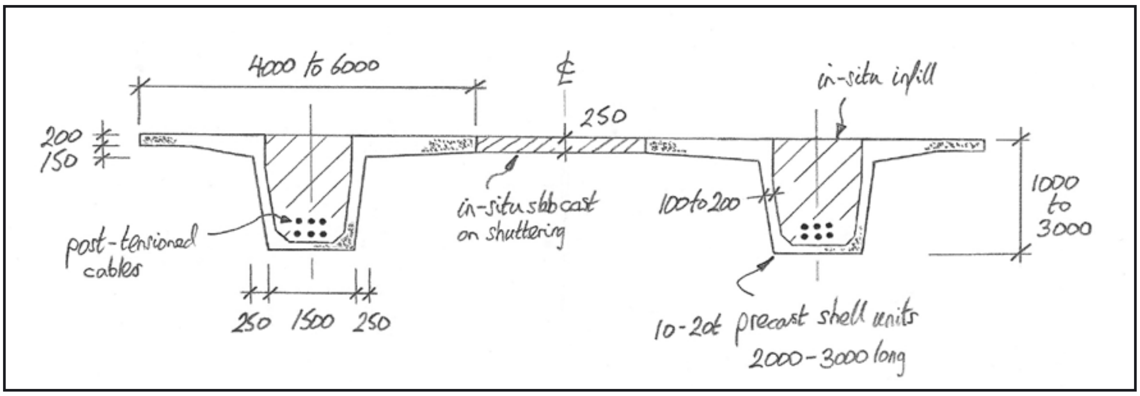

Figure 75: Modular precast section.

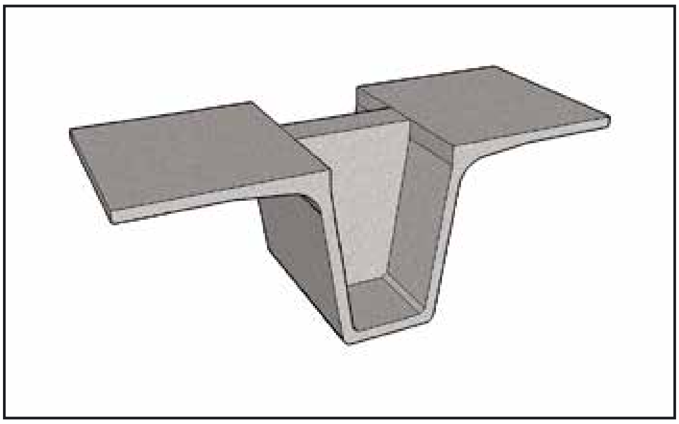

Figure 76: Modular precast shell unit.

This new system therefore provides an elegant and robust solution using low maintenance precast shells cast in a factory environment, and the simple section of the deck makes concreting easy. Once a good erection method is selected, modular bridges have low construction costs at any site, depending on the degree of access and temporary works.

Figure 77: Completed modular precast bridge.

Formwork/Falsework Costs – Scaffold/Beams

Typical production rates – 1-3 weeks per span for scaffold/beam erection, i.e. about 15m per week.

Table 15a shows the breakdown of deck costs for 50m, 150m and 600m deck lengths with 30m spans.

It can be seen that this scaffolding solution is comparable to casting an in-situ twin rib on scaffolding – there is a smaller area of scaffold support needed and the precast shell units are easier to form and cast in a yard than casting the whole twin rib section on site, but some further craneage is needed, with cranes in the casting yard and on site.

Deck length (m) = 50m

- Formwork/falsework rate per total formwork area (£/m^2) = 70
- Total deck rate per total deck plan area (£/m^2) = 440

Deck length (m) = 150m

- Formwork/falsework rate per total formwork area (£/m^2) = 60
- Total deck rate per total deck plan area (£/m^2) = 420

Deck length (m) = 600m

- Formwork/falsework rate per total formwork area (£/m^2) = 60
- Total deck rate per total deck plan area (£/m^2) = 410

Formwork/Falsework Costs – Launched

(allowing for the cost of the launching equipment)

Typical production rates – 1-2 weeks per span for launching, i.e. about 20m per week.

Table 15b shows the breakdown of deck costs for 50m, 150m and 600m deck lengths with 30m spans.

It can be seen that this launching solution is more economical than the comparable incremental launching of the whole section – there is a smaller and less rigid launching area needed and the precast shell units are easier to form and cast in a yard than casting sections of the twin rib on site, although some further craneage is needed, with cranes in the casting yard and on site. A similar amount of launching nose (and/or temporary props) is needed in either case.

Deck length (m) = 50m

- Formwork/falsework rate per total formwork area (£/m^2) = 90
- Total deck rate per total deck plan area (£/m^2) = 480

Deck length (m) = 150m

- Formwork/falsework rate per total formwork area (£/m^2) = 70
- Total deck rate per total deck plan area (£/m^2) = 430

Deck length (m) = 600m

- Formwork/falsework rate per total formwork area (£/m^2) = 60
- Total deck rate per total deck plan area (£/m^2) = 400

Commentary on total deck rates and typical formwork/falsework rates

Given the caveat that this assessment has only considered the assumed aspects of this guide, i.e. it has used short spans of 30m, a 15m constant deck width and has taken the deck to be 6m clear from good ground with good access, we can see that the CBDG's modular precast system should be very competitive.

Erection on scaffolding should be used where possible, but in all other cases, the bridge is also competitive as a launched system, as long as the alignment of the deck suits launching. The modular system has been based on two precast shell schemes used in Ireland, but has not yet been used in the UK. It can be seen that the modular system is very comparable to the in-situ twin ribs for decks shorter than about 300m – this fact is not surprising, as it was developed to fill this gap and is effectively a part-precast version of the in-situ twin rib. With further use, confidence should grow in the system, allowing it to become more common, although spans only go up to 40-50m. The costs are all calculated in the same way as precast beam schemes, i.e. with casting yard, mould and launching costs, where appropriate, amortised over several projects. A *span-lift* version of the system has also been developed, although it has not been assessed in this guide. This solution is very comparable to the erection of large precast U beams and further details of this method can be seen in CBDG TG 11[54].

3.11 Arches and Frames

Summary	Concrete arches and frames using the best attributes of concrete in compression
Key deck features	Thin arch sections supporting soil loads or concrete decks; flexible solution for many sites; calm aesthetic
Typical spans	5-25m for standard arches; 50-400m for bespoke arches
Best method for	Underground sites with good access for standard arches; any large crossings for bespoke arches and frames

Description

Arch solutions cover a wide range of spans from the very small (5m) to the very largest (over 400m). They can conveniently split into two types – the standard precast arches (or portals) that can span up to 25m and the bespoke arches (which may be in-situ or precast) that can span anywhere up to 400m, or more, but which are generally used in the 80-200m range. The CBDG Technical Guide No. 5 on fast construction also gives general guidance on many of these bridge types[30].

Standard Precast Arches

The choice of standard precast arches tends to suit single earth-retaining spans of 5-25m (Figure 78). Arches are very efficient structures that carry the traffic and fill loads to the foundations with little effort by primarily using axial compressions in the arch. Great care is needed in their actual design though, and in the backfilling/compaction methods that are used, to avoid any excessive bending moments in the arch. Typically for these earth-retaining structures, the span/rise ratios are 2-3, but can vary from 1 to 4 depending on the amount of overburden being supported, with around 500mm being the normal minimum level of cover. Span/thickness ratios are 25-50, giving arch thicknesses of 200-400mm. The structures are quite flexible in relation to the ground and therefore tend to be designed using soil springs to represent the appropriate ground movements, subject to non-linear behaviour close to the active and passive horizontal earth pressure limits (K_a and K_p). Arches often also have a lower curvature around the crown (where the pressures are less) and a higher curvature towards the springings (where the earth pressures are more) – this also creates an intrados profile that better suits the required clearances.

These arches are generally cast off site in precast factories, from where they are then transported to site. They can also be cast on site though, enabling sections to be chosen that exactly match the requirements of the location. In this case, simple steel moulds would be required on site, together with suitable storage facilities. The precast units will usually be made from solid concrete sections, 2-4m wide, and they would be erected using two, three or four elements to form either 2-pin or 3-pin arches. Each pin has a male/female concrete socket detail, specially designed to resist the high stress concentrations at the bearing points – the detailing of these areas is similar to the areas around prestressing anchorages. The units weigh 10-35t, allowing them to be simply erected by crane, or pairs of cranes (Figure 79). No temporary works are generally needed as most types of arch system are designed and manufactured as stable structures. However, there are other types that can be supported by cranes throughout, or are designed to rest against each other in the short term. With some types of arch, the units may be stitched with in-situ concrete at a later stage, often at the crown, either to provide continuity, a simple restraint at the joint or to mitigate the impact of shallow overburden. Using these methods, 20-40 units can be installed during a working day, which is a very fast erection rate – this equates to 100-200m per week, plus several weeks to cast any in-situ stitches. Once waterproofing is applied to the joints and the external surface, the backfilling can be installed. This is applied gradually so that both sides of the arch are backfilled evenly to avoid any sway effects, and areas close to the arch itself are protected by being compacted only by hand-operated, non-vibratory plant. Portal solutions are also available in a very similar format to the arches, though they tend to have a much more rectangular intrados, enabling even better clearance profiles to be achieved for railway or highway crossings. There is also an innovative precast concrete block system (developed by Macrete and Queen's University[55]) that is delivered flat to site, but once lifted into place it takes the form of the required arch, and can span 3-15m. A polymeric fabric is fixed against all the voussoirs of the arch, holding all the blocks in position. There is no other reinforcement, making it an extremely durable solution – a return to the traditional un-reinforced arches that have survived for centuries, but this new system is built without any centring.

Figure 78: Maryville Railway Bridge - standard precast arch.

Overall, precast arch units are produced on a regular cycle in controlled, factory conditions and can be erected in an efficient manner, as long as there is good access for craneage. River crossings, highway and railway bridges, as well as pedestrian underpasses, waterway, vehicle and rail tunnels can all be built successfully using this very simple form of construction. Arches also have a very calm aesthetic, which is widely liked by the general public. Further details can be seen in CBDG CPS 8[56] and CBDG TG 12[57].

Figure 79: Cahir Railway Bridge - precast arch unit erection.

Bespoke Arches

Away from earth-retaining structures, longer span bridges can be supported on discrete arches. These bespoke arch structures are often tailored to suit particular sites that involve a large single span, often in a cutting, and good foundations, though they can also be used in many other locations. As for the precast arches, the arch is a very efficient structural member carrying much of the load in direct compression and thus ideally suited to be constructed in concrete. These concrete arch spans tend to start at around 50m and can be used successfully up to around 400m, with the current world record sitting at 420m. These bridges carry the highway or railway traffic on separate decks, which can be above the arch (supported on columns as in Figure 80), below the arch (supported by hangers), or a combination of these two systems. With the deck below the arch, the arch thrust can be resisted by the deck in tension, creating the tied arch.

The aesthetics of the arch are quite complex and great care is needed to ensure the right balance between the depth of the deck and the depth of the arch, both of which intimately affect the distribution of forces in the system. Generally, it would be best visually to avoid having deck and arch depths that are too similar, i.e. any moments in the system (caused by asymmetric or concentrated traffic loads) should primarily be carried by either the arch or the deck, not by both – the symmetric and uniformly distributed self-weight and traffic loads are mainly carried by the simple thrust of the arch. The junction between the arch and deck also needs very careful design and detailing, and well-designed details, such as those shown on Maillart's work (Figure 4), can be truly stunning. Various construction methods can be used to form the arch, but the decks, which are generally supported by the arch at regular intervals and thus have shorter spans (of 10-40m), tend to be beam structures, such as in-situ slabs or twin ribs, precast beams, precast segmental or incrementally launched boxes, all of which were described earlier.

Figure 80: Bloukrans Bridge - 272m main span.

Typically for these bespoke arched structures, the span/rise ratios are about 6-8, but can vary from 4 to 12, whereas the span/thickness ratios are 40-100, giving thicknesses of 1-5m. As was seen with prestressing, these deeper arches are best formed as box sections, as the section becomes more efficient under the axial arch compressions as more material is removed from the centre of the member. These larger arches are usually built as fixed-end structures, without any pins, making them more rigid and easier to build. However, shortening of the arch under elastic deformations, creep, shrinkage and temperature effects causes the arch crown to drop, which then generates sagging moments at midspan and hogging moments at the springings. These moments are minimised by using as thin an arch as possible. This shortening of the arch is the main reason to avoid the arch being too flat, as once the span/rise ratio is greater than about 12, its length becomes very close to the chord length, and thus much more sensitive to this shortening. Buckling of the arch also needs to be considered, both in-plane and out-of-plane, but in both cases, the deck provides additional stability, requiring the whole system to be analysed.

Modern casting and erection methods can now be used to form these arches, instead of the classical (and expensive) centring methods used historically. Such techniques include balanced cantilevering with cable-stays using in-situ or precast segments (Figure 81), or casting the arch vertically above the abutment (in a similar way to slipforming) and rotating the arch downwards, or casting the arch horizontally above the abutment (on the ground) and rotating it sideways in plan. Both of these latter two techniques would also need support from temporary towers and cable-stays.

Figure 81: Sungai Dinding Bridge - balanced cantilever erection.

Figure 82: River Tyne Bridge with framed legs.

Frame Bridges

Whereas beam bridges mainly carry the loads in bending and arch bridges mainly carry the loads in compression, frame bridges can be seen as a intermediate position, with major loads carried in both bending and compression. So, whereas an arch might have a curved (ideally parabolic) intrados, a frame structure will have a clearly pronounced polygonal intrados, formed from the legs and the deck. Because of these similarities, frame bridges are often used in locations where both beam bridges and arch bridges might be appropriate. As with the longer arches described in the last section, frame bridges are frequently tailored to suit particular sites that involve a large single span, or where the aesthetics are particularly awkward, due to the peculiarities of the site (Figure 82). Due to these constraints, frame bridges will generally be cast in-situ, as precasting might not suit the variations in deck and leg section that could be needed. Casting would therefore tend to take place on scaffolding or on other falseworks, such as sets of beams/girders resting on temporary towers. They can also be built over the land, in the same way as arches, and then rotated horizontally into position – Ove Arup's famous Kingsgate Footbridge in Durham was built in this manner.

3.12 Tunnels, Jacked Portal and Box Bridges

Summary	Concrete culverts, tunnels and boxes using the best attributes of concrete underground
Key deck features	Simple box sections supporting soil loads; flexible solution for many sites
Typical spans	1-30m
Best method for	Small underground spans

Description

Tunnel and box solutions cover a wide range of underground structures including culverts, cut-and-cover tunnels and boxes that are slid or jacked into place. The CBDG Technical Guide No. 5 on fast construction also gives general guidance on many of these bridge types[30].

Tunnels

Tunnel solutions cover spans from 1-2m up to 20-30m. As with arches, they can conveniently split into two types – the standard precast tunnel (or box culvert unit) that can span up to about 6m and the bespoke cut-and-cover tunnels that can be up to 50m wide, with intermediate walls.

Figure 83: Standard precast culvert units.

Standard precast box culverts are best suited to single earth-retaining spans, with spans of 1-6m (Figure 83). As earth-retaining box structures, the span/depth ratios are typically 10-15, giving wall and slab thicknesses of 200-500mm. The structures are quite stiff in relation to the ground and therefore tend to be designed using *at rest* horizontal earth pressures, K_o. Box culverts are cast off site as 2-4m long units and are then transported to site, where the 10-35t units are crane erected. Once the units are all positioned next to each other, waterproofing is applied to the joints and the external surface, and the backfilling can then be placed. These standard precast units, which are left as jointed structures, are ideal for small waterways, pedestrian underpasses or small vehicle access roads.

Box culverts are a smaller example of the larger cut-and-cover tunnels, which are all generally cast in-situ. The design of these cut-and-cover structures is dominated by the geotechnical considerations and the precise methods of construction. As much of this information is well documented elsewhere[58 & 59], only the basic structural parameters will be described here. With these larger spans, the effects of the earth and water pressures are much more dominant and due care should be taken of the soil-structure interaction, and how the flexibility of the structure affects the possible range of earth pressures. Flotation of the whole structure will also often become an issue and measures will need to be taken to prevent any upward movements. These measures might include the provision of sufficient levels of overburden, positive means to optimise the side friction, or tension capacity from the side walls or other forms of vertical piling.

The simplest method to construct any underground tunnel is to build it in open cut. Such box structures are simply cast in-situ on the ground and are then backfilled on completion. The base slab is cast first, followed by the walls and finally the roof slab. The roof slab will be cast using scaffolding or proprietary formwork systems that allow the rapid movement of each shutter panel after the concrete has gained sufficient strength. Panel lengths are often chosen to suit standard reinforcement bar lengths and arrangements, and thus will often be around 11m long. Care needs to be taken with heat of hydration and shrinkage cracking between adjacent pours, and the overall water-tightness of the box is then completed with the addition of waterproofing at the joints and on the external surface.

Figure 84: Singapore Central Expressway - bottom-up construction.

If open cut is not possible, then the next best method is to build the tunnel *bottom-up* within a temporary cofferdam (Figure 84). The cofferdam, which can be formed from sheet piles or bored piles, creates a hole within which the tunnel box can be built in exactly the same way as with the open cut method described above. The cofferdam will almost certainly need to be propped (or anchored back) during the works to carry all the horizontal pressures until the permanent box is completed. In urban or restricted sites, it will be necessary to build the tunnel *top-down*, as this method is significantly stiffer than *bottom-up* construction, in order to limit the settlement of any adjacent properties. In this case, bored pile or diaphragm walls are installed first, and the deck or roof slab is then cast on the ground. Although the excavation that then follows is more expensive in the more confined space, it does allow the excavation to proceed with much greater control of the adjacent ground movements. Some temporary propping of the walls might also still be needed. The tunnel box is then formed from the deck or roof slab, the piled walls and the base slab. In some cases where the water pressures are controlled and/or the piled side walls are extended to a deeper level, the structural base slab might be omitted or simply replaced with a propping slab. This situation could also apply to a bridge deck cast on the ground (Figures 85a and 85b).

Figure 85a: A350 Canal Aqueduct - top-down construction.

Figure 85b: A350 Canal Aqueduct - completed.

Each of these bespoke tunnels is designed to suit the particular geotechnics of the site and thus it is not really possible to quote any general guidance rules, except that walls and slabs tend to have quite small span to depth ratios, of 10-15, which produces roof and base slabs that can be 0.5-2.5m deep and walls that can be 0.5-1.5m thick. With larger spans, it also becomes economic to haunch the roof and base slabs, in the areas where the slabs intersect the supporting walls (as can be seen in Figure 84).

Jacked Portal and Box Bridges

This section describes the special cases where portal or tunnel box bridges are either slid or rolled into place. Typical spans of such structures are up to about 25m. Where an existing bridge needs to be replaced or a new bridge is to be installed under live traffic, it is increasingly desirable to limit the disruption to the existing road or railway by building the new structure alongside. A short but large disruption can often be more preferable than a long series of minor disruptions. The traffic management in the area can be greatly improved by avoiding the phased or piecemeal construction of traditional replacement operations. The temporary support of services during the sliding operation also becomes more feasible, with a potential reduction in the need to divert or move services. Although these options may appear to more expensive, the greater degree of programme certainty and the reduced level of risk, as well as the unhindered deck construction, will often make these solutions faster, and therefore more economic. They may be the only possible solutions in the railway environment.

Concrete portal or box structures are then built in an adjacent casting area. In a single road or rail closure, over a weekend for example, any existing bridge is slid or lifted away to allow its demolition off the critical path. Alternatively for new bridges, the embankment is partially removed during this long possession period. Either way, the new structure is then slid or rolled into place during this possession, generally on slide tracks that have been previously installed underneath the embankment in pre-bored mini-tunnels. The new deck can be either pulled into place using strand jacks, or pushed into its final position with long-stroke jacks. In a similar manner, large wheeled transporters (self-propelled modular transporters - SPMT) can be used to move complete portals or decks, or full span units, from adjacent casting areas to prepared substructure locations. Whole spans or decks, weighing up to several thousand tonnes, can be cast away from the site, transported and then installed in very large pieces. In the case of rail bridges, they can be complete with ballast and rails. Redundant bridge spans can also be lifted off their supports by the SPMT and transported for demolition away from the site.

In the most special cases, jacked concrete boxes can also be slid or jacked beneath embankments, obviating the need to close the railway or highway above at any stage (Figure 86). These boxes are also formed in adjacent casting areas and are then pushed into the embankment using jacking points in the casting area. A steel or concrete shield is used to support the advancing front face beneath the embankment. The frictional load on the box can be limited by either the use of proprietary anti-drag systems, or by the prior installation of a steelwork grillage that supports the traffic above. See CBDG CPS 14[60] for further details.

All these jacking techniques use the advantage of unhindered deck casting away from the critical locations, followed by a concentrated burst of erection activity. These solutions would all be developed to speed up the construction process and to minimise disruption at the most sensitive bridge sites.

Figure 86: A43 Bridge under the M1 - completed jacked box.

3.13 Cable-Stayed Bridges

Summary	Cable-supported decks built in balanced cantilever
Key deck features	Thin decks; tall, slender towers; almost invisible cables; very dramatic aesthetic
Typical spans	100-600m
Best method for	Longest spans over deep valleys or wide stretches of water

Description

These bridges are used for the longest spans, where bridges need to cross deep valleys or wide stretches of water with significant navigation channels. They are ideal for spans from about 100m up to 1,100m, although the maximum span using a concrete deck is just over 600m. In the range 100-500m, concrete spans are competitive but beyond about 500m, the weight penalty forces most schemes to use steel-composite or steel orthotropic decks. The actual main span is often determined by the best position to locate the towers, which can be affected by the navigation channel, depth of water, geology, the degree of any ship impact and intensity of any seismicity or high winds. Cable-stayed bridges have a very dramatic aesthetic, with relatively thin decks supported by almost invisible cables and discreet towers. By their nature, they are nearly always built in balanced cantilever, where each new extension of the deck is supported by a further set of inclined cable-stays, until the deck tips meet at midspan. The tower height is typically around 1/5 of the main span, compared to about 1/10 for a suspension bridge, i.e. cable-stayed towers are quite tall, but slender. The decks are also quite slender with typical section depths of 1.5-4.0m, which is 1/100-1/150 of the main span.

Figure 87: Mersey Gateway Crossing with central towers.

There are three basic types of tower and cable plane configuration that are widely used. H-frame towers with twin planes of cable-stays provide support right to the edge of the deck, which is good for torsional stability, though not as elegant as some other tower options. This configuration also provides the simplest solution for the deck, with edge beams supported directly by the cable-stays. Concrete cross-girders (usually prestressed) then support the deck slab, which can be made as thin as 200-250mm to keep the overall weight down. A second and more elegant configuration uses a single tower, with an A-frame or inverted Y-frame, but still with twin planes of cable-stays to keep the same simple deck solution (Figures 23 & 46). The third configuration uses a single tower, which penetrates the centre of the deck, and a single plane of cable-stays. This solution requires a central box girder to provide the torsional stability to the deck (Figure 87). All options have towers that are primarily in compression, which makes them ideally suited to being made with concrete. Towers, which can be 30-160m tall, are generally formed from a single box section that can be slip-formed or cast in discrete lifts of 4-6m. Due to the balanced cantilevering effects, the towers have little moment under permanent loads. Traffic loads in the main span are mainly carried by the front stays, over the tower and into the back stays where they react against the piers or the deck weight, which generally produces quite small moments in the towers. The towers can therefore be made quite slender – the more slender they are, the less moment that they attract, of course.

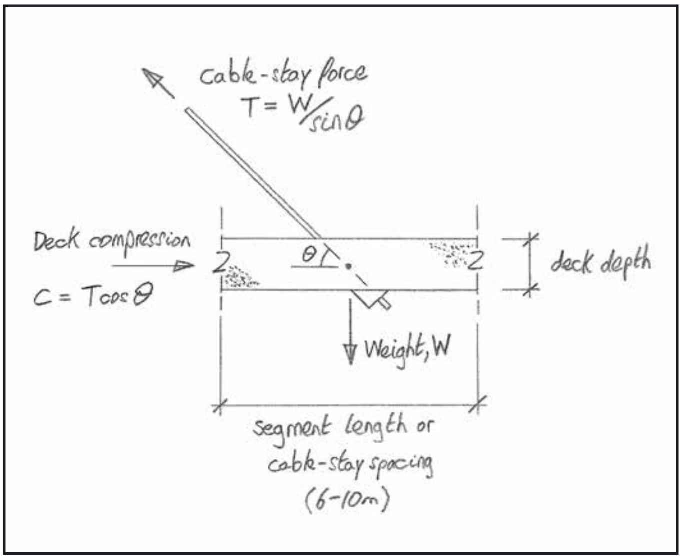

Figure 88: Cable-stay loads.

The cable-stays carry the vast majority of all loads and form the tension component of the overall strut and tie system. There are three types of cable-stay configuration, although only the third system is used widely, as it is considerably more efficient. The harp configuration has all the cable-stays placed at the same angle, θ to the deck, which does have an interesting aesthetic. However, even though the longest cable-stay is as efficient as it can be, the shortest stay, which is closest to the tower, is inefficient as it has too small an angle. There can also be significant moments in the tower. These issues are resolved in the fan configuration, which has all the cable-stay anchorages at the top of the tower, thus maximising θ for every cable-stay. Under self-weight loads, the tension force in each stay is simply the vertical weight of the associated length of deck/sin θ and maximising θ enables the lowest cable-stay force (Figure 88). This determinate situation also ensures that the moments in the deck are close to zero under these loads. In practical terms, it is not possible to anchor all the cable-stays at the top of the tower. A hybrid system is thus produced that has the cable-stays as high up the tower as possible within the constraints of the anchorages – the vast majority of all cable-stayed bridges have this hybrid format (Figure 89).

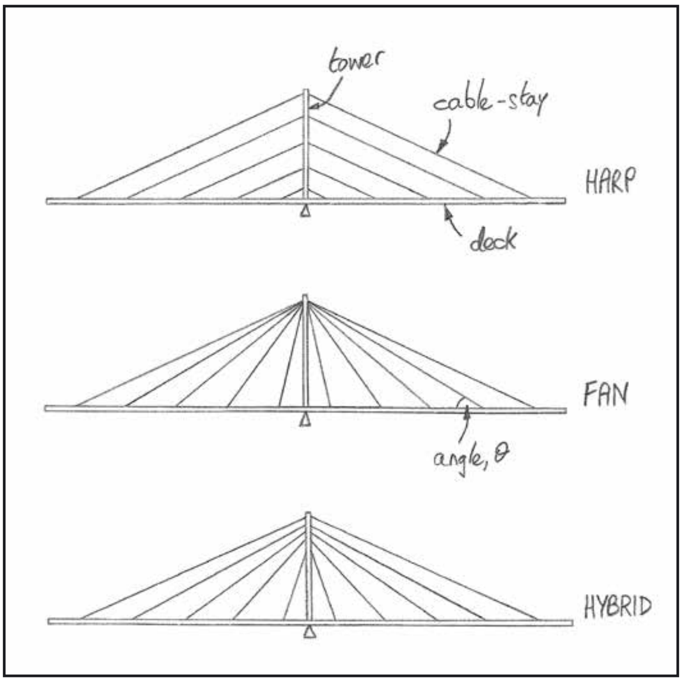

Figure 89: Cable-stay configurations.

As each new deck segment is added in balanced cantilever, the cable-stay size is increased to match the decreasing θ. Cable-stays are typically spaced at 6-10m centres to fit a sensible layout of deck segment lengths during construction. Each cable-stay is generally made from a group of high strength steel strands, which are effectively the same as prestressing cables, using low relaxation superstrands with an f_{pk} of 1,860MN/m^2. Cable-stays can vary from 12/15mm up to 127/15mm. In most codes, the maximum SLS cable stress under permanent and normal traffic loads is 0.45 f_{pk}, which is 840MN/m^2. The maximum stress range (due to traffic load and wind variations) in order to control fatigue is generally 150-200MN/m^2. Even though these cable-stays are very similar to post-tensioning cables, they do have additional features to control fatigue, especially around the anchorages. They also have additional features to ensure their durability over the life of the bridge, with each strand being galvanised and individually sheathed and greased, before being placed within an outer HDPE sheath, which is also then packed with high performance grease or grout. These additional features, along with the costs of erecting the cable-stays, typically make cable-stays about twice the price of post-tensioning cables.

Cable-stays also exhibit non-linear effects in that long cables will sag under their own weight, meaning that their effective stiffness is dependent on the load within the cable. Such effects need to be included in the overall analysis of the system. As noted above, the cable-stays are generally sized such that the deck has no moments under self-weight, i.e. the deck is evenly supported at every cable-stay location, while under traffic loads, the deck acts as a beam on elastic foundation. Influence lines for cable-stay forces and deck moments are the only way to analyse the required loading patterns that generate the peak effects. As the balanced cantilever construction extends towards midspan, the deck builds up a significant compression from the horizontal component of the cable-stay forces. This force is zero at midspan, rising to a peak at the towers. This axial compression is conveniently carried by the concrete deck and is of such a scale that no additional prestressing in the deck is needed close to the towers, as the compression is usually sufficient to overcome any bending moments. Closer to midspan, additional deck post-tensioning is used to keep the deck compressed under all normal loads (Figure 90). Overall, the detailed design is rather complex as it is highly dependent on strains in the non-linear system, due to creep, shrinkage, steel relaxation and temperature, as well as the applied loads and the stage by stage construction process.

At the locations of the cable-stay anchorages, both in the tower and deck, there are significant forces distributed into the section, and the same types of bursting, spalling, equilibrium and following steel should be provided as are used for post-tensioning anchorages – see CBDG TN 10[29]. The construction of the deck segments can use either in-situ or precast units, but the basic principles are exactly the same as have already been described for in-situ and precast segmental balanced cantilevering. The dynamic behaviour of these relatively flexible structures always needs to be carefully assessed, for both traffic and wind, and seismic effects where necessary. Concrete cable-stayed bridges are quite stiff though in both planes and are relatively heavy, and so even though the dynamic effects will be significant for larger spans, they are unlikely to be dominant for smaller spans. Dynamic effects on the cable-stay sheaths also need to be carefully considered to avoid vibrations of the cable, often caused by rain-wind interaction. Good guidance on cable-stayed bridges can be found in the Swiss Federal Institute of Technology book[61].

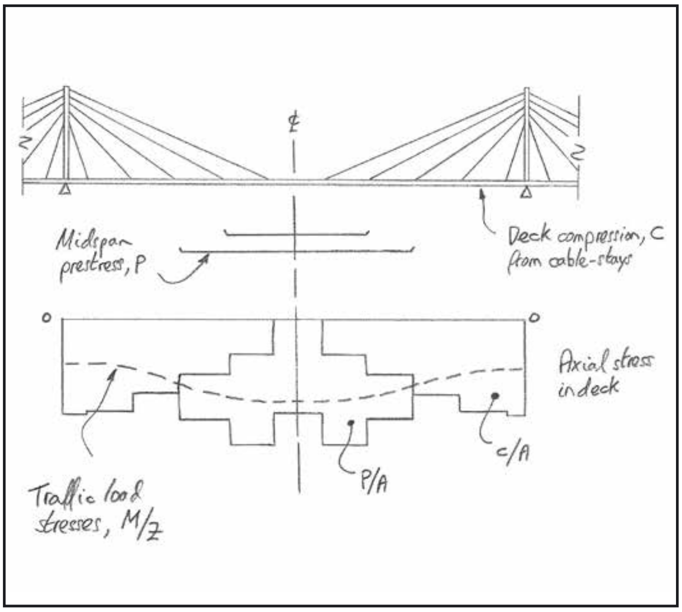

Figure 90: Cable-stay bridge prestressing.

3.14 Extradosed Bridges

Summary	Cable-supported decks built in balanced cantilever
Key deck features	Hybrid between balanced cantilevered and cable-stayed decks with relatively short towers; striking aesthetic
Typical spans	100-300m
Best method for	Long spans over valleys or water

Description

These bridges are hybrid solutions that sit between externally post-tensioned balanced cantilever beams and concrete cable-stayed bridges. They are ideal for spans from about 100m up to 300m. Extradosed bridges can have a striking aesthetic, but great care needs to be taken in the choice of bridge deck depth and tower height in order to create a good sense of proportion (Figure 91). As a hybrid between beam and cable-stayed schemes, they generally have a stiffer deck than a cable-stayed solution and a correspondingly shorter tower. The external prestressing cables from within the deck are effectively taken outside the section at the piers (i.e. the extrados), in order to maximise their eccentricity. However, the cables can also directly support the deck in the same way as a cable-stay. By their nature, extradosed bridges are nearly always built in balanced cantilever. The tower height is typically around 1/10 of the main span, and the decks can be either haunched or constant depth, with typical section depths of 1/15-1/50 of the span at the piers, and 1/30-1/60 at midspan.

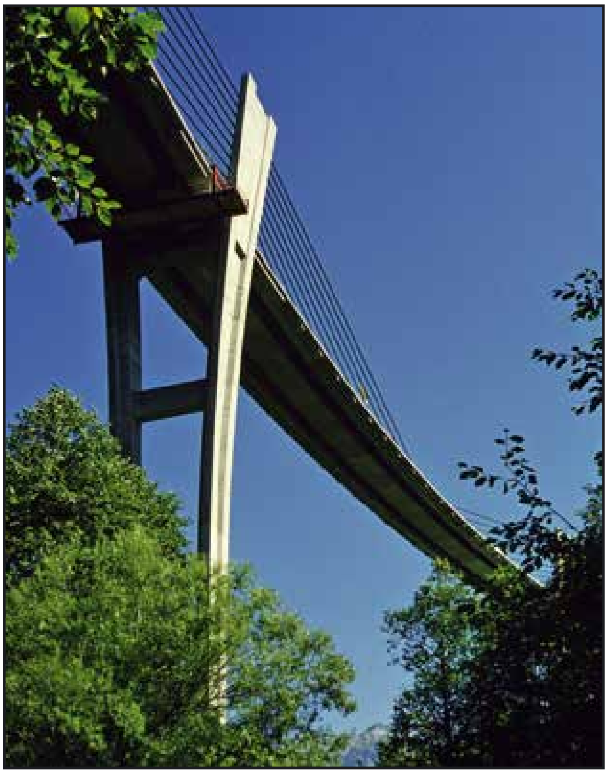

Figure 91: Sunniberg Bridge - beautiful extradosed bridge by Menn.

Typical configurations have twin towers, twin cable planes and edge beams, or a single tower and single plane of extradosed cables arising out of a central torsion box (Figure 92). The main incentive to use extradosed bridges is to incorporate external prestressing technology as opposed to the more expensive cable-stay technology. So, whereas cable-stays have their maximum SLS stress limited to about 0.45 f_{pk} and their range (due to fatigue) limited to 150-200MN/m^2, prestressing cables have a much lower stress range (of less than about 50MN/m^2) and a correspondingly higher maximum SLS stress of 0.60 f_{pk}. If an extradosed bridge therefore behaves similar to a prestressed beam (with a low stress range in the cables), then it can use external prestressing technology. However, as soon as it behaves more like a cable-stayed bridge (with a higher stress range in the cables), then it must use cable-stay technology. There is a transition between these two forms of behaviour, which is not yet covered by codes, but is described in some guides[62] (Figure 93). In all cases, the durability of any cables that are outside the section must be suitable for the life of the bridge. Typically, each strand is individually sheathed and greased, before being placed within an HDPE sheath, which is also filled with high performance grease or grout – it may also be necessary to galvanise the strands. The construction of the deck segments can use either in-situ or precast units. As the deck is often haunched, the first sections of the span are generally built without any cables coming out of the section. Similarly at midspan, the extradosed cables stop, as the shorter tower height makes any cables that come out of the section too shallow, attracting too much load variation. Much of the work on extradosed bridges has been carried out in Japan, where good references can be found[63].

Figure 92: 3rd Karnaphuli Bridge with central extradosed towers.

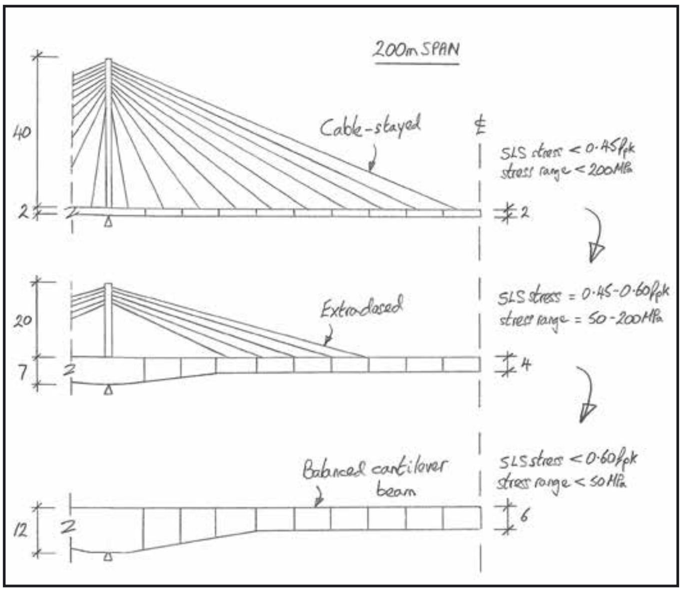

Figure 93: Extradosed bridge transitions for 200m span.

3.15 Stressed Ribbon Bridges

Summary	Thin concrete decks suspended on a stressed catenary
Key deck features	Very thin decks; straight alignment; dramatically simple aesthetic
Typical spans	20-120m
Best method for	Footbridges over deep valleys or water

Description

Concrete stressed ribbon bridges are a particular type of pedestrian suspension bridge with a very flat profile. Typical spans range from 20-120m, but can reach 200m with prestressed steel structures. As they are no more than a flat catenary, they have a beautifully simple aesthetic, ideally suited to both areas of outstanding natural beauty or the urban landscape (Figure 94). Some solutions are just concrete planks sat on steel suspension cables, but the true stressed ribbon has the whole section of concrete walkway fully prestressed by the suspension cables. This makes the ribbon much stiffer, as it is the prestressed concrete that carries the tension in the system, while the prestressing/suspension cables maintain an almost constant force. The typical sag of the catenary is 1/40 to 1/60 of the span, compared to 1/10 for a normal suspension bridge. Stressed ribbons are only suitable for footbridges where the loads are light enough to be accommodated by the shallow profile of the catenary. As the end gradient is about 4 times the sag to span ratio (r), the common pedestrian gradient of 1/12 requires r to be 1/48, which is quite typical. However, where a shallow pedestrian gradient of 1/20 is required for disabled users, r should drop to 1/80 – but, this is too shallow for the catenary, as creep, shrinkage and temperature contraction would almost eliminate the sag, rendering the ribbon incapable of carrying the load without enormous axial forces. 1/20 gradients therefore have to be made by using a raised floor that is supported off the ribbon, which can detract from the overall simplicity.

Figure 94: Kent Messenger Footbridge - stressed ribbon.

In most cases, a first set of cables is placed across the span, from which thin precast concrete slab units are suspended. The units are then monolithically stitched together with in-situ concrete, before the whole concrete ribbon is prestressed further. The ribbon is generally 200-400mm thick. Even though the overall forces in the ribbon are primarily calculated from the free moments (e.g. WL/8) divided by the sag, the system is hugely non-linear and very sensitive to the imposed deformations, i.e. the elastic, creep, shrinkage and temperature strains, all of which act upon each other. The design is therefore extremely complex, as the sag is constantly changing under all load cases. At the ends of the span, the very large horizontal forces in the system need to be carried to firm foundations, and even the slightest flexibility in these foundations will also affect the sag of the ribbon. Besides making the ribbon stiffer, the concrete also acts to spread any concentrated applied loads, with local moments in the ribbon. At the ends of the span, where the ribbon is built in to the abutment or pier, there can be much more significant local moments. The ribbon must not be thickened too quickly though, as the increase in stiffness simply attracts yet more moment. It is common therefore to see very small increases in thickness in these locations, applied very gradually. The reader should consult Strasky's book for further guidance[64].

4. Conclusions

Programme Summary

This technical guide has described a simple summary of production rates that allow programme comparisons to be made between the 15 different concrete bridge types that cover every possible in-situ and precast option. This programme and production rate data has been summarised in Table 2. Table 3 describes the balance that can be struck between casting, erection and storage for the various precast schemes. All this programme information has then been fed in to the input data of Tables 5a and 5b, which then have been used to create the breakdown of all the cost data in Tables 6 to 15b.

Cost Summary

Tables 6 to 15b describe the detailed breakdown of costs for each of the 15 different bridge types, covering the range of deck lengths over which they would generally be effective and competitive.

Each option has been priced from extensive comparisons to multiple sources of data from bridge schemes worldwide that had been collated by Benaim, and with the substantial assistance of the chief civil engineering estimators at Bam Nuttall, plus other key suppliers and contractors. The options are shown for a 15m wide deck where the total formwork/falsework cost for each scheme has been converted back in to a typical formwork/falsework rate, which can be applied to the total formwork area. The rates are shown as they might be applied to a 50m, 150m, 600m, 1,200m or 5,000m long bridge, as appropriate, allowing teams to pick the most suitable rate for their project. So, in conjunction with the concrete, reinforcement and prestressing rates, teams will now be able to price the full range of suitable concrete bridge decks, for any size of scheme. For detailed pricing, a thorough programme and cost exercise would still need to be carried out, but these broad rates will allow teams to consider all the options at an early stage. All these rates can be adjusted pro rata over time or in to different locations, to suit the prevailing conditions and local rates in each particular market – a series of indices/factors will be made available on the CBDG website in late 2015 to assist in the process. The breakdown of the combined formwork/falsework costs also allows teams to re-assess these figures in their own markets.

In order to make comparisons with other schemes, especially lighter steel-composite bridges, the substructure costs should also be included. Rates for these items are well defined and there is no need to discuss them further here. Finally, if a real cost estimate is needed, rather than just a comparison in order to select a solution, the costs need to include all the deck finishes and be factored for preliminaries, overheads and profit. Such factors might add another 30-50%. It is then useful to check the overall cost of the bridge per m^2 of deck area. These overall costs/m^2 vary reasonably linearly with typical span, but are very dependent on bridge types and local conditions. Very roughly, total bridge costs in £/m^2 are currently about 1,000 + 15L, where L is the typical span (in m). These figures apply up to spans of 100-150m and need to be treated with great caution as the variation could easily be +/- 25%, or more.

Tables 6 to 15b show that the:

- Combined formwork/falsework costs per total formwork area for each bridge vary from £50-150/m^2
- Overall deck costs per total deck plan area for each bridge type vary from £300-600/m^2

The total formwork area should include all the external and internal sections of formwork, especially for the box and precast shell solutions, and should also include all formed areas of both the precast and in-situ sections, excluding any free, unformed surfaces, of course.

The whole team should always ensure that all the major quantities are thoroughly checked and that the basic programme and cost data being used is correct for the particular type and location of each bridge deck, ensuring that the material, labour and plant costs are all appropriate.

Overall Summary

Table 1 allows teams to select the most suitable bridge deck type dependent on the main series of spans, or allows them to select the best span for a particular bridge type. The detailed descriptions given in Sections 3.1 to 3.15 then give further detail to aid this critical process. This is the first time that such extensive programming and cost data for all concrete bridge types has been published in a useable format. Teams are now able to price the full range of suitable concrete bridge decks, for any size of scheme. Table 5c shows a summary (rounded up to the nearest 10) of all the key output data in Tables 6 to 15b (see Appendix). This summary data has been shown graphically in Figure 95, which plots the total bridge deck costs per total deck plan area (in £/m^2) for each bridge type against the appropriate range of deck lengths.

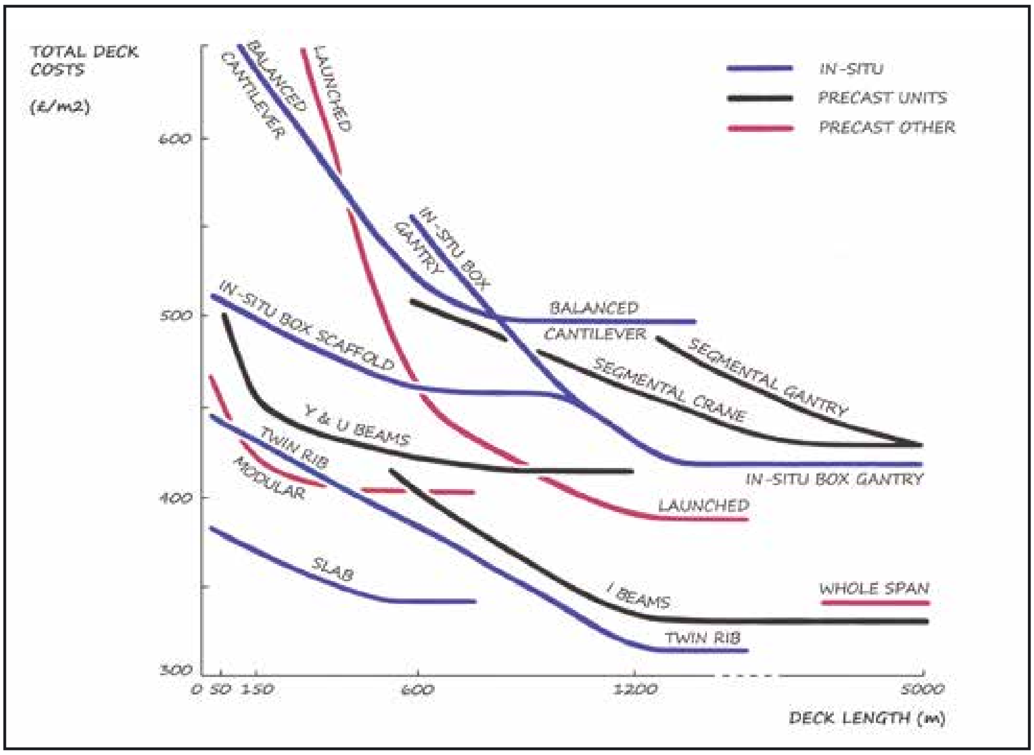

Figure 95: Total concrete bridge deck costs.

Figure 95 is immensely useful in that it allows the correct bridge deck type to be accurately selected. It also provides an excellent match for when these various schemes have actually been used in practice, both in the UK and worldwide. Given the caveat that this assessment has only considered the assumed aspects of this guide, i.e. it has used short to medium spans of 15-50m, a 15m constant deck width and has taken the deck to be 6m clear from good ground with good access, Figure 95 can be summarised as follows:

- In-situ slabs are extremely cost effective. However, 15-30m spans may be too small for some projects and the cost of scaffolding would increase for taller piers and/or deck construction over water, traffic or more difficult ground. These issues tend to render in-situ slab bridges less useful for anything other than the shortest decks.
- In-situ twin ribs are very cost effective, either on scaffolding where possible, or on gantries (for decks over about 600m long). They have been used extensively overseas, but are rarely seen in the UK. For all the reasons noted, they should become much more common, although spans only go up to 30-50m.
- CBDG's modular precast system should be very competitive. Erection on scaffolding should be used where possible, but in all other cases, the bridge is also competitive as a launched system, as long as the alignment of the deck suits launching. The modular system has been based on two precast shell schemes used in Ireland, but has not yet been used in the UK. It can be seen that it is very comparable to the in-situ twin ribs for decks shorter than about 300m – this fact is not surprising, as it was developed to fill this gap and is effectively a part-precast version of the in-situ twin rib. With further use, confidence should grow in the system, allowing it to become more common, although spans only go up to 40-50m. The costs are all calculated in the same way as precast beam schemes, i.e. with casting yard, mould and launching costs, where appropriate, amortised over several projects.
- Standard precast Y or SY beams are very competitive as long as there is good access for crane erection. They are used extensively worldwide, although spans only go up to 35-40m.
- Bespoke pre-tensioned U beams are also all very competitive as long as there is good access for crane erection. For deck lengths over about 600m, gantry erection becomes effective, obviating the need for any access. Gantry-erected post-tensioned I beams are extremely cost effective for these larger deck lengths – they have been used extensively overseas, for some very long bridges as well, where they can compete with the exceptionally low costs of the whole span precast system. They have not been used in the UK – probably due to the need for gantry erection, which is seen as more complex. Spans are also able to go up to 50-60m.
- Once spans are over 40-50m, one of the box solutions will be required, which rules out the various slab, rib and beam schemes.
- Whole span precast bridges are one of the best options for very long decks, but really need decks well over 5km long, which are only seen in the rarest of cases.
- For deck lengths over about 600m, incremental launching should be used wherever the deck alignment is suitable. For shorter deck lengths, in-situ boxes on scaffolding are clearly

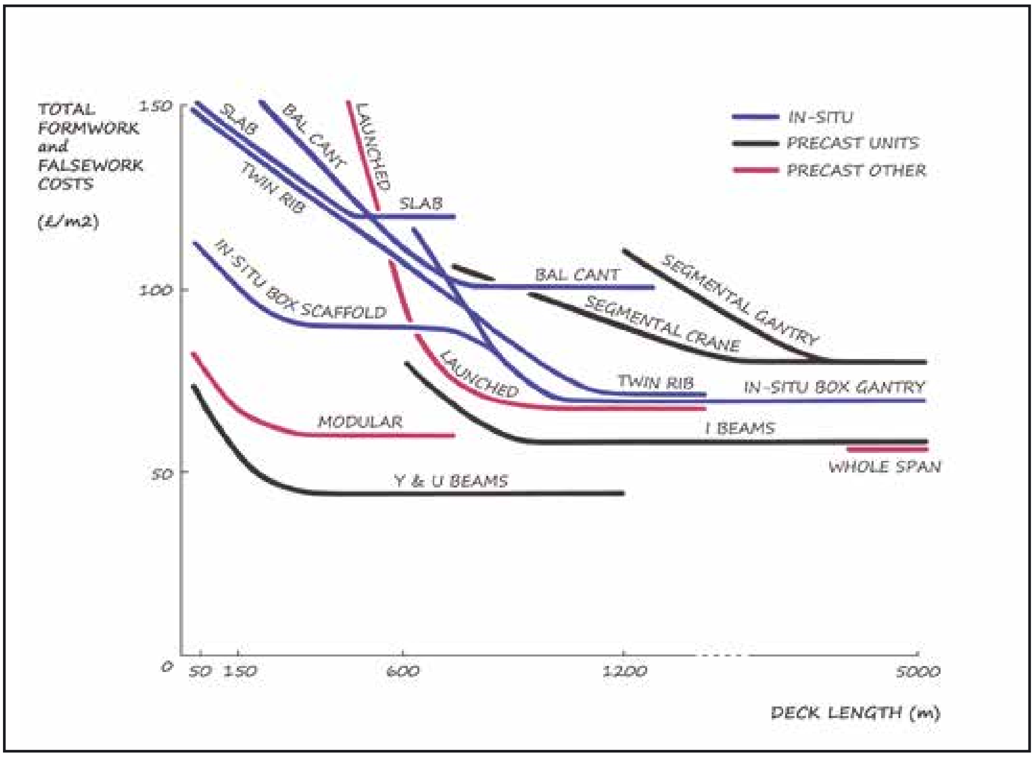

Figure 96: Combined total formwork and falsework costs.

the best option (although scaffolding may not always be possible or may become less cost effective as piers get taller or the ground conditions get worse), but launching is still competitive (although launching does not start being truly competitive until deck lengths are over about 300m).

- For shorter deck lengths, in-situ boxes on scaffolding are the best option. However, the cost of scaffolding would increase for taller piers and/or deck construction over water, traffic or more difficult ground. With deck lengths over 600-1,200m, and where the alignment does not allow launching, the use of gantries to cast in-situ boxes is the best solution, as long as the alignment is gentle enough to accommodate this method. As with twin ribs, these gantry schemes are used extensively overseas, but are not often seen in the UK.
- Precast segmental construction is only really competitive with deck lengths over about 1,200m. However, with crane-erected deck lengths from 600-1,200m, where scaffolding or launching are not possible or feasible, it can still be competitive with in-situ balanced cantilevering or in-situ boxes cast on gantries, especially if the deck alignment is particularly complex.
- In-situ balanced cantilevering, on the surface, appears rarely to be cost effective. However, on closer examination, it can be seen that it is effective, in the right circumstances. For deck lengths of 150-600m, where launching or scaffolding are not possible or sensible, it becomes not only the best box option, but the only one. While for deck lengths of 600-1,200m, also where launching or scaffolding are not possible, it becomes comparable to in-situ boxes on gantries or crane-erected precast segmental solutions. Once spans are closer to 100m, and/or where the bridge deck crosses either a deep valley or difficult water/ground conditions, it would become very competitive.

The summary data of Table 5c has also been shown graphically in Figure 96, which plots the total formwork/falsework costs per total formwork area (in £/m^2) for each bridge type against the appropriate range of deck lengths. Figure 96 allows the formwork/falsework rate to be accurately selected by the team for each option.

This CBDG Technical Guide has thus produced expert and simple guidance for owners, designers and contractors, enabling the best choice of concrete bridge deck to be made at an early stage. It outlines the critical importance of the construction method in this choice, and gives detailed data relating to production rates, programme and cost breakdowns.

Further data will be made available on the CBDG website in late 2015 to keep these costs up to date in any location.

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Appendix. Breakdown of Deck Costs

This section contains the breakdown of cost tables for each bridge deck type.

Table 6: In-situ slabs, scaffolding. 150m length.

Span	15	m	Width		15	m		
Length	150	m	Depth		0.8	m		
Span/Depth ratio	19							
Concrete area	9.5	m^3/m	Concrete rate		120	£/m^3		
Concrete volume	1,425	m^3	Concrete cost		171,000	£		
Rebar density	250	kg/m^3	Rebar rate		900	£/t		
Rebar tonnage	356	t	Rebar cost		320,625	£		
Prestress density	-	kg/m^3	Prestress rate		2,500	£/t		
Prestress tonnage	-	t	Prestress cost		-	£		
Total formwork perimeter	16	m	Formwork/Falsework rate		**143**	£/m^2	per total formwork area	
Total formwork area	2,400	m^2	Formwork/Falsework cost		**342,600**	£		
Production rate	10	m/week	Total cost		**834,225**	£		
Learning curve	25	%	Total deck rate		**371**	£/m^2	per total deck plan area	
Overall erection programme	19	weeks						
	Men	Weeks	Quantity		Rate		Cost (£)	Notes
Casting								
Mould, formwork or travellers			2,400	m^2	20	£/m^2	48,000	material only
Ancillary shutters			1	item	-	£	-	
Casting area and foundations			2,250	m^2	60	£/m^2	135,000	incl scaffolding & scaffolders
Shuttering labour	6	19	114	man-weeks	900	£/week	102,600	joiners
Cranes or lifting			19	weeks	3,000	£/week	57,000	50t crawler crane incl operator
Storage area			-	weeks	-	£/week	-	
Transport								none
Vehicles			-	weeks	-	£/week	-	
Transport labour	-	-	-	man-weeks	900	£/week	-	
Erection								incl in Casting
Cranes or lifting			19	weeks	-	£/week	-	
Gantry, girders or noses			1	item	-	£	-	
Falsework and temp works			-	t	3,000	£/t	-	
Ancillary items			1	item	-	£	-	
Erection area and foundations			-	m^2	-	£/m^2	-	
Erection labour	-	19	-	man-weeks	1,000	£/week	-	
						Total	**342,600**	
						Formwork/Falsework cost		

Table 6: In-situ slabs, scaffolding. 50m length.

Span	15	m	Width	15	m			
Length	50	m	Depth	0.8	m			
Span/Depth ratio	19							
Concrete area	9.5	m^3/m	Concrete rate	120	£/m^3			
Concrete volume	475	m^3	Concrete cost	57,000	£			
Rebar density	250	kg/m^3	Rebar rate	900	£/t			
Rebar tonnage	119	t	Rebar cost	106,875	£			
Prestress density	-	kg/m^3	Prestress rate	2,500	£/t			
Prestress tonnage	-	t	Prestress cost	-	£			
Total formwork perimeter	16	m	Formwork/Falsework rate	**150**	£/m^2	per total formwork area		
Total formwork area	800	m^2	Formwork/Falsework cost	**119,800**	£			
Production rate	10	m/week	Total cost	**283,675**	£			
Learning curve	35	%	Total deck rate	**378**	£/m^2	per total deck plan area		
Overall erection programme	7	weeks						
	Men	Weeks	Quantity		Rate		Cost (£)	Notes
Casting								
Mould, formwork or travellers			800	m^2	20	£/m^2	16,000	material only
Ancillary shutters			1	item	-	£	-	
Casting area and foundations			750	m^2	60	£/m^2	45,000	incl scaffolding & scaffolders
Shuttering labour	6	7	42	man-weeks	900	£/week	37,800	joiners
Cranes or lifting			7	weeks	3,000	£/week	21,000	50t crawler crane incl operator
Storage area			-	weeks	-	£/week	-	
Transport								none
Vehicles			-	weeks	-	£/week	-	
Transport labour	-	-	-	man-weeks	900	£/week	-	
Erection								incl in Casting
Cranes or lifting			7	weeks	-	£/week	-	
Gantry, girders or noses			1	item	-	£	-	
Falsework and temp works			-	t	3,000	£/t	-	
Ancillary items			1	item	-	£	-	
Erection area and foundations			-	m^2	-	£/m^2	-	
Erection labour	-	7	-	man-weeks	1,000	£/week	-	
						Total	**119,800**	
						Formwork/Falsework cost		

Table 6: In-situ slabs, scaffolding. 600m length.

Span	15	m	Width	15	m			
Length	600	m	Depth	0.8	m			
Span/Depth ratio	19							
Concrete area	9.5	m^3/m	Concrete rate	120	£/m^3			
Concrete volume	5,700	m^3	Concrete cost	684,000	£			
Rebar density	250	kg/m^3	Rebar rate	900	£/t			
Rebar tonnage	1,425	t	Rebar cost	1,282,500	£			
Prestress density	-	kg/m^3	Prestress rate	2,500	£/t			
Prestress tonnage	-	t	Prestress cost	-	£			
Total formwork perimeter	16	m	Formwork/Falsework rate	**118**	£/m^2	per total formwork area		
Total formwork area	9,600	m^2	Formwork/Falsework cost	**1,131,600**	£			
Production rate	10	m/week	Total cost	**3,098,100**	£			
Learning curve	15	%	Total deck rate	**344**	£/m^2	per total deck plan area		
Overall erection programme	69	weeks						
	Men	Weeks	Quantity		Rate		Cost (£)	Notes
Casting								
Mould, formwork or travellers			9,600	m^2	20	£/m^2	192,000	material only
Ancillary shutters			1	item	-	£	-	
Casting area and foundations			9,000	m^2	40	£/m^2	360,000	incl scaffolding & scaffolders
Shuttering labour	6	69	414	man-weeks	900	£/week	372,600	joiners
Cranes or lifting			69	weeks	3,000	£/week	207,000	50t crawler crane incl operator
Storage area			-	weeks	-	£/week	-	
Transport								none
Vehicles			-	weeks	-	£/week	-	
Transport labour	-	-	-	man-weeks	900	£/week	-	
Erection								incl in Casting
Cranes or lifting			69	weeks	-	£/week	-	
Gantry, girders or noses			1	item	-	£	-	
Falsework and temp works			-	t	3,000	£/t	-	
Ancillary items			1	item	-	£	-	
Erection area and foundations			-	m^2	-	£/m^2	-	
Erection labour	-	69	-	man-weeks	1,000	£/week	-	
						Total	**1,131,600**	
						Formwork/Falsework cost		

Table 7a: In-situ twin ribs, scaffolding. 150m length.

Span	30	m	Width	15	m			
Length	150	m	Depth	2.0	m			
Span/Depth ratio	15							
Concrete area	9.5	m^3/m	Concrete rate	120	£/m^3			
Concrete volume	1,425	m^3	Concrete cost	171,000	£			
Rebar density	150	kg/m^3	Rebar rate	900	£/t			
Rebar tonnage	214	t	Rebar cost	192,375	£			
Prestress density	40	kg/m^3	Prestress rate	2,500	£/t			
Prestress tonnage	57	t	Prestress cost	142,500	£			
Total formwork perimeter	22	m	Formwork/Falsework rate	**140**	£/m^2	per total formwork area		
Total formwork area	3,300	m^2	Formwork/Falsework cost	**462,300**	£			
Production rate	10	m/week	Total cost	**968,175**	£			
Learning curve	25	%	Total deck rate	**430**	£/m^2	per total deck plan area		
Overall erection programme	19	weeks						
	Men	Weeks	Quantity		Rate		Cost (£)	Notes
Casting								
Mould, formwork or travellers			3,300	m^2	20	£/m^2	66,000	material only
Ancillary shutters			1	item	-	£	-	
Casting area and foundations			2,250	m^2	90	£/m^2	202,500	incl scaffolding & scaffolders
Shuttering labour	8	19	152	man-weeks	900	£/week	136,800	joiners
Cranes or lifting			19	weeks	3,000	£/week	57,000	50t crawler crane incl operator
Storage area			-	weeks	-	£/week	-	
Transport								none
Vehicles			-	weeks	-	£/week	-	
Transport labour	-	-	-	man-weeks	900	£/week	-	
Erection								incl in Casting
Cranes or lifting			19	weeks	-	£/week	-	
Gantry, girders or noses			1	item	-	£	-	
Falsework and temp works			-	t	3,000	£/t	-	
Ancillary items			1	item	-	£	-	
Erection area and foundations			-	m^2	-	£/m^2	-	
Erection labour	-	19	-	man-weeks	1,000	£/week	-	
						Total	**462,300**	
						Formwork/Falsework cost		

Table 7a: In-situ twin ribs, scaffolding. 50m length.

Span	30	m	Width	15	m			
Length	50	m	Depth	2.0	m			
Span/Depth ratio	15							
Concrete area	9.5	m^3/m	Concrete rate	120	£/m^3			
Concrete volume	475	m^3	Concrete cost	57,000	£			
Rebar density	150	kg/m^3	Rebar rate	900	£/t			
Rebar tonnage	71	t	Rebar cost	64,125	£			
Prestress density	40	kg/m^3	Prestress rate	2,500	£/t			
Prestress tonnage	19	t	Prestress cost	47,500	£			
Total formwork perimeter	22	m	Formwork/Falsework rate	**146**	£/m^2	per total formwork area		
Total formwork area	1,100	m^2	Formwork/Falsework cost	**160,900**	£			
Production rate	10	m/week	Total cost	**329,525**	£			
Learning curve	35	%	Total deck rate	**439**	£/m^2	per total deck plan area		
Overall erection programme	7	weeks						
	Men	Weeks	Quantity		Rate		Cost (£)	Notes
Casting								
Mould, formwork or travellers			1,100	m^2	20	£/m^2	22,000	material only
Ancillary shutters			1	item	-	£	-	
Casting area and foundations			750	m^2	90	£/m^2	67,500	incl scaffolding & scaffolders
Shuttering labour	8	7	56	man-weeks	900	£/week	50,400	joiners
Cranes or lifting			7	weeks	3,000	£/week	21,000	50t crawler crane incl operator
Storage area			-	weeks	-	£/week	-	
Transport								none
Vehicles			-	weeks	-	£/week	-	
Transport labour	-	-	-	man-weeks	900	£/week	-	
Erection								incl in Casting
Cranes or lifting			7	weeks	-	£/week	-	
Gantry, girders or noses			1	item	-	£	-	
Falsework and temp works			-	t	3,000	£/t	-	
Ancillary items			1	item	-	£	-	
Erection area and foundations			-	m^2	-	£/m^2	-	
Erection labour	-	7	-	man-weeks	1,000	£/week	-	
						Total	**160,900**	
						Formwork/Falsework cost		

Table 7a: In-situ twin ribs, scaffolding. 600m length.

Span	30	m	Width	15	m			
Length	600	m	Depth	2.0	m			
Span/Depth ratio	15							
Concrete area	9.5	m^3/m	Concrete rate	120	£/m^3			
Concrete volume	5,700	m^3	Concrete cost	684,000	£			
Rebar density	150	kg/m^3	Rebar rate	900	£/t			
Rebar tonnage	855	t	Rebar cost	769,500	£			
Prestress density	40	kg/m^3	Prestress rate	2,500	£/t			
Prestress tonnage	228	t	Prestress cost	570,000	£			
Total formwork perimeter	22	m	Formwork/Falsework rate	**114**	£/m^2	per total formwork area		
Total formwork area	13,200	m^2	Formwork/Falsework cost	**1,507,800**	£			
Production rate	10	m/week	Total cost	**3,531,300**	£			
Learning curve	15	%	Total deck rate	**392**	£/m^2	per total deck plan area		
Overall erection programme	69	weeks						
	Men	Weeks	Quantity		Rate		Cost (£)	Notes
Casting								
Mould, formwork or travellers			13,200	m^2	20	£/m^2	264,000	material only
Ancillary shutters			1	item	-	£	-	
Casting area and foundations			9,000	m^2	60	£/m^2	540,000	incl scaffolding & scaffolders
Shuttering labour	8	69	552	man-weeks	900	£/week	496,800	joiners
Cranes or lifting			69	weeks	3,000	£/week	207,000	50t crawler crane incl operator
Storage area			-	weeks	-	£/week	-	
Transport								none
Vehicles			-	weeks	-	£/week	-	
Transport labour	-	-	-	man-weeks	900	£/week	-	
Erection								incl in Casting
Cranes or lifting			69	weeks	-	£/week	-	
Gantry, girders or noses			1	item	-	£	-	
Falsework and temp works			-	t	3,000	£/t	-	
Ancillary items			1	item	-	£	-	
Erection area and foundations			-	m^2	-	£/m^2	-	
Erection labour	-	69	-	man-weeks	1,000	£/week	-	
						Total	**1,507,800**	
						Formwork/Falsework cost		

Table 7b: In-situ twin ribs, gantry. 600m length.

Span	30	m	Width	15	m			
Length	600	m	Depth	2.0	m			
Span/Depth ratio	15							
Concrete area	9.5	m^3/m	Concrete rate	100	£/m^3			
Concrete volume	5,700	m^3	Concrete cost	570,000	£			
Rebar density	150	kg/m^3	Rebar rate	900	£/t			
Rebar tonnage	855	t	Rebar cost	769,500	£			
Prestress density	40	kg/m^3	Prestress rate	2,500	£/t			
Prestress tonnage	228	t	Prestress cost	570,000	£			
Total formwork perimeter	22	m	Formwork/Falsework rate	**113**	£/m^2	per total formwork area		
Total formwork area	13,200	m^2	Formwork/Falsework cost	**1,496,000**	£			
Production rate	25	m/week	Total cost	**3,405,500**	£			
Learning curve	25	%	Total deck rate	**378**	£/m^2	per total deck plan area		
Overall erection programme	30	weeks						
	Men	Weeks	Quantity		Rate		Cost (£)	Notes
Casting								
Mould, formwork or travellers			1	item	300,000	£	300,000	1 mould written off on this project
Ancillary shutters			1	item	10,000	£	10,000	incl diaphragm shutters
Casting area and foundations			-	m^2	-	£/m^2	-	
Shuttering labour	8	30	240	man-weeks	900	£/week	216,000	joiners
Cranes or lifting			30	weeks	2,500	£/week	75,000	50t mobile crane incl operator
Storage area			-	weeks	-	£/week	-	
Transport								none
Vehicles			-	weeks	-	£/week	-	
Transport labour	-	-	-	man-weeks	900	£/week	-	
Erection								
Cranes or lifting			2	weeks	12,500	£/week	25,000	300t mobile crane incl operator
Gantry, girders or noses			1	item	800,000	£	800,000	1 gantry written off on this project
Falsework and temp works			15	t	3,000	£/t	45,000	pier falsework
Ancillary items			1	item	25,000	£	25,000	jacks, bearings and temp stressing
Erection area and foundations			-	m^2	-	£/m^2	-	
Erection labour	-	30	-	man-weeks	1,000	£/week	-	incl in shuttering labour
						Total	**1,496,000**	
						Formwork/Falsework cost		

Table 7b: In-situ twin ribs, gantry. 1,200m length.

Span	30	m	Width	15	m			
Length	1,200	m	Depth	2.0	m			
Span/Depth ratio	15							
Concrete area	9.5	m^3/m	Concrete rate	100	£/m^3			
Concrete volume	11,400	m^3	Concrete cost	1,140,000	£			
Rebar density	150	kg/m^3	Rebar rate	900	£/t			
Rebar tonnage	1,710	t	Rebar cost	1,539,000	£			
Prestress density	40	kg/m^3	Prestress rate	2,500	£/t			
Prestress tonnage	456	t	Prestress cost	1,140,000	£			
Total formwork perimeter	22	m	Formwork/Falsework rate	**66**	£/m^2	per total formwork area		
Total formwork area	26,400	m^2	Formwork/Falsework cost	**1,738,500**	£			
Production rate	25	m/week	Total cost	**5,557,500**	£			
Learning curve	15	%	Total deck rate	**309**	£/m^2	per total deck plan area		
Overall erection programme	55	weeks						
	Men	Weeks	Quantity		Rate		Cost (£)	Notes
Casting								
Mould, formwork or travellers			1	item	300,000	£	300,000	1 mould written off on this project
Ancillary shutters			1	item	10,000	£	10,000	incl diaphragm shutters
Casting area and foundations			-	m^2	-	£/m^2	-	
Shuttering labour	8	55	440	man-weeks	900	£/week	396,000	joiners
Cranes or lifting			55	weeks	2,500	£/week	137,500	50t mobile crane incl operator
Storage area			-	weeks	-	£/week	-	
Transport								none
Vehicles			-	weeks	-	£/week	-	
Transport labour	-	-	-	man-weeks	900	£/week	-	
Erection								
Cranes or lifting			2	weeks	12,500	£/week	25,000	300t mobile crane incl operator
Gantry, girders or noses			1	item	800,000	£	800,000	1 gantry written off on this project
Falsework and temp works			15	t	3,000	£/t	45,000	pier falsework
Ancillary items			1	item	25,000	£	25,000	jacks, bearings and temp stressing
Erection area and foundations			-	m^2	-	£/m^2	-	
Erection labour	-	55	-	man-weeks	1,000	£/week	-	incl in shuttering labour
						Total	**1,738,500**	
						Formwork/Falsework cost		

Table 8a: In-situ span by span boxes, scaffolding. 150m length.

Span	50	m	Width	15	m			
Length	150	m	Depth	2.8	m			
Span/Depth ratio	18							
Concrete area	9.0	m^3/m	Concrete rate	140	£/m^3			
Concrete volume	1,350	m^3	Concrete cost	189,000	£			
Rebar density	200	kg/m^3	Rebar rate	900	£/t			
Rebar tonnage	270	t	Rebar cost	243,000	£			
Prestress density	45	kg/m^3	Prestress rate	2,500	£/t			
Prestress tonnage	61	t	Prestress cost	151,875	£			
Total formwork perimeter	35	m	Formwork/Falsework rate	**102**	£/m^2	per total formwork area		
Total formwork area	5,250	m^2	Formwork/Falsework cost	**535,950**	£			
Production rate	10	m/week	Total cost	**1,119,825**	£			
Learning curve	25	%	Total deck rate	**498**	£/m^2	per total deck plan area		
Overall erection programme	19	weeks						
	Men	Weeks	Quantity		Rate		Cost (£)	Notes
Casting								
Mould, formwork or travellers			5,250	m^2	20	£/m^2	105,000	material only
Ancillary shutters			1	item	-	£	-	
Casting area and foundations			2,250	m^2	75	£/m^2	168,750	incl scaffolding & scaffolders
Shuttering labour	12	19	228	man-weeks	900	£/week	205,200	joiners
Cranes or lifting			19	weeks	3,000	£/week	57,000	50t crawler crane incl operator
Storage area			-	weeks	-	£/week	-	
Transport								none
Vehicles			-	weeks	-	£/week	-	
Transport labour	-	-	-	man-weeks	900	£/week	-	
Erection								incl in Casting
Cranes or lifting			19	weeks	-	£/week	-	
Gantry, girders or noses			1	item	-	£	-	
Falsework and temp works			-	t	3,000	£/t	-	
Ancillary items			1	item	-	£	-	
Erection area and foundations			-	m^2	-	£/m^2	-	
Erection labour	-	19	-	man-weeks	1,000	£/week	-	
						Total	**535,950**	
						Formwork/Falsework cost		

Table 8a: In-situ span by span boxes, scaffolding. 50m length.

Span	50	m	Width	15	m			
Length	50	m	Depth	2.8	m			
Span/Depth ratio	18							
Concrete area	9.0	m^3/m	Concrete rate	140	£/m^3			
Concrete volume	450	m^3	Concrete cost	63,000	£			
Rebar density	200	kg/m^3	Rebar rate	900	£/t			
Rebar tonnage	90	t	Rebar cost	81,000	£			
Prestress density	45	kg/m^3	Prestress rate	2,500	£/t			
Prestress tonnage	20	t	Prestress cost	50,625	£			
Total formwork perimeter	35	m	Formwork/Falsework rate	**107**	£/m^2	per total formwork area		
Total formwork area	1,750	m^2	Formwork/Falsework cost	**187,850**	£			
Production rate	10	m/week	Total cost	**382,475**	£			
Learning curve	35	%	Total deck rate	**510**	£/m^2	per total deck plan area		
Overall erection programme	7	weeks						
	Men	Weeks	Quantity		Rate		Cost (£)	Notes
Casting								
Mould, formwork or travellers			1,750	m^2	20	£/m^2	35,000	material only
Ancillary shutters			1	item	-	£	-	
Casting area and foundations			750	m^2	75	£/m^2	56,250	incl scaffolding & scaffolders
Shuttering labour	12	7	84	man-weeks	900	£/week	75,600	joiners
Cranes or lifting			7	weeks	3,000	£/week	21,000	50t crawler crane incl operator
Storage area			-	weeks	-	£/week	-	
Transport								none
Vehicles			-	weeks	-	£/week	-	
Transport labour	-	-	-	man-weeks	900	£/week	-	
Erection								incl in Casting
Cranes or lifting			7	weeks	-	£/week	-	
Gantry, girders or noses			1	item	-	£	-	
Falsework and temp works			-	t	3,000	£/t	-	
Ancillary items			1	item	-	£	-	
Erection area and foundations			-	m^2	-	£/m^2	-	
Erection labour	-	7	-	man-weeks	1,000	£/week	-	
						Total	**187,850**	
						Formwork/Falsework cost		

Table 8a: In-situ span by span boxes, scaffolding. 600m length.

Span	50	m	Width	15	m			
Length	600	m	Depth	2.8	m			
Span/Depth ratio	18							
Concrete area	9.0	m^3/m	Concrete rate	140	£/m^3			
Concrete volume	5,400	m^3	Concrete cost	756,000	£			
Rebar density	200	kg/m^3	Rebar rate	900	£/t			
Rebar tonnage	1,080	t	Rebar cost	972,000	£			
Prestress density	45	kg/m^3	Prestress rate	2,500	£/t			
Prestress tonnage	243	t	Prestress cost	607,500	£			
Total formwork perimeter	35	m	Formwork/Falsework rate	**87**	£/m^2	per total formwork area		
Total formwork area	21,000	m^2	Formwork/Falsework cost	**1,822,200**	£			
Production rate	10	m/week	Total cost	**4,157,700**	£			
Learning curve	15	%	Total deck rate	**462**	£/m^2	per total deck plan area		
Overall erection programme	69	weeks						
	Men	Weeks	Quantity		Rate		Cost (£)	Notes
Casting								
Mould, formwork or travellers			21,000	m^2	20	£/m^2	420,000	material only
Ancillary shutters			1	item	-	£	-	
Casting area and foundations			9,000	m^2	50	£/m^2	450,000	incl scaffolding & scaffolders
Shuttering labour	12	69	828	man-weeks	900	£/week	745,200	joiners
Cranes or lifting			69	weeks	3,000	£/week	207,000	50t crawler crane incl operator
Storage area			-	weeks	-	£/week	-	
Transport								none
Vehicles			-	weeks	-	£/week	-	
Transport labour	-	-	-	man-weeks	900	£/week	-	
Erection								incl in Casting
Cranes or lifting			69	weeks	-	£/week	-	
Gantry, girders or noses			1	item	-	£	-	
Falsework and temp works			-	t	3,000	£/t	-	
Ancillary items			1	item	-	£	-	
Erection area and foundations			-	m^2	-	£/m^2	-	
Erection labour	-	69	-	man-weeks	1,000	£/week	-	
						Total	**1,822,200**	
						Formwork/Falsework cost		

Table 8a: In-situ span by span boxes, scaffolding. 1,200m length.

Span	50	m	Width		15	m		
Length	1,200	m	Depth		2.8	m		
Span/Depth ratio	18							
Concrete area	9.0	m^3/m	Concrete rate		140	£/m^3		
Concrete volume	10,800	m^3	Concrete cost		1,512,000	£		
Rebar density	200	kg/m^3	Rebar rate		900	£/t		
Rebar tonnage	2,160	t	Rebar cost		1,944,000	£		
Prestress density	45	kg/m^3	Prestress rate		2,500	£/t		
Prestress tonnage	486	t	Prestress cost		1,215,000	£		
Total formwork perimeter	35	m	Formwork/Falsework rate		**87**	£/m^2	per total formwork area	
Total formwork area	42,000	m^2	Formwork/Falsework cost		**3,644,400**	£		
Production rate	10	m/week	Total cost		**8,315,400**	£		
Learning curve	15	%	Total deck rate		**462**	£/m^2	per total deck plan area	
Overall erection programme	138	weeks						
	Men	Weeks	Quantity		Rate		Cost (£)	Notes
Casting								
Mould, formwork or travellers			42,000	m^2	20	£/m^2	840,000	material only
Ancillary shutters			1	item	-	£	-	
Casting area and foundations			18,000	m^2	50	£/m^2	900,000	incl scaffolding & scaffolders
Shuttering labour	24	69	1,656	man-weeks	900	£/week	1,490,400	joiners
Cranes or lifting			69	weeks	6,000	£/week	414,000	2 No. 50t crawlers incl operators
Storage area			-	weeks	-	£/week	-	
Transport								none
Vehicles			-	weeks	-	£/week	-	
Transport labour	-	-	-	man-weeks	900	£/week	-	
Erection								incl in Casting
Cranes or lifting			138	weeks	-	£/week	-	
Gantry, girders or noses			1	item	-	£	-	
Falsework and temp works			-	t	3,000	£/t	-	
Ancillary items			1	item	-	£	-	
Erection area and foundations			-	m^2	-	£/m^2	-	
Erection labour	-	138	-	man-weeks	1,000	£/week	-	
						Total	**3,644,400**	
						Formwork/Falsework cost		

Table 8b: In-situ span by span boxes, gantry. 600m length.

Span	50	m	Width	15	m			
Length	600	m	Depth	2.8	m			
Span/Depth ratio	18							
Concrete area	9.0	m^3/m	Concrete rate	140	£/m^3			
Concrete volume	5,400	m^3	Concrete cost	756,000	£			
Rebar density	200	kg/m^3	Rebar rate	900	£/t			
Rebar tonnage	1,080	t	Rebar cost	972,000	£			
Prestress density	45	kg/m^3	Prestress rate	2,500	£/t			
Prestress tonnage	243	t	Prestress cost	607,500	£			
Total formwork perimeter	35	m	Formwork/Falsework rate	**123**	£/m^2	per total formwork area		
Total formwork area	21,000	m^2	Formwork/Falsework cost	**2,579,000**	£			
Production rate	25	m/week	Total cost	**4,914,500**	£			
Learning curve	25	%	Total deck rate	**546**	£/m^2	per total deck plan area		
Overall erection programme	30	weeks						
	Men	Weeks	Quantity		Rate		Cost (£)	Notes
Casting								
Mould, formwork or travellers			1	item	750,000	£	750,000	1 mould written off on this project
Ancillary shutters			1	item	10,000	£	10,000	incl diaphragm shutters
Casting area and foundations			-	m^2	-	£/m^2	-	
Shuttering labour	12	30	360	man-weeks	900	£/week	324,000	joiners
Cranes or lifting			30	weeks	4,500	£/week	135,000	100t mobile crane incl operator
Storage area			-	weeks	-	£/week	-	
Transport								none
Vehicles			-	weeks	-	£/week	-	
Transport labour	-	-	-	man-weeks	900	£/week	-	
Erection								
Cranes or lifting			3	weeks	15,000	£/week	45,000	500t mobile crane incl operator
Gantry, girders or noses			1	item	1,200,000	£	1,200,000	1 gantry written off on this project
Falsework and temp works			30	t	3,000	£/t	90,000	pier falsework
Ancillary items			1	item	25,000	£	25,000	jacks, bearings and temp stressing
Erection area and foundations			-	m^2	-	£/m^2	-	
Erection labour	-	30	-	man-weeks	1,000	£/week	-	incl in shuttering labour
						Total	**2,579,000**	
						Formwork/Falsework cost		

Table 8b: In-situ span by span boxes, gantry. 1,200m length.

Span	50	m	Width	15	m			
Length	1,200	m	Depth	2.8	m			
Span/Depth ratio	18							
Concrete area	9.0	m^3/m	Concrete rate	140	£/m^3			
Concrete volume	10,800	m^3	Concrete cost	1,512,000	£			
Rebar density	200	kg/m^3	Rebar rate	900	£/t			
Rebar tonnage	2,160	t	Rebar cost	1,944,000	£			
Prestress density	45	kg/m^3	Prestress rate	2,500	£/t			
Prestress tonnage	486	t	Prestress cost	1,215,000	£			
Total formwork perimeter	35	m	Formwork/Falsework rate	**71**	£/m^2	per total formwork area		
Total formwork area	42,000	m^2	Formwork/Falsework cost	**2,961,500**	£			
Production rate	25	m/week	Total cost	**7,632,500**	£			
Learning curve	15	%	Total deck rate	**424**	£/m^2	per total deck plan area		
Overall erection programme	55	weeks						
	Men	Weeks	Quantity		Rate		Cost (£)	Notes
Casting								
Mould, formwork or travellers			1	item	750,000	£	750,000	1 mould written off on this project
Ancillary shutters			1	item	10,000	£	10,000	incl diaphragm shutters
Casting area and foundations			-	m^2	-	£/m^2	-	
Shuttering labour	12	55	660	man-weeks	900	£/week	594,000	joiners
Cranes or lifting			55	weeks	4,500	£/week	247,500	100t mobile crane incl operator
Storage area			-	weeks	-	£/week	-	
Transport								none
Vehicles			-	weeks	-	£/week	-	
Transport labour	-	-	-	man-weeks	900	£/week	-	
Erection								
Cranes or lifting			3	weeks	15,000	£/week	45,000	500t mobile crane incl operator
Gantry, girders or noses			1	item	1,200,000	£	1,200,000	1 gantry written off on this project
Falsework and temp works			30	t	3,000	£/t	90,000	pier falsework
Ancillary items			1	item	25,000	£	25,000	jacks, bearings and temp stressing
Erection area and foundations			-	m^2	-	£/m^2	-	
Erection labour	-	55	-	man-weeks	1,000	£/week	-	incl in shuttering labour
						Total	**2,961,500**	
						Formwork/Falsework cost		

Table 8b: In-situ span by span boxes, gantry. 5,000m length.

Span	50	m	Width	15	m			
Length	5,000	m	Depth	2.8	m			
Span/Depth ratio	18							
Concrete area	9.0	m^3/m	Concrete rate	140	£/m^3			
Concrete volume	45,000	m^3	Concrete cost	6,300,000	£			
Rebar density	200	kg/m^3	Rebar rate	900	£/t			
Rebar tonnage	9,000	t	Rebar cost	8,100,000	£			
Prestress density	45	kg/m^3	Prestress rate	2,500	£/t			
Prestress tonnage	2,025	t	Prestress cost	5,062,500	£			
Total formwork perimeter	35	m	Formwork/Falsework rate	**69**	£/m^2	per total formwork area		
Total formwork area	175,000	m^2	Formwork/Falsework cost	**12,029,600**	£			
Production rate	25	m/week	Total cost	**31,492,100**	£			
Learning curve	15	%	Total deck rate	**420**	£/m^2	per total deck plan area		
Overall erection programme	230	weeks						
	Men	Weeks	Quantity		Rate		Cost (£)	Notes
Casting								
Mould, formwork or travellers			4	item	750,000	£	3,000,000	4 moulds written off this project
Ancillary shutters			4	item	10,000	£	40,000	incl diaphragm shutters
Casting area and foundations			-	m^2	-	£/m^2	-	
Shuttering labour	48	58	2,784	man-weeks	900	£/week	2,505,600	joiners
Cranes or lifting			58	weeks	18,000	£/week	1,044,000	4 No. 100t mobiles incl operators
Storage area			-	weeks	-	£/week	-	
Transport								none
Vehicles			-	weeks	-	£/week	-	
Transport labour	-	-	-	man-weeks	900	£/week	-	
Erection								
Cranes or lifting			12	weeks	15,000	£/week	180,000	500t mobile crane incl operator
Gantry, girders or noses			4	item	1,200,000	£	4,800,000	4 gantries written off this project
Falsework and temp works			120	t	3,000	£/t	360,000	pier falsework
Ancillary items			4	item	25,000	£	100,000	jacks, bearings and temp stressing
Erection area and foundations			-	m^2	-	£/m^2	-	
Erection labour	-	58	-	man-weeks	1,000	£/week	-	incl in shuttering labour
						Total	**12,029,600**	
						Formwork/Falsework cost		

Table 9: In-situ balanced cantilever, travellers. 600m length.

Span	50	m	Width	15	m			
Length	600	m	Depth	2.8	m			
Span/Depth ratio	18							
Concrete area	9.0	m^3/m	Concrete rate	160	£/m^3			
Concrete volume	5,400	m^3	Concrete cost	864,000	£			
Rebar density	200	kg/m^3	Rebar rate	900	£/t			
Rebar tonnage	1,080	t	Rebar cost	972,000	£			
Prestress density	45	kg/m^3	Prestress rate	2,500	£/t			
Prestress tonnage	243	t	Prestress cost	607,500	£			
Total formwork perimeter	35	m	Formwork/Falsework rate	**105**	£/m^2	per total formwork area		
Total formwork area	21,000	m^2	Formwork/Falsework cost	**2,196,000**	£			
Production rate	14	m/week	Total cost	**4,639,500**	£			
Learning curve	25	%	Total deck rate	**516**	£/m^2	per total deck plan area		
Overall erection programme	54	weeks						
	Men	Weeks	Quantity		Rate		Cost (£)	Notes
Casting								
Mould, formwork or travellers			4	item	125,000	£	500,000	2 pairs of travellers on this project
Ancillary shutters			1	item	150,000	£	150,000	incl pier, stitch and end shutters
Casting area and foundations			1	item	80,000	£	80,000	pier scaffolding & scaffolders
Shuttering labour	20	54	1,080	man-weeks	900	£/week	972,000	joiners
Cranes or lifting			54	weeks	6,000	£/week	324,000	2 tower cranes incl operators
Storage area			-	weeks	-	£/week	-	
Transport								none
Vehicles			-	weeks	-	£/week	-	
Transport labour	-	-	-	man-weeks	900	£/week	-	
Erection								
Cranes or lifting			20	weeks	3,000	£/week	60,000	50t crawler crane incl operator
Gantry, girders or noses			1	item	-	£	-	
Falsework and temp works			20	t	3,000	£/t	60,000	pier falsework and end props
Ancillary items			1	item	50,000	£	50,000	jacks, bearings and temp stressing
Erection area and foundations			-	m^2	-	£/m^2	-	
Erection labour	-	54	-	man-weeks	1,000	£/week	-	incl in shuttering labour
						Total	**2,196,000**	
						Formwork/Falsework cost		

Table 9: In-situ balanced cantilever, travellers. 150m length.

Span	50	m	Width	15	m			
Length	150	m	Depth	2.8	m			
Span/Depth ratio	18							
Concrete area	9.0	m^3/m	Concrete rate	160	£/m^3			
Concrete volume	1,350	m^3	Concrete cost	216,000	£			
Rebar density	200	kg/m^3	Rebar rate	900	£/t			
Rebar tonnage	270	t	Rebar cost	243,000	£			
Prestress density	45	kg/m^3	Prestress rate	2,500	£/t			
Prestress tonnage	61	t	Prestress cost	151,875	£			
Total formwork perimeter	35	m	Formwork/Falsework rate	**162**	£/m^2	per total formwork area		
Total formwork area	5,250	m^2	Formwork/Falsework cost	**853,000**	£			
Production rate	7	m/week	Total cost	**1,463,875**	£			
Learning curve	35	%	Total deck rate	**651**	£/m^2	per total deck plan area		
Overall erection programme	29	weeks						

	Men	Weeks	Quantity		Rate		Cost (£)	Notes
Casting								
Mould, formwork or travellers			2	item	125,000	£	250,000	1 pair of travellers on this project
Ancillary shutters			1	item	150,000	£	150,000	incl pier, stitch and end shutters
Casting area and foundations			1	item	20,000	£	20,000	pier scaffolding & scaffolders
Shuttering labour	10	29	290	man-weeks	900	£/week	261,000	joiners
Cranes or lifting			29	weeks	3,000	£/week	87,000	tower crane incl operator
Storage area			-	weeks	-	£/week	-	
Transport								none
Vehicles			-	weeks	-	£/week	-	
Transport labour	-	-	-	man-weeks	900	£/week	-	
Erection								
Cranes or lifting			10	weeks	3,000	£/week	30,000	50t crawler crane incl operator
Gantry, girders or noses			1	item	-	£	-	
Falsework and temp works			10	t	3,000	£/t	30,000	pier falsework and end props
Ancillary items			1	item	25,000	£	25,000	jacks, bearings and temp stressing
Erection area and foundations			-	m^2	-	£/m^2	-	
Erection labour	-	29	-	man-weeks	1,000	£/week	-	incl in shuttering labour
						Total	**853,000**	
						Formwork/Falsework cost		

Table 9: In-situ balanced cantilever, travellers. 1,200m length.

Span	50	m	Width	15	m			
Length	1,200	m	Depth	2.8	m			
Span/Depth ratio	18							
Concrete area	9.0	m^3/m	Concrete rate	160	£/m^3			
Concrete volume	10,800	m^3	Concrete cost	1,728,000	£			
Rebar density	200	kg/m^3	Rebar rate	900	£/t			
Rebar tonnage	2,160	t	Rebar cost	1,944,000	£			
Prestress density	45	kg/m^3	Prestress rate	2,500	£/t			
Prestress tonnage	486	t	Prestress cost	1,215,000	£			
Total formwork perimeter	35	m	Formwork/Falsework rate	**99**	£/m^2	per total formwork area		
Total formwork area	42,000	m^2	Formwork/Falsework cost	**4,152,000**	£			
Production rate	28	m/week	Total cost	**9,039,000**	£			
Learning curve	15	%	Total deck rate	**502**	£/m^2	per total deck plan area		
Overall erection programme	49	weeks						
	Men	Weeks	Quantity		Rate		Cost (£)	Notes
Casting								
Mould, formwork or travellers			8	item	125,000	£	1,000,000	4 pairs of travellers on this project
Ancillary shutters			2	item	150,000	£	300,000	incl pier, stitch and end shutters
Casting area and foundations			2	item	80,000	£	160,000	pier scaffolding & scaffolders
Shuttering labour	40	49	1,960	man-weeks	900	£/week	1,764,000	joiners
Cranes or lifting			49	weeks	12,000	£/week	588,000	4 tower cranes incl operators
Storage area			-	weeks	-	£/week	-	
Transport								none
Vehicles			-	weeks	-	£/week	-	
Transport labour	-	-	-	man-weeks	900	£/week	-	
Erection								
Cranes or lifting			20	weeks	6,000	£/week	120,000	2 No. 50t crawler cranes
Gantry, girders or noses			1	item	-	£	-	
Falsework and temp works			40	t	3,000	£/t	120,000	pier falsework and end props
Ancillary items			2	item	50,000	£	100,000	jacks, bearings and temp stressing
Erection area and foundations			-	m^2	-	£/m^2	-	
Erection labour	-	49	-	man-weeks	1,000	£/week	-	incl in shuttering labour
						Total	**4,152,000**	
						Formwork/Falsework cost		

Table 10: Standard precast beams, crane. 150m length.

Span	30	m	Width	15	m			
Length	150	m	Depth	1.8	m			
Span/Depth ratio	17							
Concrete area	9.5	m^3/m	Concrete rate	120	£/m^3			6.0m^3/m precast and 3.5 in-situ
Concrete volume	1,425	m^3	Concrete cost	171,000	£			
Rebar density	125	kg/m^3	Rebar rate	900	£/t			
Rebar tonnage	178	t	Rebar cost	160,313	£			
Prestress density	55	kg/m^3	Prestress rate	2,250	£/t			10 No. pre-tensioned SY beams
Prestress tonnage	78	t	Prestress cost	176,344	£			
Total formwork perimeter	57	m	Formwork/Falsework rate	**60**	£/m^2	per total formwork area		43m precast and 14 in-situ
Total formwork area	8,550	m^2	Formwork/Falsework cost	**513,000**	£			
Production rate	20	m/week	Total cost	**1,020,656**	£			
Learning curve	25	%	Total deck rate	**454**	£/m^2	per total deck plan area		
Overall erection programme	9	weeks						
	Men	Weeks	Quantity		Rate		Cost (£)	Notes
Casting								
Mould, formwork or travellers			1	item	100,000	£	25,000	mould amortised over 4 projects
Ancillary shutters			1	item	-	£	-	
Casting area and foundations			500	m^2	100	£/m^2	50,000	casting bed
Shuttering labour	8	12	96	man-weeks	900	£/week	86,400	
Cranes or lifting			12	weeks	3,000	£/week	36,000	50t crawler crane incl operator
Storage area			12	weeks	1,500	£/week	18,000	
Transport								
Vehicles			9	weeks	1,500	£/week	13,500	
Transport labour	1	9	9	man-weeks	900	£/week	8,100	
Erection								
Formwork			2,100	m^2	60	£/m^2	126,000	GRC slab & dia shutters
Cranes or lifting			9	weeks	5,000	£/week	45,000	150t crawler crane incl operator
Gantry, girders or noses			1	item	-	£	-	
Falsework and temp works			5	t	3,000	£/t	15,000	falsework
Ancillary items			1	item	-	£	-	
Erection area and foundations			-	m^2	-	£/m^2	-	
Erection labour	10	9	90	man-weeks	1,000	£/week	90,000	
						Total	**513,000**	
						Formwork/Falsework cost		

Table 10: Standard precast beams, crane. 50m length.

Span	30	m	Width	15	m			
Length	50	m	Depth	1.8	m			
Span/Depth ratio	17							
Concrete area	9.5	m^3/m	Concrete rate	120	£/m^3			6.0m^3/m precast and 3.5 in-situ
Concrete volume	475	m^3	Concrete cost	57,000	£			
Rebar density	125	kg/m^3	Rebar rate	900	£/t			
Rebar tonnage	59	t	Rebar cost	53,438	£			
Prestress density	55	kg/m^3	Prestress rate	2,250	£/t			10 No. pre-tensioned SY beams
Prestress tonnage	26	t	Prestress cost	58,781	£			
Total formwork perimeter	57	m	Formwork/Falsework rate	**75**	£/m^2	per total formwork area		43m precast and 14 in-situ
Total formwork area	2,850	m^2	Formwork/Falsework cost	**214,333**	£			
Production rate	20	m/week	Total cost	**383,552**	£			
Learning curve	35	%	Total deck rate	**511**	£/m^2	per total deck plan area		
Overall erection programme	3	weeks						
	Men	Weeks	Quantity		Rate		Cost (£)	Notes
Casting								
Mould, formwork or travellers			1	item	100,000	£	8,333	mould amortised over 12 projects
Ancillary shutters			1	item	-	£	-	
Casting area and foundations			500	m^2	100	£/m^2	50,000	casting bed
Shuttering labour	8	4	32	man-weeks	900	£/week	28,800	
Cranes or lifting			4	weeks	3,000	£/week	12,000	50t crawler crane incl operator
Storage area			4	weeks	1,500	£/week	6,000	
Transport								
Vehicles			3	weeks	1,500	£/week	4,500	
Transport labour	1	3	3	man-weeks	900	£/week	2,700	
Erection								
Formwork			700	m^2	60	£/m^2	42,000	GRC slab & dia shutters
Cranes or lifting			3	weeks	5,000	£/week	15,000	150t crawler crane incl operator
Gantry, girders or noses			1	item	-	£	-	
Falsework and temp works			5	t	3,000	£/t	15,000	falsework
Ancillary items			1	item	-	£	-	
Erection area and foundations			-	m^2	-	£/m^2	-	
Erection labour	10	3	30	man-weeks	1,000	£/week	30,000	
						Total	**214,333**	
						Formwork/Falsework cost		

Table 10: Standard precast beams, crane. 600m length.

Span	30	m	Width	15	m			
Length	600	m	Depth	1.8	m			
Span/Depth ratio	17							
Concrete area	9.5	m^3/m	Concrete rate	120	£/m^3			6.0m^3/m precast and 3.5 in-situ
Concrete volume	5,700	m^3	Concrete cost	684,000	£			
Rebar density	125	kg/m^3	Rebar rate	900	£/t			
Rebar tonnage	713	t	Rebar cost	641,250	£			
Prestress density	55	kg/m^3	Prestress rate	2,250	£/t			10 No. pre-tensioned SY beams
Prestress tonnage	314	t	Prestress cost	705,375	£			
Total formwork perimeter	57	m	Formwork/Falsework rate	**54**	£/m^2	per total formwork area		43m precast and 14 in-situ
Total formwork area	34,200	m^2	Formwork/Falsework cost	**1,839,600**	£			
Production rate	20	m/week	Total cost	**3,870,225**	£			
Learning curve	15	%	Total deck rate	**430**	£/m^2	per total deck plan area		
Overall erection programme	35	weeks						
	Men	Weeks	Quantity		Rate		Cost (£)	Notes
Casting								
Mould, formwork or travellers			1	item	100,000	£	100,000	1 mould written off on this project
Ancillary shutters			1	item	-	£	-	
Casting area and foundations			500	m^2	100	£/m^2	50,000	casting bed
Shuttering labour	8	48	384	man-weeks	900	£/week	345,600	
Cranes or lifting			48	weeks	3,000	£/week	144,000	50t crawler crane incl operator
Storage area			48	weeks	1,500	£/week	72,000	
Transport								
Vehicles			35	weeks	1,500	£/week	52,500	
Transport labour	1	35	35	man-weeks	900	£/week	31,500	
Erection								
Formwork			8,400	m^2	60	£/m^2	504,000	GRC slab & dia shutters
Cranes or lifting			35	weeks	5,000	£/week	175,000	150t crawler crane incl operator
Gantry, girders or noses			1	item	-	£	-	
Falsework and temp works			5	t	3,000	£/t	15,000	falsework
Ancillary items			1	item	-	£	-	
Erection area and foundations			-	m^2	-	£/m^2	-	
Erection labour	10	35	350	man-weeks	1,000	£/week	350,000	
						Total	**1,839,600**	
						Formwork/Falsework cost		

Table 10: Standard precast beams, crane. 1,200m length.

Span	30	m	Width	15	m			
Length	1,200	m	Depth	1.8	m			
Span/Depth ratio	17							
Concrete area	9.5	m^3/m	Concrete rate	120	£/m^3			6.0m^3/m precast and 3.5 in-situ
Concrete volume	11,400	m^3	Concrete cost	1,368,000	£			
Rebar density	125	kg/m^3	Rebar rate	900	£/t			
Rebar tonnage	1,425	t	Rebar cost	1,282,500	£			
Prestress density	55	kg/m^3	Prestress rate	2,250	£/t			10 No. pre-tensioned SY beams
Prestress tonnage	627	t	Prestress cost	1,410,750	£			
Total formwork perimeter	57	m	Formwork/Falsework rate	**52**	£/m^2	per total formwork area		43m precast and 14 in-situ
Total formwork area	68,400	m^2	Formwork/Falsework cost	**3,535,200**	£			
Production rate	20	m/week	Total cost	**7,596,450**	£			
Learning curve	15	%	Total deck rate	**422**	£/m^2	per total deck plan area		
Overall erection programme	69	weeks						
	Men	Weeks	Quantity		Rate		Cost (£)	Notes
Casting								
Mould, formwork or travellers			2	item	100,000	£	200,000	2 moulds written off this project
Ancillary shutters			1	item	-	£	-	
Casting area and foundations			1,000	m^2	100	£/m^2	100,000	casting bed
Shuttering labour	16	48	768	man-weeks	900	£/week	691,200	
Cranes or lifting			48	weeks	3,000	£/week	144,000	50t crawler crane incl operator
Storage area			48	weeks	3,000	£/week	144,000	
Transport								
Vehicles			35	weeks	3,000	£/week	105,000	
Transport labour	2	35	70	man-weeks	900	£/week	63,000	
Erection								
Formwork			16,800	m^2	60	£/m^2	1,008,000	GRC slab & dia shutters
Cranes or lifting			35	weeks	10,000	£/week	350,000	2 No. 150t crawler cranes
Gantry, girders or noses			1	item	-	£	-	
Falsework and temp works			10	t	3,000	£/t	30,000	falsework
Ancillary items			1	item	-	£	-	
Erection area and foundations			-	m^2	-	£/m^2	-	
Erection labour	20	35	700	man-weeks	1,000	£/week	700,000	
						Total	**3,535,200**	
						Formwork/Falsework cost		

Table 11a: Bespoke precast beams, crane. 150m length.

Span	40	m	Width	15	m			
Length	150	m	Depth	2.5	m			
Span/Depth ratio	16							
Concrete area	9.5	m^3/m	Concrete rate	120	£/m^3			6.0m^3/m precast and 3.5 in-situ
Concrete volume	1,425	m^3	Concrete cost	171,000	£			
Rebar density	125	kg/m^3	Rebar rate	900	£/t			
Rebar tonnage	178	t	Rebar cost	160,313	£			
Prestress density	55	kg/m^3	Prestress rate	2,250	£/t			5 No. pre-tensioned U beams
Prestress tonnage	78	t	Prestress cost	176,344	£			
Total formwork perimeter	70	m	Formwork/Falsework rate	**48**	£/m^2	per total formwork area		57.5m precast and 12.5 in-situ
Total formwork area	10,500	m^2	Formwork/Falsework cost	**504,250**	£			
Production rate	25	m/week	Total cost	**1,011,906**	£			
Learning curve	25	%	Total deck rate	**450**	£/m^2	per total deck plan area		
Overall erection programme	8	weeks						
	Men	Weeks	Quantity		Rate		Cost (£)	Notes
Casting								
Mould, formwork or travellers			1	item	200,000	£	25,000	mould amortised over 8 projects
Ancillary shutters			1	item	-	£	-	
Casting area and foundations			500	m^2	100	£/m^2	50,000	casting bed
Shuttering labour	8	5	40	man-weeks	900	£/week	36,000	
Cranes or lifting			5	weeks	4,250	£/week	21,250	100t crawler crane incl operator
Storage area			5	weeks	1,500	£/week	7,500	
Transport								
Vehicles			5	weeks	2,500	£/week	12,500	
Transport labour	1	5	5	man-weeks	900	£/week	4,500	
Erection								
Formwork			1,875	m^2	60	£/m^2	112,500	GRC slab & dia shutters
Cranes or lifting			8	weeks	15,000	£/week	120,000	500t mobile crane incl operator
Gantry, girders or noses			1	item	-	£	-	
Falsework and temp works			5	t	3,000	£/t	15,000	falsework
Ancillary items			1	item	-	£	-	
Erection area and foundations			400	m^2	50	£/m^2	20,000	hardstanding for cranes
Erection labour	10	8	80	man-weeks	1,000	£/week	80,000	
						Total	**504,250**	
						Formwork/Falsework cost		

Table 11a: Bespoke precast beams, crane. 50m length.

Span	40	m	Width	15	m			
Length	50	m	Depth	2.5	m			
Span/Depth ratio	16							
Concrete area	9.5	m^3/m	Concrete rate	120	£/m^3			6.0m^3/m precast and 3.5 in-situ
Concrete volume	475	m^3	Concrete cost	57,000	£			
Rebar density	125	kg/m^3	Rebar rate	900	£/t			
Rebar tonnage	59	t	Rebar cost	53,438	£			
Prestress density	55	kg/m^3	Prestress rate	2,250	£/t			5 No. pre-tensioned U beams
Prestress tonnage	26	t	Prestress cost	58,781	£			
Total formwork perimeter	70	m	Formwork/Falsework rate	**64**	£/m^2	per total formwork area		57.5m precast and 12.5 in-situ
Total formwork area	3,500	m^2	Formwork/Falsework cost	**223,533**	£			
Production rate	25	m/week	Total cost	**392,752**	£			
Learning curve	35	%	Total deck rate	**524**	£/m^2	per total deck plan area		
Overall erection programme	3	weeks						
	Men	Weeks	Quantity		Rate		Cost (£)	Notes
Casting								
Mould, formwork or travellers			1	item	200,000	£	8,333	mould amortised over 24 projects
Ancillary shutters			1	item	-	£	-	
Casting area and foundations			500	m^2	100	£/m^2	50,000	casting bed
Shuttering labour	8	2	16	man-weeks	900	£/week	14,400	
Cranes or lifting			2	weeks	4,250	£/week	8,500	100t crawler crane incl operator
Storage area			2	weeks	1,500	£/week	3,000	
Transport								
Vehicles			2	weeks	2,500	£/week	5,000	
Transport labour	1	2	2	man-weeks	900	£/week	1,800	
Erection								
Formwork			625	m^2	60	£/m^2	37,500	GRC slab & dia shutters
Cranes or lifting			3	weeks	15,000	£/week	45,000	500t mobile crane incl operator
Gantry, girders or noses			1	item	-	£	-	
Falsework and temp works			5	t	3,000	£/t	15,000	falsework
Ancillary items			1	item	-	£	-	
Erection area and foundations			100	m^2	50	£/m^2	5,000	hardstanding for cranes
Erection labour	10	3	30	man-weeks	1,000	£/week	30,000	
						Total	**223,533**	
						Formwork/Falsework cost		

Table 11a: Bespoke precast beams, crane. 600m length.

Span	40	m	Width	15	m			
Length	600	m	Depth	2.5	m			
Span/Depth ratio	16							
Concrete area	9.5	m^3/m	Concrete rate	120	£/m^3			6.0m^3/m precast and 3.5 in-situ
Concrete volume	5,700	m^3	Concrete cost	684,000	£			
Rebar density	125	kg/m^3	Rebar rate	900	£/t			
Rebar tonnage	713	t	Rebar cost	641,250	£			
Prestress density	55	kg/m^3	Prestress rate	2,250	£/t			5 No. pre-tensioned U beams
Prestress tonnage	314	t	Prestress cost	705,375	£			
Total formwork perimeter	70	m	Formwork/Falsework rate	**41**	£/m^2	per total formwork area		57.5m precast and 12.5 in-situ
Total formwork area	42,000	m^2	Formwork/Falsework cost	**1,717,000**	£			
Production rate	25	m/week	Total cost	**3,747,625**	£			
Learning curve	15	%	Total deck rate	**416**	£/m^2	per total deck plan area		
Overall erection programme	28	weeks						
	Men	Weeks	Quantity		Rate		Cost (£)	Notes
Casting								
Mould, formwork or travellers			1	item	200,000	£	100,000	mould amortised over 2 projects
Ancillary shutters			1	item	-	£	-	
Casting area and foundations			500	m^2	100	£/m^2	50,000	casting bed
Shuttering labour	8	20	160	man-weeks	900	£/week	144,000	
Cranes or lifting			20	weeks	4,250	£/week	85,000	100t crawler crane incl operator
Storage area			20	weeks	1,500	£/week	30,000	
Transport								
Vehicles			20	weeks	2,500	£/week	50,000	
Transport labour	1	20	20	man-weeks	900	£/week	18,000	
Erection								
Formwork			7,500	m^2	60	£/m^2	450,000	GRC slab & dia shutters
Cranes or lifting			28	weeks	15,000	£/week	420,000	500t mobile crane incl operator
Gantry, girders or noses			1	item	-	£	-	
Falsework and temp works			5	t	3,000	£/t	15,000	falsework
Ancillary items			1	item	-	£	-	
Erection area and foundations			1,500	m^2	50	£/m^2	75,000	hardstanding for cranes
Erection labour	10	28	280	man-weeks	1,000	£/week	280,000	
						Total	**1,717,000**	
						Formwork/Falsework cost		

Table 11a: Bespoke precast beams, crane. 1,200m length.

Span	40	m	Width	15	m			
Length	1,200	m	Depth	2.5	m			
Span/Depth ratio	16							
Concrete area	9.5	m^3/m	Concrete rate	120	£/m^3			6.0m^3/m precast and 3.5 in-situ
Concrete volume	11,400	m^3	Concrete cost	1,368,000	£			
Rebar density	125	kg/m^3	Rebar rate	900	£/t			
Rebar tonnage	1,425	t	Rebar cost	1,282,500	£			
Prestress density	55	kg/m^3	Prestress rate	2,250	£/t			5 No. pre-tensioned U beams
Prestress tonnage	627	t	Prestress cost	1,410,750	£			
Total formwork perimeter	70	m	Formwork/Falsework rate	**40**	£/m^2	per total formwork area		57.5m precast and 12.5 in-situ
Total formwork area	84,000	m^2	Formwork/Falsework cost	**3,344,000**	£			
Production rate	25	m/week	Total cost	**7,405,250**	£			
Learning curve	15	%	Total deck rate	**411**	£/m^2	per total deck plan area		
Overall erection programme	55	weeks						
	Men	Weeks	Quantity		Rate		Cost (£)	Notes
Casting								
Mould, formwork or travellers			1	item	200,000	£	200,000	1 mould written off on this project
Ancillary shutters			1	item	-	£	-	
Casting area and foundations			500	m^2	100	£/m^2	50,000	casting bed
Shuttering labour	8	40	320	man-weeks	900	£/week	288,000	
Cranes or lifting			40	weeks	4,250	£/week	170,000	100t crawler crane incl operator
Storage area			40	weeks	1,500	£/week	60,000	
Transport								
Vehicles			40	weeks	2,500	£/week	100,000	
Transport labour	1	40	40	man-weeks	900	£/week	36,000	
Erection								
Formwork			15,000	m^2	60	£/m^2	900,000	GRC slab & dia shutters
Cranes or lifting			55	weeks	15,000	£/week	825,000	500t mobile crane incl operator
Gantry, girders or noses			1	item	-	£	-	
Falsework and temp works			5	t	3,000	£/t	15,000	falsework
Ancillary items			1	item	-	£	-	
Erection area and foundations			3,000	m^2	50	£/m^2	150,000	hardstanding for cranes
Erection labour	10	55	550	man-weeks	1,000	£/week	550,000	
						Total	**3,344,000**	
						Formwork/Falsework cost		

Table 11b: Bespoke precast beams, gantry. 600m length.

Span	40	m	Width	15	m			
Length	600	m	Depth	2.5	m			
Span/Depth ratio	16							
Concrete area	7.5	m^3/m	Concrete rate	100	£/m^3			5.0m^3/m precast and 2.5 in-situ
Concrete volume	4,500	m^3	Concrete cost	450,000	£			
Rebar density	175	kg/m^3	Rebar rate	900	£/t			
Rebar tonnage	788	t	Rebar cost	708,750	£			
Prestress density	50	kg/m^3	Prestress rate	2,500	£/t			4 No. post-tensioned I beams
Prestress tonnage	225	t	Prestress cost	562,500	£			
Total formwork perimeter	38	m	Formwork/Falsework rate	**83**	£/m^2	per total formwork area		27m precast and 11 in-situ
Total formwork area	22,800	m^2	Formwork/Falsework cost	**1,903,000**	£			
Production rate	25	m/week	Total cost	**3,624,250**	£			
Learning curve	25	%	Total deck rate	**403**	£/m^2	per total deck plan area		
Overall erection programme	30	weeks						
	Men	Weeks	Quantity		Rate		Cost (£)	Notes
Casting								
Mould, formwork or travellers			1	item	150,000	£	150,000	1 mould written off on this project
Ancillary shutters			1	item	-	£	-	
Casting area and foundations			500	m^2	100	£/m^2	50,000	casting bed
Shuttering labour	8	30	240	man-weeks	900	£/week	216,000	
Cranes or lifting			1	item	100,000	£	100,000	gantry and cranes
Storage area			30	weeks	1,500	£/week	45,000	
Transport								incl in Casting
Vehicles			-	weeks	-	£/week	-	
Transport labour	-	-	-	man-weeks	900	£/week	-	
Erection								
Formwork			6,600	m^2	20	£/m^2	132,000	slab & dia shutters
Cranes or lifting			30	weeks	2,500	£/week	75,000	50t mobile crane incl operator
Cranes or lifting			2	weeks	12,500	£/week	25,000	300t mobile crane incl operator
Gantry, girders or noses			1	item	800,000	£	800,000	1 gantry written off on this project
Falsework and temp works			15	t	3,000	£/t	45,000	pier falsework and lifting beams
Ancillary items			1	item	25,000	£	25,000	jacks, bearings and temp stressing
Erection area and foundations			-	m^2	-	£/m^2	-	
Erection labour	8	30	240	man-weeks	1,000	£/week	240,000	
						Total	**1,903,000**	
						Formwork/Falsework cost		

Table 11b: Bespoke precast beams, gantry. 1,200m length.

Span	40	m	Width	15	m			
Length	1,200	m	Depth	2.5	m			
Span/Depth ratio	16							
Concrete area	7.5	m^3/m	Concrete rate	100	£/m^3			5.0m^3/m precast and 2.5 in-situ
Concrete volume	9,000	m^3	Concrete cost	900,000	£			
Rebar density	175	kg/m^3	Rebar rate	900	£/t			
Rebar tonnage	1,575	t	Rebar cost	1,417,500	£			
Prestress density	50	kg/m^3	Prestress rate	2,500	£/t			4 No. post-tensioned I beams
Prestress tonnage	450	t	Prestress cost	1,125,000	£			
Total formwork perimeter	38	m	Formwork/Falsework rate	**56**	£/m^2	per total formwork area		27m precast and 11 in-situ
Total formwork area	45,600	m^2	Formwork/Falsework cost	**2,558,500**	£			
Production rate	25	m/week	Total cost	**6,001,000**	£			
Learning curve	15	%	Total deck rate	**333**	£/m^2	per total deck plan area		
Overall erection programme	55	weeks						
	Men	Weeks	Quantity		Rate		Cost (£)	Notes
Casting								
Mould, formwork or travellers			1	item	150,000	£	150,000	1 mould written off on this project
Ancillary shutters			1	item	-	£	-	
Casting area and foundations			500	m^2	100	£/m^2	50,000	casting bed
Shuttering labour	8	60	480	man-weeks	900	£/week	432,000	
Cranes or lifting			1	item	100,000	£	100,000	gantry and cranes
Storage area			60	weeks	1,500	£/week	90,000	
Transport								incl in Casting
Vehicles			-	weeks	-	£/week	-	
Transport labour	-	-	-	man-weeks	900	£/week	-	
Erection								
Formwork			13,200	m^2	20	£/m^2	264,000	slab & dia shutters
Cranes or lifting			55	weeks	2,500	£/week	137,500	50t mobile crane incl operator
Cranes or lifting			2	weeks	12,500	£/week	25,000	300t mobile crane incl operator
Gantry, girders or noses			1	item	800,000	£	800,000	1 gantry written off on this project
Falsework and temp works			15	t	3,000	£/t	45,000	pier falsework and lifting beams
Ancillary items			1	item	25,000	£	25,000	jacks, bearings and temp stressing
Erection area and foundations			-	m^2	-	£/m^2	-	
Erection labour	8	55	440	man-weeks	1,000	£/week	440,000	
						Total	**2,558,500**	
						Formwork/Falsework cost		

Table 11b: Bespoke precast beams, gantry. 5,000m length.

Span	40	m	Width	15	m			
Length	5,000	m	Depth	2.5	m			
Span/Depth ratio	16							
Concrete area	7.5	m^3/m	Concrete rate	100	£/m^3			5.0m^3/m precast and 2.5 in-situ
Concrete volume	37,500	m^3	Concrete cost	3,750,000	£			
Rebar density	175	kg/m^3	Rebar rate	900	£/t			
Rebar tonnage	6,563	t	Rebar cost	5,906,250	£			
Prestress density	50	kg/m^3	Prestress rate	2,500	£/t			4 No. post-tensioned I beams
Prestress tonnage	1,875	t	Prestress cost	4,687,500	£			
Total formwork perimeter	38	m	Formwork/Falsework rate	**55**	£/m^2	per total formwork area		27m precast and 11 in-situ
Total formwork area	190,000	m^2	Formwork/Falsework cost	**10,378,000**	£			
Production rate	25	m/week	Total cost	**24,721,750**	£			
Learning curve	15	%	Total deck rate	**330**	£/m^2	per total deck plan area		
Overall erection programme	230	weeks						
	Men	Weeks	Quantity		Rate		Cost (£)	Notes
Casting								
Mould, formwork or travellers			4	item	150,000	£	600,000	4 moulds written off this project
Ancillary shutters			1	item	-	£	-	
Casting area and foundations			2,000	m^2	100	£/m^2	200,000	casting bed
Shuttering labour	32	65	2,080	man-weeks	900	£/week	1,872,000	
Cranes or lifting			2	item	100,000	£	200,000	gantry and cranes
Storage area			65	weeks	6,000	£/week	390,000	
Transport								incl in Casting
Vehicles			-	weeks	-	£/week	-	
Transport labour	-	-	-	man-weeks	900	£/week	-	
Erection								
Formwork			55,000	m^2	20	£/m^2	1,100,000	slab & dia shutters
Cranes or lifting			58	weeks	10,000	£/week	580,000	4 No. 50t mobile cranes
Cranes or lifting			8	weeks	12,500	£/week	100,000	300t mobile crane incl operator
Gantry, girders or noses			4	item	800,000	£	3,200,000	4 gantries written off this project
Falsework and temp works			60	t	3,000	£/t	180,000	pier falsework and lifting beams
Ancillary items			4	item	25,000	£	100,000	jacks, bearings and temp stressing
Erection area and foundations			-	m^2	-	£/m^2	-	
Erection labour	32	58	1,856	man-weeks	1,000	£/week	1,856,000	
						Total	**10,378,000**	
						Formwork/Falsework cost		

Table 12a: Precast segmental, crane. 600m length.

Span	50	m	Width	15	m			
Length	600	m	Depth	2.8	m			
Span/Depth ratio	18							
Concrete area	8.5	m^3/m	Concrete rate	120	£/m^3			
Concrete volume	5,100	m^3	Concrete cost	612,000	£			
Rebar density	200	kg/m^3	Rebar rate	900	£/t			
Rebar tonnage	1,020	t	Rebar cost	918,000	£			
Prestress density	50	kg/m^3	Prestress rate	2,500	£/t			
Prestress tonnage	255	t	Prestress cost	637,500	£			
Total formwork perimeter	35	m	Formwork/Falsework rate	**115**	£/m^2	per total formwork area		
Total formwork area	21,000	m^2	Formwork/Falsework cost	**2,425,000**	£			
Production rate	30	m/week	Total cost	**4,592,500**	£			
Learning curve	25	%	Total deck rate	**510**	£/m^2	per total deck plan area		
Overall erection programme	25	weeks						
	Men	Weeks	Quantity		Rate		Cost (£)	Notes
Casting								
Mould, formwork or travellers			1	item	200,000	£	200,000	1 mould written off on this project
Ancillary shutters			1	item	50,000	£	50,000	incl pier, stitch and end shutters
Casting area and foundations			1,500	m^2	400	£/m^2	600,000	incl shed
Shuttering labour	8	50	400	man-weeks	900	£/week	360,000	
Cranes or lifting			1	item	400,000	£	400,000	gantry and cranes
Storage area			50	weeks	3,000	£/week	150,000	
Transport								
Vehicles			25	weeks	2,500	£/week	62,500	
Transport labour	1	25	25	man-weeks	900	£/week	22,500	
Erection								
Cranes or lifting			25	weeks	2,500	£/week	62,500	50t mobile crane incl operator
Cranes or lifting			25	weeks	7,500	£/week	187,500	300t crawler crane incl operator
Gantry, girders or noses			1	item	-	£	-	
Falsework and temp works			15	t	3,000	£/t	45,000	pier falsework and lifting beams
Ancillary items			1	item	25,000	£	25,000	jacks, bearings and temp stressing
Erection area and foundations			1,200	m^2	50	£/m^2	60,000	hardstanding for cranes
Erection labour	8	25	200	man-weeks	1,000	£/week	200,000	
						Total	**2,425,000**	
						Formwork/Falsework cost		

Table 12a: Precast segmental, crane. 1,200m length.

Span	50	m	Width	15	m			
Length	1,200	m	Depth	2.8	m			
Span/Depth ratio	18							
Concrete area	8.5	m^3/m	Concrete rate	120	£/m^3			
Concrete volume	10,200	m^3	Concrete cost	1,224,000	£			
Rebar density	200	kg/m^3	Rebar rate	900	£/t			
Rebar tonnage	2,040	t	Rebar cost	1,836,000	£			
Prestress density	50	kg/m^3	Prestress rate	2,500	£/t			
Prestress tonnage	510	t	Prestress cost	1,275,000	£			
Total formwork perimeter	35	m	Formwork/Falsework rate	**93**	£/m^2	per total formwork area		
Total formwork area	42,000	m^2	Formwork/Falsework cost	**3,894,400**	£			
Production rate	30	m/week	Total cost	**8,229,400**	£			
Learning curve	15	%	Total deck rate	**457**	£/m^2	per total deck plan area		
Overall erection programme	46	weeks						
	Men	Weeks	Quantity		Rate		Cost (£)	Notes
Casting								
Mould, formwork or travellers			2	item	200,000	£	400,000	2 moulds written off this project
Ancillary shutters			1	item	50,000	£	50,000	incl pier, stitch and end shutters
Casting area and foundations			2,500	m^2	400	£/m^2	1,000,000	incl shed
Shuttering labour	16	50	800	man-weeks	900	£/week	720,000	
Cranes or lifting			1	item	400,000	£	400,000	gantry and cranes
Storage area			50	weeks	3,000	£/week	150,000	
Transport								
Vehicles			46	weeks	2,500	£/week	115,000	
Transport labour	1	46	46	man-weeks	900	£/week	41,400	
Erection								
Cranes or lifting			46	weeks	2,500	£/week	115,000	50t mobile crane incl operator
Cranes or lifting			46	weeks	7,500	£/week	345,000	300t crawler crane incl operator
Gantry, girders or noses			1	item	-	£	-	
Falsework and temp works			15	t	3,000	£/t	45,000	pier falsework and lifting beams
Ancillary items			1	item	25,000	£	25,000	jacks, bearings and temp stressing
Erection area and foundations			2,400	m^2	50	£/m^2	120,000	hardstanding for cranes
Erection labour	8	46	368	man-weeks	1,000	£/week	368,000	
						Total	**3,894,400**	
						Formwork/Falsework cost		

Table 12a: Precast segmental, crane. 5,000m length.

Span	50	m	Width	15	m			
Length	5,000	m	Depth	2.8	m			
Span/Depth ratio	18							
Concrete area	8.5	m^3/m	Concrete rate	120	£/m^3			
Concrete volume	42,500	m^3	Concrete cost	5,100,000	£			
Rebar density	200	kg/m^3	Rebar rate	900	£/t			
Rebar tonnage	8,500	t	Rebar cost	7,650,000	£			
Prestress density	50	kg/m^3	Prestress rate	2,500	£/t			
Prestress tonnage	2,125	t	Prestress cost	5,312,500	£			
Total formwork perimeter	35	m	Formwork/Falsework rate	**82**	£/m^2	per total formwork area		
Total formwork area	175,000	m^2	Formwork/Falsework cost	**14,308,000**	£			
Production rate	30	m/week	Total cost	**32,370,500**	£			
Learning curve	15	%	Total deck rate	**432**	£/m^2	per total deck plan area		
Overall erection programme	192	weeks						
	Men	Weeks	Quantity		Rate		Cost (£)	Notes
Casting								
Mould, formwork or travellers			8	item	200,000	£	1,600,000	8 moulds written off this project
Ancillary shutters			4	item	50,000	£	200,000	incl pier, stitch and end shutters
Casting area and foundations			8,000	m^2	400	£/m^2	3,200,000	incl shed
Shuttering labour	64	52	3,328	man-weeks	900	£/week	2,995,200	
Cranes or lifting			2	item	400,000	£	800,000	gantry and cranes
Storage area			52	weeks	12,000	£/week	624,000	
Transport								
Vehicles			48	weeks	10,000	£/week	480,000	
Transport labour	4	48	192	man-weeks	900	£/week	172,800	
Erection								
Cranes or lifting			48	weeks	10,000	£/week	480,000	4 No. 50t mobile cranes
Cranes or lifting			48	weeks	30,000	£/week	1,440,000	4 No. 300t crawler cranes
Gantry, girders or noses			1	item	-	£	-	
Falsework and temp works			60	t	3,000	£/t	180,000	pier falsework and lifting beams
Ancillary items			4	item	25,000	£	100,000	jacks, bearings and temp stressing
Erection area and foundations			10,000	m^2	50	£/m^2	500,000	hardstanding for cranes
Erection labour	32	48	1,536	man-weeks	1,000	£/week	1,536,000	
						Total	**14,308,000**	
						Formwork/Falsework cost		

Table 12b: Precast segmental, gantry. 1,200m length.

Span	50	m	Width	15	m			
Length	1,200	m	Depth	2.8	m			
Span/Depth ratio	18							
Concrete area	8.5	m^3/m	Concrete rate	120	£/m^3			
Concrete volume	10,200	m^3	Concrete cost	1,224,000	£			
Rebar density	200	kg/m^3	Rebar rate	900	£/t			
Rebar tonnage	2,040	t	Rebar cost	1,836,000	£			
Prestress density	50	kg/m^3	Prestress rate	2,500	£/t			
Prestress tonnage	510	t	Prestress cost	1,275,000	£			
Total formwork perimeter	35	m	Formwork/Falsework rate	**113**	£/m^2	per total formwork area		
Total formwork area	42,000	m^2	Formwork/Falsework cost	**4,732,000**	£			
Production rate	50	m/week	Total cost	**9,067,000**	£			
Learning curve	25	%	Total deck rate	**504**	£/m^2	per total deck plan area		
Overall erection programme	30	weeks						
	Men	Weeks	Quantity		Rate		Cost (£)	Notes
Casting								
Mould, formwork or travellers			2	item	200,000	£	400,000	2 moulds written off this project
Ancillary shutters			1	item	50,000	£	50,000	incl pier, stitch and end shutters
Casting area and foundations			2,500	m^2	400	£/m^2	1,000,000	incl shed
Shuttering labour	16	50	800	man-weeks	900	£/week	720,000	
Cranes or lifting			1	item	400,000	£	400,000	gantry and cranes
Storage area			50	weeks	3,000	£/week	150,000	
Transport								
Vehicles			30	weeks	2,500	£/week	75,000	
Transport labour	1	30	30	man-weeks	900	£/week	27,000	
Erection								
Cranes or lifting			30	weeks	2,500	£/week	75,000	50t mobile crane incl operator
Cranes or lifting			2	weeks	12,500	£/week	25,000	300t mobile crane incl operator
Gantry, girders or noses			1	item	1,500,000	£	1,500,000	1 gantry written off on this project
Falsework and temp works			15	t	3,000	£/t	45,000	pier falsework and lifting beams
Ancillary items			1	item	25,000	£	25,000	jacks, bearings and temp stressing
Erection area and foundations			-	m^2	-	£/m^2	-	
Erection labour	8	30	240	man-weeks	1,000	£/week	240,000	
						Total	**4,732,000**	
						Formwork/Falsework cost		

Table 12b: Precast segmental, gantry. 5,000m length.

Span	50	m	Width	15	m			
Length	5,000	m	Depth	2.8	m			
Span/Depth ratio	18							
Concrete area	8.5	m^3/m	Concrete rate	120	£/m^3			
Concrete volume	42,500	m^3	Concrete cost	5,100,000	£			
Rebar density	200	kg/m^3	Rebar rate	900	£/t			
Rebar tonnage	8,500	t	Rebar cost	7,650,000	£			
Prestress density	50	kg/m^3	Prestress rate	2,500	£/t			
Prestress tonnage	2,125	t	Prestress cost	5,312,500	£			
Total formwork perimeter	35	m	Formwork/Falsework rate	**82**	£/m^2	per total formwork area		
Total formwork area	175,000	m^2	Formwork/Falsework cost	**14,361,600**	£			
Production rate	50	m/week	Total cost	**32,424,100**	£			
Learning curve	15	%	Total deck rate	**432**	£/m^2	per total deck plan area		
Overall erection programme	115	weeks						
	Men	Weeks	Quantity		Rate		Cost (£)	Notes
Casting								
Mould, formwork or travellers			8	item	200,000	£	1,600,000	8 moulds written off this project
Ancillary shutters			4	item	50,000	£	200,000	incl pier, stitch and end shutters
Casting area and foundations			8,000	m^2	400	£/m^2	3,200,000	incl shed
Shuttering labour	64	52	3,328	man-weeks	900	£/week	2,995,200	
Cranes or lifting			2	item	400,000	£	800,000	gantry and cranes
Storage area			52	weeks	12,000	£/week	624,000	
Transport								
Vehicles			58	weeks	5,000	£/week	290,000	
Transport labour	2	58	116	man-weeks	900	£/week	104,400	
Erection								
Cranes or lifting			58	weeks	5,000	£/week	290,000	2 No. 50t mobile cranes
Cranes or lifting			4	weeks	12,500	£/week	50,000	300t mobile crane incl operator
Gantry, girders or noses			2	item	1,500,000	£	3,000,000	2 gantries written off this project
Falsework and temp works			60	t	3,000	£/t	180,000	pier falsework and lifting beams
Ancillary items			4	item	25,000	£	100,000	jacks, bearings and temp stressing
Erection area and foundations			-	m^2	-	£/m^2	-	
Erection labour	16	58	928	man-weeks	1,000	£/week	928,000	
						Total	**14,361,600**	
						Formwork/Falsework cost		

Table 13: Whole span precast, gantry. 5,000m length.

Span	40	m	Width	15	m			
Length	5,000	m	Depth	2.5	m			
Span/Depth ratio	16							
Concrete area	8.0	m^3/m	Concrete rate	100	£/m^3			
Concrete volume	40,000	m^3	Concrete cost	4,000,000	£			
Rebar density	200	kg/m^3	Rebar rate	900	£/t			
Rebar tonnage	8,000	t	Rebar cost	7,200,000	£			
Prestress density	45	kg/m^3	Prestress rate	2,500	£/t			
Prestress tonnage	1,800	t	Prestress cost	4,500,000	£			
Total formwork perimeter	34	m	Formwork/Falsework rate	**58**	£/m^2	per total formwork area		
Total formwork area	170,000	m^2	Formwork/Falsework cost	**9,875,700**	£			
Production rate	100	m/week	Total cost	**25,575,700**	£			
Learning curve	15	%	Total deck rate	**341**	£/m^2	per total deck plan area		
Overall erection programme	58	weeks						
	Men	Weeks	Quantity		Rate		Cost (£)	Notes
Casting								
Mould, formwork or travellers			1	item	750,000	£	750,000	1 mould written off on this project
Ancillary shutters			1	item	100,000	£	100,000	incl dia shutters
Casting area and foundations			6,000	m^2	400	£/m^2	2,400,000	incl shed
Shuttering labour	35	65	2,275	man-weeks	900	£/week	2,047,500	
Cranes or lifting			1	item	600,000	£	600,000	gantry and cranes
Storage area			65	weeks	3,000	£/week	195,000	
Transport								
Vehicles			58	weeks	2,500	£/week	145,000	
Transport labour	1	58	58	man-weeks	900	£/week	52,200	
Erection								
Cranes or lifting			58	weeks	2,500	£/week	145,000	50t mobile crane incl operator
Cranes or lifting			3	weeks	15,000	£/week	45,000	500t mobile crane incl operator
Gantry, girders or noses			1	item	2,500,000	£	2,500,000	1 gantry written off on this project
Falsework and temp works			50	t	3,000	£/t	150,000	pier falsework and lifting beams
Ancillary items			1	item	50,000	£	50,000	jacks, bearings and temp stressing
Erection area and foundations			-	m^2	-	£/m^2	-	
Erection labour	12	58	696	man-weeks	1,000	£/week	696,000	
						Total	**9,875,700**	
						Formwork/Falsework cost		

Table 14: Incrementally launched, launching. 600m length.

Span	40	m	Width	15	m			
Length	600	m	Depth	2.5	m			
Span/Depth ratio	16							
Concrete area	8.5	m^3/m	Concrete rate	120	£/m^3			
Concrete volume	5,100	m^3	Concrete cost	612,000	£			
Rebar density	200	kg/m^3	Rebar rate	900	£/t			
Rebar tonnage	1,020	t	Rebar cost	918,000	£			
Prestress density	45	kg/m^3	Prestress rate	2,500	£/t			
Prestress tonnage	230	t	Prestress cost	573,750	£			
Total formwork perimeter	34	m	Formwork/Falsework rate	**98**	£/m^2	per total formwork area		
Total formwork area	20,400	m^2	Formwork/Falsework cost	**1,999,000**	£			
Production rate	25	m/week	Total cost	**4,102,750**	£			
Learning curve	25	%	Total deck rate	**456**	£/m^2	per total deck plan area		
Overall erection programme	30	weeks						
	Men	Weeks	Quantity		Rate		Cost (£)	Notes
Casting								
Mould, formwork or travellers			1	item	400,000	£	400,000	1 mould written off on this project
Ancillary shutters			1	item	10,000	£	10,000	incl dia shutters
Casting area and foundations			1,500	m^2	350	£/m^2	525,000	piled casting area
Shuttering labour	12	30	360	man-weeks	900	£/week	324,000	
Cranes or lifting			30	weeks	3,000	£/week	90,000	tower crane incl operator
Storage area			-	weeks	-	£/week	-	
Transport								
Vehicles			-	weeks	-	£/week	-	
Transport labour	-	-	-	man-weeks	900	£/week	-	
Erection								
Cranes or lifting			30	weeks	2,500	£/week	75,000	50t mobile crane incl operator
Cranes or lifting			2	weeks	12,500	£/week	25,000	300t mobile crane incl operator
Gantry, girders or noses			1	item	150,000	£	150,000	1 launching kit on this project
Falsework and temp works			10	t	3,000	£/t	30,000	falsework
Ancillary items			1	item	250,000	£	250,000	jacks, bearings and temp stressing
Erection area and foundations			-	m^2	-	£/m^2	-	
Erection labour	4	30	120	man-weeks	1,000	£/week	120,000	additional on launch days
						Total	**1,999,000**	
						Formwork/Falsework cost		

Table 14: Incrementally launched, launching. 150m length.

Span	40	m	Width	15	m			
Length	150	m	Depth	2.5	m			
Span/Depth ratio	16							
Concrete area	8.5	m³/m	Concrete rate	120	£/m³			
Concrete volume	1,275	m³	Concrete cost	153,000	£			
Rebar density	200	kg/m³	Rebar rate	900	£/t			
Rebar tonnage	255	t	Rebar cost	229,500	£			
Prestress density	45	kg/m³	Prestress rate	2,500	£/t			
Prestress tonnage	57	t	Prestress cost	143,438	£			
Total formwork perimeter	34	m	Formwork/Falsework rate	**272**	£/m²	per total formwork area		
Total formwork area	5,100	m²	Formwork/Falsework cost	**1,387,400**	£			
Production rate	25	m/week	Total cost	**1,913,338**	£			
Learning curve	35	%	Total deck rate	**850**	£/m²	per total deck plan area		
Overall erection programme	8	weeks						
	Men	Weeks	Quantity		Rate		Cost (£)	Notes
Casting								
Mould, formwork or travellers			1	item	400,000	£	400,000	1 mould written off on this project
Ancillary shutters			1	item	10,000	£	10,000	incl dia shutters
Casting area and foundations			1,500	m²	350	£/m²	525,000	piled casting area
Shuttering labour	12	8	96	man-weeks	900	£/week	86,400	
Cranes or lifting			8	weeks	3,000	£/week	24,000	50t crawler crane incl operator
Storage area			-	weeks	-	£/week	-	
Transport								
Vehicles			-	weeks	-	£/week	-	
Transport labour	-	-	-	man-weeks	900	£/week	-	
Erection								
Cranes or lifting			8	weeks	2,500	£/week	20,000	50t mobile crane incl operator
Cranes or lifting			2	weeks	12,500	£/week	25,000	300t mobile crane incl operator
Gantry, girders or noses			1	item	150,000	£	150,000	1 launching kit on this project
Falsework and temp works			5	t	3,000	£/t	15,000	falsework
Ancillary items			1	item	100,000	£	100,000	jacks, bearings and temp stressing
Erection area and foundations			-	m²	-	£/m²	-	
Erection labour	4	8	32	man-weeks	1,000	£/week	32,000	additional on launch days
						Total	**1,387,400**	
						Formwork/Falsework cost		

Table 14: Incrementally launched, launching. 1,200m length.

Span	40	m	Width	15	m			
Length	1,200	m	Depth	2.5	m			
Span/Depth ratio	16							
Concrete area	8.5	m^3/m	Concrete rate	120	£/m^3			
Concrete volume	10,200	m^3	Concrete cost	1,224,000	£			
Rebar density	200	kg/m^3	Rebar rate	900	£/t			
Rebar tonnage	2,040	t	Rebar cost	1,836,000	£			
Prestress density	45	kg/m^3	Prestress rate	2,500	£/t			
Prestress tonnage	459	t	Prestress cost	1,147,500	£			
Total formwork perimeter	34	m	Formwork/Falsework rate	**68**	£/m^2	per total formwork area		
Total formwork area	40,800	m^2	Formwork/Falsework cost	**2,786,500**	£			
Production rate	25	m/week	Total cost	**6,994,000**	£			
Learning curve	15	%	Total deck rate	**389**	£/m^2	per total deck plan area		
Overall erection programme	55	weeks						
	Men	Weeks	Quantity		Rate		Cost (£)	Notes
Casting								
Mould, formwork or travellers			1	item	400,000	£	400,000	1 mould written off on this project
Ancillary shutters			1	item	10,000	£	10,000	incl dia shutters
Casting area and foundations			1,500	m^2	350	£/m^2	525,000	piled casting area
Shuttering labour	12	55	660	man-weeks	900	£/week	594,000	
Cranes or lifting			55	weeks	3,000	£/week	165,000	tower crane incl operator
Storage area			-	weeks	-	£/week	-	
Transport								
Vehicles			-	weeks	-	£/week	-	
Transport labour	-	-	-	man-weeks	900	£/week	-	
Erection								
Cranes or lifting			55	weeks	2,500	£/week	137,500	50t mobile crane incl operator
Cranes or lifting			2	weeks	12,500	£/week	25,000	300t mobile crane incl operator
Gantry, girders or noses			1	item	150,000	£	150,000	1 launching kit on this project
Falsework and temp works			20	t	3,000	£/t	60,000	falsework
Ancillary items			2	item	250,000	£	500,000	jacks, bearings and temp stressing
Erection area and foundations			-	m^2	-	£/m^2	-	
Erection labour	4	55	220	man-weeks	1,000	£/week	220,000	additional on launch days
						Total	**2,786,500**	
						Formwork/Falsework cost		

Table 15a: Modular precast, scaffolding. 150m length.

Span	30	m	Width	15	m			
Length	150	m	Depth	2.0	m			
Span/Depth ratio	15							
Concrete area	10.5	m^3/m	Concrete rate	120	£/m^3			5.0m^3/m precast and 5.5 in-situ
Concrete volume	1,575	m^3	Concrete cost	189,000	£			
Rebar density	175	kg/m^3	Rebar rate	900	£/t			
Rebar tonnage	276	t	Rebar cost	248,063	£			
Prestress density	40	kg/m^3	Prestress rate	2,500	£/t			
Prestress tonnage	63	t	Prestress cost	157,500	£			
Total formwork perimeter	36	m	Formwork/Falsework rate	**64**	£/m^2	per total formwork area		32.5m precast and 3.5 in-situ
Total formwork area	5,400	m^2	Formwork/Falsework cost	**345,400**	£			
Production rate	15	m/week	Total cost	**939,963**	£			
Learning curve	25	%	Total deck rate	**418**	£/m^2	per total deck plan area		
Overall erection programme	13	weeks						
	Men	Weeks	Quantity		Rate		Cost (£)	Notes
Casting								
Mould, formwork or travellers			1	item	40,000	£	10,000	mould amortised over 4 projects
Ancillary shutters			1	item	-	£	-	
Casting area and foundations			100	m^2	100	£/m^2	10,000	casting bed
Shuttering labour	4	15	60	man-weeks	900	£/week	54,000	
Cranes or lifting			15	weeks	3,000	£/week	45,000	50t crawler crane incl operator
Storage area			15	weeks	1,000	£/week	15,000	
Transport								
Vehicles			6	weeks	1,500	£/week	9,000	
Transport labour	1	6	6	man-weeks	900	£/week	5,400	
Erection								
Formwork			525	m^2	20	£/m^2	10,500	slab & dia shutters
Cranes or lifting			13	weeks	4,250	£/week	55,250	100t crawler crane incl operator
Gantry, girders or noses			1	item	-	£	-	
Falsework and temp works			5	t	3,000	£/t	3,750	beams amortised over 4 projects
Ancillary items			1	item	10,000	£	2,500	jacks, bearings and temp stressing
Erection area and foundations			1,000	m^2	60	£/m^2	60,000	incl scaffolding & scaffolders
Erection labour	5	13	65	man-weeks	1,000	£/week	65,000	
						Total	**345,400**	
						Formwork/Falsework cost		

Table 15a: Modular precast, scaffolding. 50m length.

Span	30	m	Width	15	m			
Length	50	m	Depth	2.0	m			
Span/Depth ratio	15							
Concrete area	10.5	m^3/m	Concrete rate	120	£/m^3			5.0m^3/m precast and 5.5 in-situ
Concrete volume	525	m^3	Concrete cost	63,000	£			
Rebar density	175	kg/m^3	Rebar rate	900	£/t			
Rebar tonnage	92	t	Rebar cost	82,688	£			
Prestress density	40	kg/m^3	Prestress rate	2,500	£/t			
Prestress tonnage	21	t	Prestress cost	52,500	£			
Total formwork perimeter	36	m	Formwork/Falsework rate	**73**	£/m^2	per total formwork area		32.5m precast and 3.5 in-situ
Total formwork area	1,800	m^2	Formwork/Falsework cost	**131,967**	£			
Production rate	15	m/week	Total cost	**330,154**	£			
Learning curve	35	%	Total deck rate	**440**	£/m^2	per total deck plan area		
Overall erection programme	5	weeks						
	Men	Weeks	Quantity		Rate		Cost (£)	Notes
Casting								
Mould, formwork or travellers			1	item	40,000	£	3,333	mould amortised over 12 projects
Ancillary shutters			1	item	-	£	-	
Casting area and foundations			100	m^2	100	£/m^2	10,000	casting bed
Shuttering labour	4	5	20	man-weeks	900	£/week	18,000	
Cranes or lifting			5	weeks	3,000	£/week	15,000	50t crawler crane incl operator
Storage area			5	weeks	1,000	£/week	5,000	
Transport								
Vehicles			2	weeks	1,500	£/week	3,000	
Transport labour	1	2	2	man-weeks	900	£/week	1,800	
Erection								
Formwork			175	m^2	20	£/m^2	3,500	slab & dia shutters
Cranes or lifting			5	weeks	4,250	£/week	21,250	100t crawler crane incl operator
Gantry, girders or noses			1	item	-	£	-	
Falsework and temp works			5	t	3,000	£/t	1,250	beams amortised over 12 projects
Ancillary items			1	item	10,000	£	833	jacks, bearings and temp stressing
Erection area and foundations			400	m^2	60	£/m^2	24,000	incl scaffolding & scaffolders
Erection labour	5	5	25	man-weeks	1,000	£/week	25,000	
						Total	**131,967**	
						Formwork/Falsework cost		

Table 15a: Modular precast, scaffolding. 600m length.

Span	30	m	Width	15	m			
Length	600	m	Depth	2.0	m			
Span/Depth ratio	15							
Concrete area	10.5	m^3/m	Concrete rate	120	£/m^3			5.0m^3/m precast and 5.5 in-situ
Concrete volume	6,300	m^3	Concrete cost	756,000	£			
Rebar density	175	kg/m^3	Rebar rate	900	£/t			
Rebar tonnage	1,103	t	Rebar cost	992,250	£			
Prestress density	40	kg/m^3	Prestress rate	2,500	£/t			
Prestress tonnage	252	t	Prestress cost	630,000	£			
Total formwork perimeter	36	m	Formwork/Falsework rate	**60**	£/m^2	per total formwork area		32.5m precast and 3.5 in-situ
Total formwork area	21,600	m^2	Formwork/Falsework cost	**1,298,500**	£			
Production rate	15	m/week	Total cost	**3,676,750**	£			
Learning curve	15	%	Total deck rate	**409**	£/m^2	per total deck plan area		
Overall erection programme	46	weeks						
	Men	Weeks	Quantity		Rate		Cost (£)	Notes
Casting								
Mould, formwork or travellers			1	item	40,000	£	40,000	1 mould written off on this project
Ancillary shutters			1	item	-	£	-	
Casting area and foundations			100	m^2	100	£/m^2	10,000	casting bed
Shuttering labour	4	60	240	man-weeks	900	£/week	216,000	
Cranes or lifting			60	weeks	3,000	£/week	180,000	50t crawler crane incl operator
Storage area			60	weeks	1,000	£/week	60,000	
Transport								
Vehicles			25	weeks	1,500	£/week	37,500	
Transport labour	1	25	25	man-weeks	900	£/week	22,500	
Erection								
Formwork			2,100	m^2	20	£/m^2	42,000	slab & dia shutters
Cranes or lifting			46	weeks	4,250	£/week	195,500	100t crawler crane incl operator
Gantry, girders or noses			1	item	-	£	-	
Falsework and temp works			5	t	3,000	£/t	15,000	lifting beams on this project
Ancillary items			1	item	10,000	£	10,000	jacks, bearings and temp stressing
Erection area and foundations			4,000	m^2	60	£/m^2	240,000	incl scaffolding & scaffolders
Erection labour	5	46	230	man-weeks	1,000	£/week	230,000	
						Total	**1,298,500**	
						Formwork/Falsework cost		

Table 15b: Modular precast, launching. 150m length.

Span	30	m	Width	15	m			
Length	150	m	Depth	2.0	m			
Span/Depth ratio	15							
Concrete area	10.5	m^3/m	Concrete rate	120	£/m^3			5.0m^3/m precast and 5.5 in-situ
Concrete volume	1,575	m^3	Concrete cost	189,000	£			
Rebar density	175	kg/m^3	Rebar rate	900	£/t			
Rebar tonnage	276	t	Rebar cost	248,063	£			
Prestress density	40	kg/m^3	Prestress rate	2,500	£/t			
Prestress tonnage	63	t	Prestress cost	157,500	£			
Total formwork perimeter	36	m	Formwork/Falsework rate	**67**	£/m^2	per total formwork area		32.5m precast and 3.5 in-situ
Total formwork area	5,400	m^2	Formwork/Falsework cost	**362,900**	£			
Production rate	20	m/week	Total cost	**957,463**	£			
Learning curve	25	%	Total deck rate	**426**	£/m^2	per total deck plan area		
Overall erection programme	9	weeks						
	Men	Weeks	Quantity		Rate		Cost (£)	Notes
Casting								
Mould, formwork or travellers			1	item	40,000	£	10,000	mould amortised over 4 projects
Ancillary shutters			1	item	-	£	-	
Casting area and foundations			100	m^2	100	£/m^2	10,000	casting bed
Shuttering labour	4	15	60	man-weeks	900	£/week	54,000	
Cranes or lifting			15	weeks	3,000	£/week	45,000	50t crawler crane incl operator
Storage area			15	weeks	1,000	£/week	15,000	
Transport								
Vehicles			6	weeks	1,500	£/week	9,000	
Transport labour	1	6	6	man-weeks	900	£/week	5,400	
Erection								
Formwork			525	m^2	20	£/m^2	10,500	slab & dia shutters
Cranes or lifting			9	weeks	4,250	£/week	38,250	100t crawler crane incl operator
Gantry, girders or noses			1	item	50,000	£	12,500	kit amortised over 4 projects
Falsework and temp works			25	t	3,000	£/t	18,750	temporary piers and lifting beams
Ancillary items			1	item	50,000	£	12,500	jacks, bearings and temp stressing
Erection area and foundations			500	m^2	100	£/m^2	50,000	launching area
Erection labour	8	9	72	man-weeks	1,000	£/week	72,000	
						Total	**362,900**	
						Formwork/Falsework cost		

Table 15b: Modular precast, launching. 50m length.

Span	30	m	Width	15	m			
Length	50	m	Depth	2.0	m			
Span/Depth ratio	15							
Concrete area	10.5	m^3/m	Concrete rate	120	£/m^3			5.0m^3/m precast and 5.5 in-situ
Concrete volume	525	m^3	Concrete cost	63,000	£			
Rebar density	175	kg/m^3	Rebar rate	900	£/t			
Rebar tonnage	92	t	Rebar cost	82,688	£			
Prestress density	40	kg/m^3	Prestress rate	2,500	£/t			
Prestress tonnage	21	t	Prestress cost	52,500	£			
Total formwork perimeter	36	m	Formwork/Falsework rate	**89**	£/m^2	per total formwork area		32.5m precast and 3.5 in-situ
Total formwork area	1,800	m^2	Formwork/Falsework cost	**160,967**	£			
Production rate	20	m/week	Total cost	**359,154**	£			
Learning curve	35	%	Total deck rate	**479**	£/m^2	per total deck plan area		
Overall erection programme	3	weeks						
	Men	Weeks	Quantity		Rate		Cost (£)	Notes
Casting								
Mould, formwork or travellers			1	item	40,000	£	3,333	mould amortised over 12 projects
Ancillary shutters			1	item	-	£	-	
Casting area and foundations			100	m^2	100	£/m^2	10,000	casting bed
Shuttering labour	4	5	20	man-weeks	900	£/week	18,000	
Cranes or lifting			5	weeks	3,000	£/week	15,000	50t crawler crane incl operator
Storage area			5	weeks	1,000	£/week	5,000	
Transport								
Vehicles			2	weeks	1,500	£/week	3,000	
Transport labour	1	2	2	man-weeks	900	£/week	1,800	
Erection								
Formwork			175	m^2	20	£/m^2	3,500	slab & dia shutters
Cranes or lifting			3	weeks	4,250	£/week	12,750	100t crawler crane incl operator
Gantry, girders or noses			1	item	50,000	£	4,167	kit amortised over 12 projects
Falsework and temp works			25	t	3,000	£/t	6,250	temporary piers and lifting beams
Ancillary items			1	item	50,000	£	4,167	jacks, bearings and temp stressing
Erection area and foundations			500	m^2	100	£/m^2	50,000	launching area
Erection labour	8	3	24	man-weeks	1,000	£/week	24,000	
						Total	**160,967**	
						Formwork/Falsework cost		

Table 15b: Modular precast, launching. 600m length.

Span	30	m	Width	15	m			
Length	600	m	Depth	2.0	m			
Span/Depth ratio	15							
Concrete area	10.5	m^3/m	Concrete rate	120	£/m^3			5.0m^3/m precast and 5.5 in-situ
Concrete volume	6,300	m^3	Concrete cost	756,000	£			
Rebar density	175	kg/m^3	Rebar rate	900	£/t			
Rebar tonnage	1,103	t	Rebar cost	992,250	£			
Prestress density	40	kg/m^3	Prestress rate	2,500	£/t			
Prestress tonnage	252	t	Prestress cost	630,000	£			
Total formwork perimeter	36	m	Formwork/Falsework rate	**58**	£/m^2	per total formwork area		32.5m precast and 3.5 in-situ
Total formwork area	21,600	m^2	Formwork/Falsework cost	**1,261,750**	£			
Production rate	20	m/week	Total cost	**3,640,000**	£			
Learning curve	15	%	Total deck rate	**404**	£/m^2	per total deck plan area		
Overall erection programme	35	weeks						
	Men	Weeks	Quantity		Rate		Cost (£)	Notes
Casting								
Mould, formwork or travellers			1	item	40,000	£	40,000	1 mould written off on this project
Ancillary shutters			1	item	-	£	-	
Casting area and foundations			100	m^2	100	£/m^2	10,000	casting bed
Shuttering labour	4	60	240	man-weeks	900	£/week	216,000	
Cranes or lifting			60	weeks	3,000	£/week	180,000	50t crawler crane incl operator
Storage area			60	weeks	1,000	£/week	60,000	
Transport								
Vehicles			25	weeks	1,500	£/week	37,500	
Transport labour	1	25	25	man-weeks	900	£/week	22,500	
Erection								
Formwork			2,100	m^2	20	£/m^2	42,000	slab & dia shutters
Cranes or lifting			35	weeks	4,250	£/week	148,750	100t crawler crane incl operator
Gantry, girders or noses			1	item	50,000	£	50,000	1 launching kit on this project
Falsework and temp works			25	t	3,000	£/t	75,000	temporary piers and lifting beams
Ancillary items			1	item	50,000	£	50,000	jacks, bearings and temp stressing
Erection area and foundations			500	m^2	100	£/m^2	50,000	launching area
Erection labour	8	35	280	man-weeks	1,000	£/week	280,000	
						Total	**1,261,750**	
						Formwork/Falsework cost		

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CONCRETE BRIDGE DEVELOPMENT GROUP

The Concrete Bridge Development Group aims to promote excellence in the design, construction and management of concrete bridges.

With a membership that includes all sectors involved in the concrete bridge industry –bridge owners and managers, contractors, designers and suppliers– the Group acts as a forum for debate and the exchange of new ideas. A major programme of bridge assessment, strengthening and widening is already underway to accommodate European standards and the increasing pressures on the UK road network. The Group provides an excellent vehicle for the industry to co-ordinate an effective approach and to enhance the use of concrete.

Through an active programme of events and seminars, task groups, newsletters, study visits and publications, the Concrete Bridge Development Group aims to:

- Address the challenge of the national bridge programme
- Provide a focus for all those involved in concrete bridge design, construction and management
- Promote an integrated approach and encourage development of innovative ideas and concepts
- Promote best practice in design and construction through education, training and information dissemination
- Make representations on national and international codes and standards
- Identify future research and development needs
- Maximise opportunities to develop the wider and better use of concrete.

Membership of the Concrete Bridge Development Group is open to those who have an interest in promoting and enhancing the concrete bridge industry. Five main types of membership are available:

- Group membership for industry organisations and associations
- Corporate membership for contractors, consultants, suppliers and specialist service companies
- Associate membership for academic organisations
- Bridge owners for all organisations that commission, own, maintain and manage concrete bridges
- Individual consultants

By being representative of the whole industry, the Concrete Bridge Development Group acts as a catalyst for the best in concrete bridge design, construction, maintenance and management.

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CONCRETE BRIDGE DEVELOPMENT GROUP

Best Construction Methods for Concrete Bridge Decks - Cost Data: A state-of-the-art report

This technical guide summarises all the key areas concerning concrete bridge decks. It will encourage early participation between the owners, developers, designers and contractors who are intending to construct a bridge. It sets out to help those teams to better understand the many factors that contribute to the best construction methods, and to appreciate the essential requirements and consequences of achieving these aims successfully. It also covers the conceptual, general and particular choices of bridge deck, and the construction methods for each bridge deck type.

It will allow teams to select the most suitable bridge deck type dependent on the main series of spans, or allows them to select the best span for a particular bridge type. Detailed descriptions are given of fifteen bridge types to aid this critical process. This is the first time that such extensive programming and cost data for all concrete bridge types has been published in a useable format. Teams are now able to price the full range of suitable concrete bridge decks, for any size of scheme.

A summary of all the key output data is shown in both tabular, and graphical format that plots the total bridge deck costs per total deck plan area (in £/m^2) for each bridge type against the appropriate range of deck lengths.

Simon Bourne, Bridge Consultant and former owner of Benaim. Benaim was a company that specialised in the design of major bridges for contractors, working with alternative designs, value engineering commissions or design and construct projects. Simon has designed many award-winning bridges, which have been recognised for their elegance, economy and innovation including the multi-award winning Clackmannanshire Bridge across the Firth of Forth. Simon was Chairman of the CBDG from 2012-2015 and has worked extensively with the Technical Committee since 2003. He was the winner of the IABSE Milne Medal in 2012 for major and personal contribution to excellence in structural engineering design.

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