Concrete Bridge Design and Construction series

This series is authored by the Concrete Bridge Development Group (CBDG)

The group 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. Further information on the CBDG can be found at: www.cbdg.org.uk

No.5: Concrete bridge formwork and falsework

Introduction

In this article, the various types of formwork and falsework needed to construct a concrete bridge are examined. As noted in the previous article[1], the choice of bridge type depends not only on the general parameters of the scheme (such as typical spans, overall deck area, clearance requirements, alignment and the overall aesthetic), but also on the particular and local parameters of the site, many of which are related to construction. The CBDG's forthcoming Technical Guide: *Best construction methods for concrete bridge decks* will give further information about all these key parameters, especially programme and costs. The deck construction process can be broadly split into three areas; casting, transportation and erection, which are outlined here. Further details of the particular bridge types will be provided during the course of the next three articles. CBDG TG 5[2] also gives further information about these formwork and falsework options.

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 pre-existing 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 – quite possibly some distance away. The precast units then need to be erected into their final bridge form, which needs a falsework system.


Figure 1
In situ casting gantry: Incarville Viaduct, France

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 1). The formwork for these 20-40m long pours would usually be steel, as large steel forms can accommodate the casting of around 20-100 units before needing to be refurbished or re-faced.

Figure 2
Short timber forms:
Medway Crossing Viaducts, UK

Figure 3
Long steel forms:
Clackmannanshire Bridge, UK

Figure 4
Clackmannanshire Bridge: internal steel formwork

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 to in excess of 300m. Here, the bridge is formed from short *in situ* segments, or units, each 3-5m long and cast in a travelling formwork system. These tend to be timber forms (Figure 2) though they can also be steel, depending on the number of uses.

For precast units, the formwork is invariably steel, as the mould is used many times. Long, steel moulds (around 10-50m for beams) can cast 20-100 units before needing to be refurbished, whereas short, steel moulds (3-5m for segments) can cast 50-300 units. As such, 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 3). 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, thus creating the desired alignment. In the UK, formwork and falsework should be designed in accordance with BS 5975[3], with consideration also given to The Concrete Society's *Formwork – a guide to good practice*[4].

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 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[5]. 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 >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 4). 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 will be explained in more detail in future articles. 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.

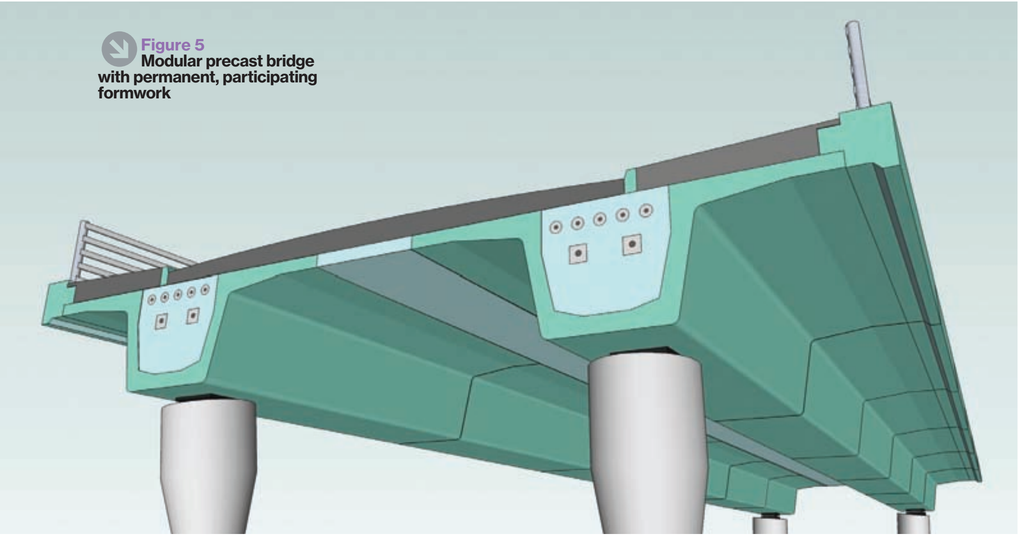

Figure 5
Modular precast bridge with permanent, participating formwork

Figure 8
Stanstead Abbotts Viaduct, UK: falsework girder and towers

Figure 7
Scaffolding birdcage

Figure 6
Controlled permeability formwork: Flintshire Bridge, UK

Precasting facilities, either in a bespoke factory or in a yard set up on site, will comprise the formwork and its foundations, as well as 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. 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 1,000t or more. The precasting facility also needs to have sufficient land for the areas needed to store the units. As noted in a previous article[1] 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 pushed or pulled out over the piers.

Plain concrete finishes, as defined in BS EN 13670[6], 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.
Precast concrete lattice girder panels, which can span up to 4m, can be used as they are easily made to become both permanent and participating. Two types of non-participating permanent formwork are also 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, 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[7].

The modular precast bridge, developed by the CBDG, is also a permanent formwork system, having short, precast shell segments that provide a permanent and participating structural formwork for the *in situ* infill concrete (Figure 5). In a similar way, precast units can also be used to form the exposed face of a wall or column. In these cases, high quality concrete (e.g. using white cement or pigments in the mix) can be used to give the required appearance, with lower quality concrete used for the infill material.

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. 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 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 some, or all of these elements. Two excellent Concrete Society documents describe the use of these visual concretes[8-9].

It is possible to increase the density and reduce the porosity of the concrete cover zone through the use of controlled permeability formwork[10]. 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 6).

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 7) 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, moving themselves forward as the construction progresses. Such gantries may be placed either above the deck or below it, depending on the clearance and operational issues, many of which will be discussed in more detail later in this series. 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 9
Precast segmental gantry: A13 West of Heathway Viaduct, UK

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 while others might be purpose-made.

The erection of precast elements entails the use of cranes and/or various falsework to support the precast units. Standard (and some bespoke) precast beams (weighing 5-80t) are erected using a range of 100-800t mobile or tracked cranes, in either single or tandem formation. The heaviest beams (weighing 80-120t) will use the biggest 1,200t cranes, which are becoming more prevalent in many developed 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, Figure 8) or balanced cantilever construction, where the balanced cantilever is held stable with falsework 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 and move it both 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 exceeds c.20,000m^2, gantries can be used, which can erect segments span by span (either overhead or under-slung), or in balanced cantilever (where

Figure 10
Launching nose and bearings: Clackmannanshire Bridge, UK

they also tend to provide the stability to the balanced cantilever) (Figure 9). 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 10). Modular precast schemes, using short shell segments, infilled with *in situ* concrete into 20-40m lengths, can also be launched into place in a similar manner.

The bridge and all its falsework must remain stable during 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, either to clamp concrete elements together, or to clamp 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 (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.

Conclusions

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. *fib* Bulletin 48[11] gives further details of the aspects described here. It was noted in the previous article[1] how further pricing information was needed to describe the details of both programme and costs of all the various concrete bridge options, so that informed choices can be made at a sufficiently early stage in the design process. The forthcoming CBDG Technical Guide, TG 14, will feature all these key pricing issues, while future articles in this series will examine the principles behind the whole range of available bridge types.

References and further reading

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Further reading

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