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. 7: Concrete bridge construction methods — precast

Introduction

This month's article from the CBDG's Technical Committee examines the precast construction methods for a bridge. It should be read in conjunction with the previous article[1], which described the various *in situ* techniques. There are six basic types of precast concrete bridge:

- Standard precast inverted T/Y, I or U beams
- Bespoke precast T, I or U beams
- Precast segmental box girders with short segments
- Whole span precast box girders
- Incrementally launched box girders
- Modular precast system with short shell segments

These options 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. Comparisons between *in situ* and precast methods were described in the first article in the series[2]. Precast bridges are commonly 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. CBDG Technical Guide No. 5 gives general guidance on many of these production issues[3].

Standard precast beam bridges

These bridges utilise standard precast sections, which are cast in 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-lying sites with good access.

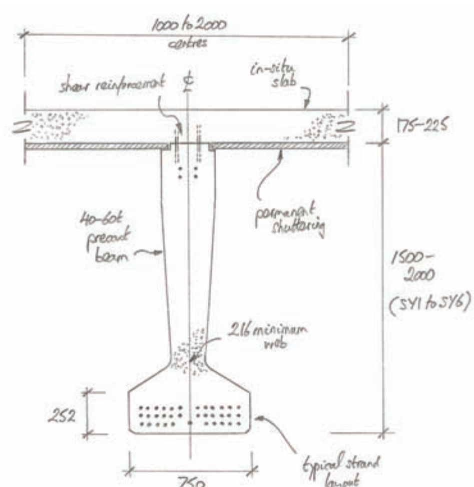

Figure 1
Standard precast SY beam

Various types of standard precast beams have been discussed in previous articles, along with details of how they are joined together to form either solid slabs, or beams and slabs[4,5]. 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 approx. 160mm thick (this thickness increases to 175-225mm for SY beams (Figure 1)). To maximise efficiency of the prestressing, beams should be made as deep as possible and spaced far apart. Typical spans for these beam and slab decks vary from 15-40m. 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. De-bonding of some of the

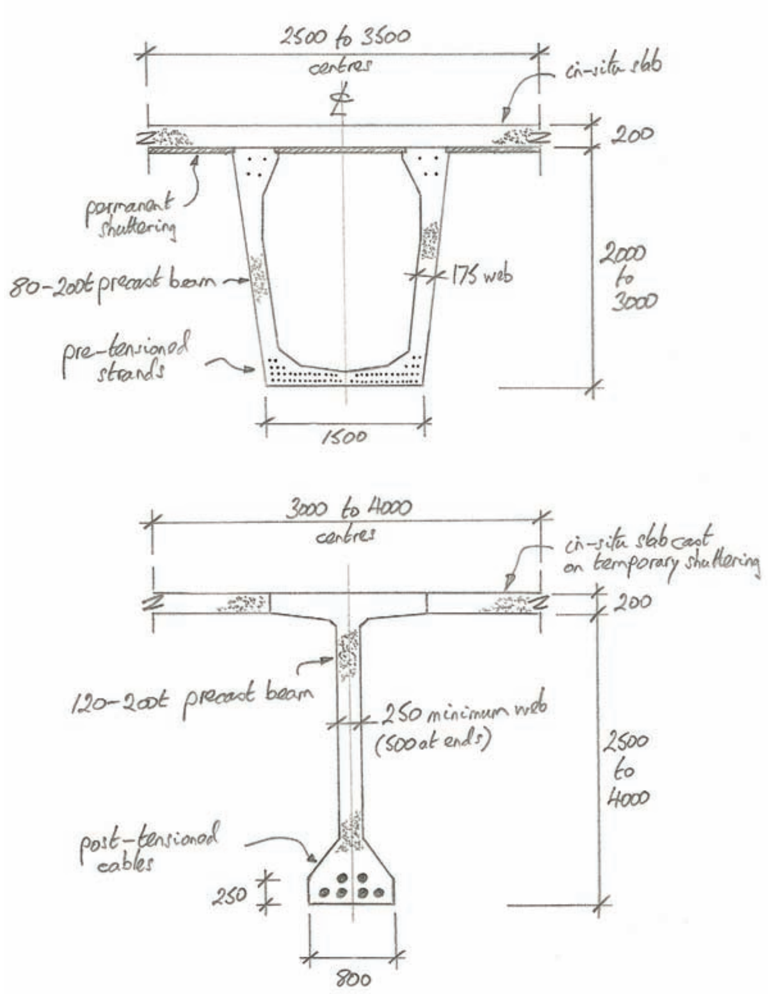

Figure 2 Kingsway Canal Bridge, UK: standard precast beams

Figure 3 Two bespoke precast beam types

prestressing strands is often used at the ends of the beams, so as not to either overstress the bottom fibre or put tension into the top fibre. Alternatively, further strands or reinforcement can be added to the top of the beam to control these effects. The prestress and self-weight loads are carried on the precast beam alone and all other loads (finishes and traffic) are carried on the composite section, i.e. including the top slab. Beams weigh 5-60t and can be readily transported by low-loader.

Beams are erected as simple spans (Figure 2), but are often then made continuous to avoid the need for expansion joints. 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[6]. The CBDG's Technical Guide No. 13[7] provides a set of integral bridge calculations to Eurocode 2.

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, provided there is good access for crane erection.

Bespoke precast beam bridges

These bridges utilise bespoke precast sections, which are cast either on or off site, and then erected by crane or gantry. They are ideal for medium spans, ranging from 30-60m. The precast beams can be either pre-tensioned 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-lying 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 3). With post-tensioned beams, a significant shear relief is obtained from the inclined cables, allowing thinner webs to be used. Beams can be 2-4m deep and weigh 60-200t. If cast on site, further facilities will be required such as a casting shed and lifting equipment to move the beams to the storage area and 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 erected in balanced cantilever, with an *in situ*, post-tensioned concrete stitch formed between the beam ends. Cranes can accommodate beams to approx. 150t, but in the 100-200t range, gantries would normally be required (Figure 4). However, gantries

Figure 4
Egea Bridge, Spain: gantry-erected bespoke beams

Figure 5
Segments in storage: A13 Viaduct, UK

can normally only be justified once the deck area is more than about 10 000m². Such gantries 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, or using temporary formwork or precast concrete slabs as permanent, participating shuttering.

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.

Precast segmental bridges

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 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 000m², where the investment in casting areas and erection equipment is justified. The aesthetics are very good, especially with variable depth girders and inclined webs. With crane erection, the method is best suited to low-lying sites with good access, but once gantries are used, it suits any large site.

The sizing of the box has been described previously[1], though the minimum web thickness is now 300mm, as there is more control of concreting in the precast factory. Each 2-5m long segment is poured in one operation, typically on a daily cycle. 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[8,9].

Segments are poured in steel moulds, each able to cast 200-300 segments. Segment lengths vary, though around 3m is usual, and widths can be tailored to suit the site. Typical weights are 25-75t for segments closer to the piers, or with those having large blisters/deviators, being around 100-150t. 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 alignment being incorporated by small angular changes between these two segments. The casting process takes the form of a production line, with many activities taken off the critical path so as to guarantee the daily cycle. Reinforcement is fixed in a jig and the cage (including all prestressing ducts and anchorages) is then lifted into the mould as a single piece. Segments are stored before being transported to the bridge, with the amount of storage being dependent on the relative rates of casting and erecting (Figure 5).

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 25-60m 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, the simplest solution is to erect all the segments using cranes (Figure 6). Sophisticated gantries then become economic for larger structures, with a total deck area of over 20 000m². Gantries are supported on the previously built deck and the next pier location, and launch themselves forward to the next position. Construction concludes with any continuity stitches, end span units and final prestressing. Creep occurs in any configuration where the as-built moments are not the same as the monolithic moments[1]. As there is no reinforcement across the joints, they are always designed as fully compressed under all SLS load combinations. In the UK currently, precast segmental schemes must use external cables[10].

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

Whole span precast bridges

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. They are best suited to either 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.

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 600-2000t, not 50-100t! Steel moulds are used to cast the whole span, generally in a 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. Though 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 into storage. The units are then usually taken along the completed bridge deck on wheeled bogies or rail systems. Erection of the whole span is then carried out by an overhead gantry or marine shear legs. 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 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 for the very longest bridge sites.

Figure 7
Launching nose: Clackmannanshire Bridge, UK

Figure 6
Crane-erected pier segment: A13 Viaduct, UK

Incrementally launched bridges

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. Bridges should be at least 200m long with deck areas of at least 3000m^2, though maximum lengths of over 1000m 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.

The sizing of the box is as described previously, but the web thickness is kept to at least 400mm, as every section will experience high shears during the launch. Webs should be positioned directly above the temporary bearing locations, to ensure there are no moments in the section during the launch[9,11]. The typical span for launching is 40-50m, with maximum spans of about 80m, though such spans will need temporary props during launch. The main series of spans should, wherever possible, be of equal length. The length of each unit to be cast is chosen to suit the particular span. Typically, each 15-30m long unit is poured on a weekly cycle, though it is possible to cast whole 40-50m spans on a two-weekly cycle. In either case, the typical production rates are about 25m/week.

Plywood formwork could be used for smaller decks, but for larger decks (over about 5000m^2) steel moulds should be used. Generally, the bottom slab and webs are cast first, followed by the top slab. The typical weekly cycle begins on a Monday with the launching of the unit, followed by the concrete pours during the week. The unit is then cured over the weekend ready for stressing again the following Monday. The foundations for the casting area would generally be piled, as they need to be rigid enough to show virtually no movement during casting. This alignment control is vital because once the unit is cast, its shape cannot be changed. The casting process is also run as a production line, with most activities taken off the critical path to guarantee the weekly cycle. Reinforcement and prestressing is pre-assembled in jigs, and then lifted into the mould in a series of large pieces.

In order to limit the moments in the deck during the launch, a nose is attached to the front of the bridge, with an approx. length 70% that of a typical span (Figure 7). The bridge slides over temporary

Figure 8 Clackmannanshire Bridge, UK: pushing jacks

launching bearings at every pier and the total weight being launched can be 4000-40 000t, which will require longitudinal forces of 200 – 2000t, depending on the deck gradients. The deck can be pulled forward using prestressing strands or pushed forward with long-stroke jacks (Figure 8). 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 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.

Incrementally launched bridges, using

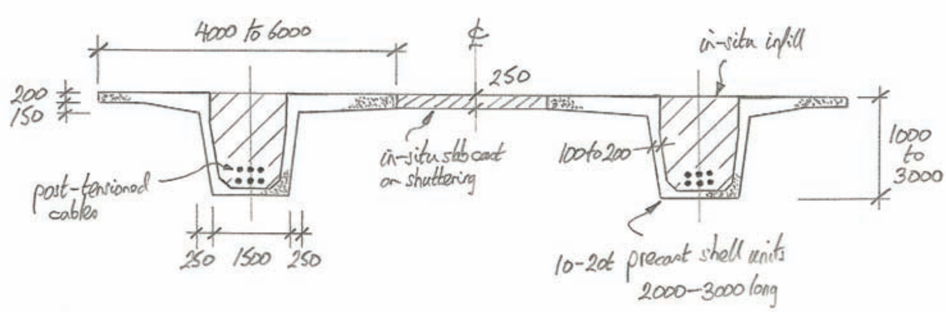

Figure 9a Modular precast section

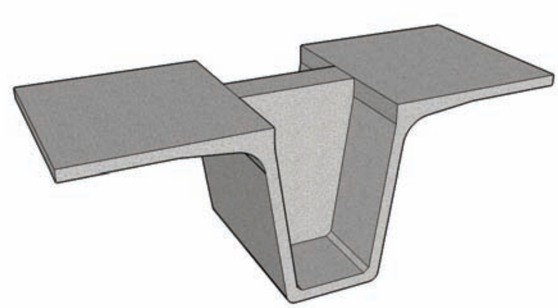

Figure 9b Modular precast shell unit

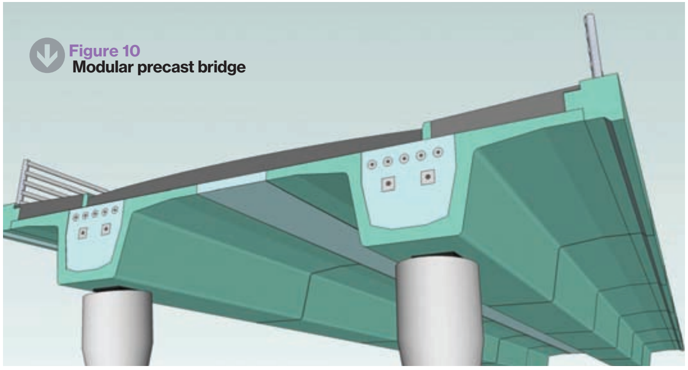

Figure 10
Modular precast bridge

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.

Modular precast bridges

Modular precast bridges were developed by Benaim for the CBDG in order to create a solution that could be used at any site with 15-50m spans. They are an *in situ* twin rib deck[1] cast inside precast shells, with span to depth ratios of 14-18, which can be erected using several techniques. 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[9,12].

The solution was developed into a modular system from the use of similar precast shells on two recent bridges. The system consists of 2-3m long precast shells, cast in factories off site, that are 4-6m wide and 1-3m deep, allowing a whole range of spans, widths and alignments to be accommodated (Figure 9a and b). Post-tensioning is then placed inside the shells and an *in situ* concrete core is cast to complete the rib (Figure 10). 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. Steel moulds are used to form the precast shells, which weigh 10-20t and are easily transported to site. The construction methods can be varied to suit specific bridges, but suggested methods include erection on scaffold/ beams or gantries, or the launching, or lifting of whole ribs using cranes; all of which produce typical production rates of 15-20m/week. A railway version is also available, which for the typical spans seen in most situations (10-15m weighing 100-200t) can be slid or lifted into place with cranes or transporters.

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

Conclusions

Various methods for the precast construction of concrete bridges have been described, which allow both the smallest slab bridges, and some of the longest beam bridges in the world, to be built. A forthcoming CBDG Technical Guide (TG 14) is due to be published this year that will contain further information about the detailed programming and costing of 15 different bridge types (including all the ones described here) allowing teams to select the best bridge solution at an early stage.

References and further reading

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