Bridge Replacement Guide

A state-of-the-art report

Technical Guide No. 15

Transport Scotland · highways england · Shay Murtagh · NetworkRail · Banagher Precast Concrete · PERI · bam nuttall

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CONCRETE BRIDGE DEVELOPMENT GROUP

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1. Introduction

The purpose of this technical guide is to address the many small to medium-span bridge replacement situations, in the UK especially, where steel-composite bridge solutions are often developed, mainly because the owners, consultants and contractors are not sufficiently aware of the wide range of suitable concrete bridge solutions that are equally viable and competitive.

1.1 Scope

This guide concentrates on the typical bridge replacement schemes that are most often seen in the UK, i.e. spans of 10-30m that are either single-span or two-span structures. Such schemes need to be built safely, simply, quickly and effectively across a live roadway, railway or waterway. The solutions cover best practices for both the design and construction of replacement road and rail bridges. Speed and ease of construction is very important in order to limit possession and/or traffic management costs and delays. As well as these typical bridge replacement schemes, the guide equally addresses the creation of new concrete bridges of this size and type.

Both in-situ and precast solutions are examined and shown, together with both reinforced concrete (RC) or prestressed concrete (PSC) schemes. In-situ solutions include slabs, downstand twin-ribs and concrete through-girders – generally cast on a temporary support system consisting of girders/beams and props, where needed, i.e. to avoid scaffolding and to therefore allow traffic below. An innovative new system for casting these simple spans in-situ is described in detail, allowing such options to become more common in the UK. Precast solutions include standard precast beams to form solid slabs or beams and slabs, which are all generally erected by crane. An innovative solution for railway schemes is also examined and shown, using new precast concrete through-girders – bespoke precast edge beams that are lifted on site by large mobile cranes and are then completed with an in-situ infill and precast transverse slabs – the '*UU-Bridge*'. The precasting of whole spans is demonstrated too – generally by sliding methods or by using a self-propelled modular transporter (SPMT). All these railway methods using precast elements allow decks to be completed within 2-3 days, i.e. normal to long weekend possessions.

The Modular System created by the Concrete Bridge Development Group (CBDG) is briefly included, although much of this system is already described in detail in CBDG TG 11[1]. Precast arches and portals are also mentioned, although these are also described in much greater detail in CBDG TG 12[2]. CBDG TG 14[3] is widely referenced as it outlines the critical importance of the construction method in the choice of all concrete bridge decks, and it goes on to give detailed data relating to production rates, programme and cost breakdowns for every available concrete bridge deck solution, including the majority of those shown in this guide.

1.2 Target Audience

The target audience is consultants, designers, contractors, sub-contractors, suppliers and owners. This guide will generate a significant additional area of expertise that owners, consultants and contractors can call upon when investigating bridge replacement schemes, or indeed new schemes of this size and type. The greater use of high quality, good value, robust, durable and sustainable concrete options with a high aesthetic content should result.

For a general description of all the issues related to concrete bridges, the reader is directed towards twelve CBDG Technical Notes in CBDG TN 1-12[4]. These notes were also published monthly in *The Structural Engineer* during 2014.

2. Bridge Replacement Issues

2.1 General

This guide is aimed primarily at the UK market, where there is an unusual dominance of steel-composite bridges that is not generally seen globally. However, all the solutions shown do equally apply to the global market, particularly as the stock of bridges worldwide continues to age, and where client authorities do need to consider the increasing prevalence of bridge replacement issues. The key issue in the majority of all these cases is invariably the maintenance of live traffic both on the structure itself and on the route over which the bridge spans. This guide therefore considers both highway and railway bridges spanning over roads, railways or waterways. The replacement bridge solutions described are equally applicable to locations where new bridges of this size and form are being investigated.

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 therefore 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. Further discussion of these broad benefits of concrete bridges can be seen in CBDG TG 14[3], while the particular nature of the speed of construction required to limit traffic interruptions can be seen in CBDG TG 5[5].

2.2 Concrete

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 that is virtually free of maintenance.

The solutions described are mainly aimed at modest 10-30m spans, generally single spans, but some of the solutions can also extend up to 40-50m and these are noted where necessary. Many of the highway options will encompass the range within which integral bridges should be used, i.e. bridges with no joints and ideally without any bearings either. In the railway environment, generally away from road salts, the standard option would be to have single span jointed structures, i.e. with joints and bearings, in order to avoid the need for any joints in the railway track itself.

Much of the guide correctly concentrates on PSC bridges, although RC solutions are shown where they are applicable. In broad terms, RC sections are only used for spans smaller than about 20m in the highway environment (15-20m in the railway). These RC sections are relatively simple to design as they are invariably governed by ultimate limit state (ULS) actions. Crack widths are checked under the quasi-permanent actions and serviceability limit state (SLS) stresses under the characteristic actions. However, PSC solutions are normally more economical than the equivalent RC sections, and PSC also lends itself to easier and faster construction methods. As can be seen in most highway markets, once a PSC system of precast beams exist, then RC solutions tend not to be used, even with these smaller spans.

Many of the best precast solutions also now use High Strength Concrete (HSC), which is defined as having a specified characteristic cube strength between 60 and 100 N/mm^2, although higher strengths have been achieved and used. These offer significant long-term benefits (in terms of durability and lighter sections), but are often mainly used in order to facilitate the construction methods (as they also allow much earlier striking of the forms and application of the prestressing). Further details about HSC can be seen in both CBDG TG 6[9] and TG 14[3].

Precast construction is a major feature of this guide as it does often enable the fastest form of construction in these live traffic configurations. However, in-situ construction can also be used in the right circumstances as long as both the bridge designer and the main contractor are suitably experienced and technically skilful enough. In these circumstances, a number of innovative formwork and falsework solutions could be used and some are presented here. In-situ construction mainly applies to the highway environment where works can be carried out during diversions and in stages. In the railway environment, most solutions would use some form of precasting, unless the scheme is to provide for a new railway. In-situ railway bridges can be built alongside the existing structure though and then lifted, slid or moved across. In all cases, the buildability of the scheme is paramount – the overall form and all the key details should be considered in relation to safety, speed and ease of construction, and good value.

Concrete bridges with simple outlines, forms and details generally have far fewer potential hidden defects than the corresponding steel solutions, which have a multiplicity of plate, weld, bolt and connection details, all of which have the potential to become hidden defects if great care is not taken in the design, detailing, construction and maintenance. In broad terms, concrete bridges are always simpler and more robust. Well designed and constructed, modern concrete bridges should be virtually maintenance free for the life of the bridge.

2.3 Prestressing

There are no issues with protection of the strands in any modern, pre-tensioned scheme as the strands are all cast within high-quality, high-strength concrete. The ends of the beams or girders are also often cast in to in-situ concrete diaphragms that form part of the integral abutment (or pier). Where there is no in-situ diaphragm (e.g. at movement joints) then options are to add a specified concrete cover to the ends of the beams as would be done for any PSC anchorage, recess the concrete around the strands then patch over and paint with a suitable water proofer, or paint over without recessing and patching, dependant on the Exposure category. Equally, there are no post-tensioning issues in modern concrete bridges as all the areas related to good grouting practice and good anchorage design and detailing are described in The Concrete Society TR 72[10]. This provides a three-layer protection system comprising the high-performance grout, continuous plastic ducts and the high-quality concrete section itself. Similarly, anchorages are protected by bonded RC, typically waterproofed for added durability. There are no precast segmental duct issues at all in these sections as all the post-tensioning for the schemes shown is located within in-situ, monolithic concrete with continuously sealed plastic ducts and high-performance grout.

All the sections shown therefore have bonded prestressing, i.e. pre-tensioning or internal post-tensioning. As a result, all the PSC sections will be governed by decompression of the extreme bottom fibres, i.e. the SLS frequent traffic combinations, which are the quasi-permanent and prestressing actions plus 70-80% of the typical traffic loading. These decompression checks are on the basis that any air around the highway or railway deck would contain de-icing salt spray, i.e. class XD3, from a highway below. Conservatively, it has also been assumed that this criterion includes both edge beams and internal beams. As well as this dominant decompression check, stress checks are also then made for the SLS characteristic combinations and the ULS combinations, but these are unlikely to ever be critical for the prestressing, although they will determine the concrete strengths required.

The advantages of PSC for these internally bonded members are that the section is fully compressed under all frequent traffic loads, giving a durable and stiff structure with small deflections. All the post-tensioned solutions also have the ability, through the use of the inclined cables, to carry a significant proportion of the shear loads, which reduces the size of the webs, further increasing the section efficiency and overall deck weight.

The deck sizes and layouts are not overly governed by any particular codes, standards or loadings, making the suggested solutions applicable to most global locations.

Good engineering judgement and the practicalities of the construction method actually define most of the main member sizes and details. Of course, the particular codes need to be fully addressed to define all the detailed prestressing and reinforcement requirements, but the concrete outline is best developed by a skilful and experienced bridge engineer. A good description of all the key issues related to concrete bridges is shown in CBDG TN 1-12[4] and in accordance with EC2[8] for an integral precast beam highway bridge is shown with calculations in CBDG TG 13[11].

3. Highway Bridge Replacement

3.1 Issues

3.1.1 General

These highway bridge solutions typically cover the 10m to 30m spans that are most common, although it is noted where solutions can extend to 40-50m. Typical highway bridge widths are about 10m to 20m, although wider schemes are readily accommodated by the same solutions. In the railway environment, new bridges are generally built off-line and moved across during short possessions. In the highway environment, the most common arrangement is to build the new bridge on-line, i.e. directly in the location of the old bridge. This can be done in two ways – diversions or stages. As highway traffic can usually be readily diverted, the optimum method for the construction of the new bridge would be to divert the traffic. This option leaves the construction site clear of traffic on or around the bridge, although there may well still be traffic underneath the bridge. In urban locations, it is generally possible to find a suitable diversionary route, albeit with some additional congestion and costs. In rural or urban locations where a long diversion may not be acceptable, then a temporary bridge may be installed nearby. This takes all the traffic off the bridge site, allowing a much faster construction process. If diversions are not acceptable, then the second method is to replace the existing bridge on-line in two stages. The first half of the bridge is closed to traffic while the existing bridge is removed and replaced. Once that half is completed, the traffic is moved on to the new bridge while the second half is then replaced. This option does have the disadvantage of reducing the traffic capacity by half while also being slower, and therefore more expensive. It does avoid the cost of the diversion but a suitable balance needs to be struck between these options. If either of these options were prohibited, then the scheme can also be treated like a railway option, i.e. with a new bridge built off-line that is then lifted, slid or moved across in a short possession period.

There will often also be live traffic under the replacement bridge (as a footway, highway, railway or waterway) – the construction methods outlined for all the various solutions shown allow for the works to progress safely, easily and quickly above such live traffic below. As with any solution where live traffic is involved, speed is the main motivation, as traffic diversionary costs can be substantial, taking due account of safety.

Figure 1 shows the Kingsway Canal Bridge with a typical single-span bridge. The solutions described below cover both in-situ and precast options. It is more obvious with the precast options as to how the works can progress easily over live traffic, but all the in-situ options shown are also determined on the same basis. All in-situ schemes therefore use full span temporary falseworks, or a series of long-spanning girders/beams with widely-spaced temporary props, as the temporary means of supporting the formwork and the in-situ concrete pours – these are all easily removed after the in-situ concrete has developed sufficient strength. Birdcage scaffolding solutions are not therefore shown as they would inhibit any live traffic movements below the bridge replacement. In particular, an innovative and new system for casting in-situ bridges is described that can be used at any new or replacement bridge location.

Figure 1: Kingsway Canal Bridge.

For this shorter range of spans, most in-situ and precast solutions will probably involve integral abutments and if necessary, integral piers. RC solutions can be used for spans <20m, i.e. for 10-20m spans (or indeed for 5-20m spans). However, PSC solutions can be used for all spans, as a PSC precast beam system exists in most countries, allowing all spans to be accommodated, i.e. for 10 to 40-50m spans. PSC solutions are also normally better value than the equivalent RC section, both due to material savings and savings as a result of the easier and faster construction methods that are suited to PSC.

3.1.2 Loads and Stresses

Typical highway bridge loadings were described by HA loads and the possible use of the abnormal HB vehicles – the Eurocodes now describe very similar loadings as LM 1 loads for the special vehicles LM 3 loads.

As noted in the general section, all the PSC sections will tend to be governed by decompression of the extreme bottom fibre, i.e. the SLS frequent traffic combinations, which are the quasi-permanent and prestressing actions plus 75% of the LM 1 loading. Stress checks are then made for the SLS characteristic combinations, but these checks are unlikely to be critical, although they will determine the concrete strengths required. ULS combinations are also checked, but again, these checks will not usually determine the prestressing sizes. If any increase in ULS capacity were required, then it would normally be best provided by additional passive reinforcement.

RC sections will tend to be governed exclusively by the ULS combinations, although both stresses under the SLS characteristic combinations and crack widths under the SLS quasi-permanent combinations do also need to be checked.

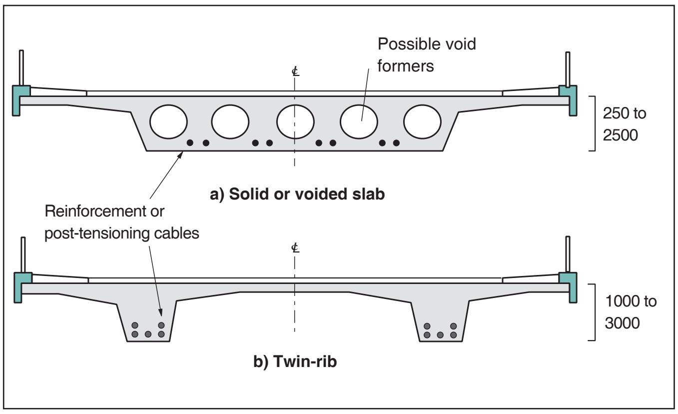


Figure 2: Highway in-situ sections.

3.1.3 Details

All the solutions can readily accommodate the typical features of many highway bridges, i.e. those of variable road alignment, variable widths and skews. As noted in section 3.1.1, the solutions shown are all suited to highway bridge replacements, but can equally apply to the construction of new highway bridges.

A wider discussion of the advantages of concrete construction, and of the more particular details concerning programme and costs, can be found in CBDG TG 14[3]. A full set of calculations for a two-span, integral, precast beam, highway bridge designed in accordance with EC2[8] can be found in CBDG TG 13[11].

3.2 Highway Bridge In-situ Solutions

3.2.1 Standard Sections

There are a number of simple cross-sections that suit both these relatively small spans and the need to form the section using in-situ concrete. They are all described extensively in CBDG TG 14[3]. In summary though, they are basically either a simple slab (which may or may not be voided) or a simple twin-rib section that uses two wide concrete ribs beneath a transverse deck slab. In all cases, the span/depth ratio is about 18 for these highway schemes. Figure 2 shows the various in-situ sections for the highway.

Solid slabs can accommodate 10-20m spans and might often be made of RC, although they can just as easily be formed using PSC. The sections tend not to be more than about 1m deep. For longer 20-40m spans, it becomes better to use a voided slab and in these cases, PSC is then required. These sections then tend not to be more than about 2.5m deep. 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. However overall, bridges of this nature have very low construction costs, as long as there is good access.

It is generally more sensible with the longer 20-50m spans to reduced the concrete volume by moving away from a simple slab deck towards a more efficient deck cross-section. The very simplest version of this solution is the classic PSC twin-rib deck, which can get up to about 3m deep. These decks have always been very common in Europe and worldwide, but are rarely seen in the UK. 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. Overall though, simple bridges of this nature do have low construction costs, again as long as the access is good.

3.2.2 New Construction Method

3.2.2.1 Development

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. In these bridge replacement schemes though, where access for live traffic beneath the bridge deck will be required, it will be necessary to use a series of temporary steel beams or girders to support the formwork. These steel beams are then used to span over the live traffic or carriageways below. For smaller spans, the temporary steelwork can span the whole way from abutment to abutment, whereas for longer spans, it will be necessary to also incorporate temporary intermediate piers or props to reduce the span of the steelwork. Such temporary piers or props will almost certainly need properly designed foundations and collision protection systems.

A new falsework system for casting these in-situ decks is therefore proposed, which allows safe, quick and easy construction in these locations where the decks need to be formed over live traffic. Having looked at the many configurations of traffic that might be under the bridge, together with the various types and widths of bridge itself, it has been determined that the most sensible, single solution is a new girder system that is about 7.5m wide and that can span 20m. For all spans less than 20m, the new system spans the entire width of traffic below without any scaffolding or temporary props. For spans from 20-40m, the new system spans the entire width of traffic below with a single central (or near central) temporary prop. This system therefore keeps the maximum span of the structure carrying the wet concrete to 20m. Whereas it would be possible to place the girder system below the deck with the in-situ twin-rib, it is not possible to place it here for slab decks without infringing upon the clearances. Therefore the girder system should be positioned above the new deck. The system consists of a twin-plate girder spine, 20m long and 2.5m wide, making it suitable for road transport. It sits above the new deck and supports a series of transverse UBs that in turn support the new formwork below (via a series of high-strength steel ties). Figure 3 shows the layout and details for this plate girder falsework system. The grid of ties and supports is based on a set of standard formwork panels that could be either 1.5m by 1.5m or 2m by 2m.

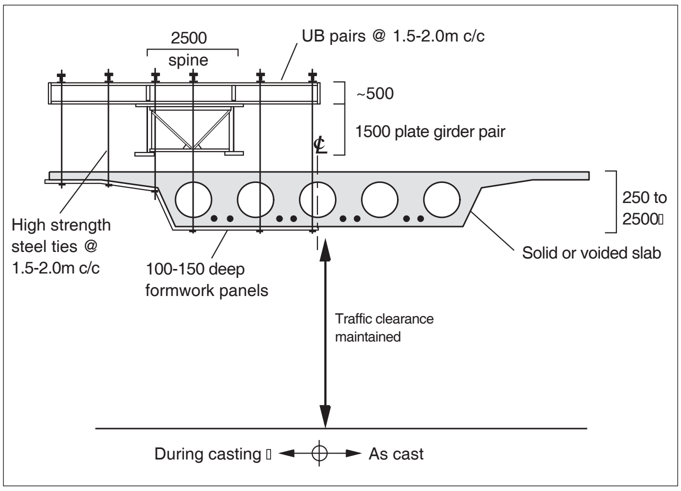


Figure 3: In-situ construction methods.

3.2.2.2 Details

The pair of plate girders is braced together in section and in plan and consists of 1.5m deep members with 20mm webs and approximately 500mm by 40mm flanges. The pairs of ~500mm deep UBs on top are placed at 1.5-2.0m centres to support the formwork tie bars. The UBs are about 7.5m wide, allowing decks below to be cast that are 4-8m wide. The system thus allows any width of deck from 4-24m to be cast using 1, 2 or 3 sets of braced girder pairs. A standard pair of 20m long plate girders might weigh about 30t with another 10t of UBs on top – it can cast a section of deck up to 8m wide and 20m long.

This plate girder system is effectively a very simple gantry – for simplicity, it is not mechanised and is simply moved each time with mobile cranes, while the UBs on top, all the tie bars and the formwork panels are installed in a piecemeal fashion. The intention would be for the girder system to be re-used many times for different projects, as cranes or scaffolding would be. In this case, it can be shown relatively easily that once the girder system is used 5-10 times, its effective cost makes it the same cost as a simple birdcage of scaffolding.

In these circumstances, the solution is very competitive with other concrete solutions and indeed with any steel-composite solution.

As noted above, once the spans are more than 20m, it would be necessary to include a temporary prop (and suitable foundation) to maintain the support to the girder system at no more than 20m. Such props would be in addition to the temporary props needed at the ends of each gantry. For ease of construction and the ability to re-use the girder system, it would be beneficial to have a standard set of either steel towers or precast RC box units, both of which could be stacked to suit varying heights of prop. Each prop could sit on a standard precast RC pad (3m by 2m by 600m deep, say, weighing ~9t). If ground conditions allow, then this pad simply sits on a prepared sand bed placed directly on the best ground beneath the topsoil. If the ground conditions were less good, then instead of a piling solution, it would be best to simply improve the ground (e.g. with stone columns), before using the same RC pad solution. Such props and foundations need to be included in the overall costs, but studies have shown that these costs can still be incorporated within a competitive overall package.

The installation of this girder system can commence once the existing bridge has been lifted or slid out of the way, either in small or large pieces. Clearly, the installation of the girders is very similar to the initial erection stages of a steel-composite deck, both of which would be carried out during short possession periods. The positioning of the panels of deck formwork below this grillage of temporary steelwork is also not dissimilar to the installation of the permanent formwork for a steel-composite deck, both of which would be carried out in stages that require short possessions or limited lane closures below. At this stage, the whole deck then becomes a safe environment for traffic below, allowing the fixing of all the deck reinforcement and prestressing, and the casting of the deck concrete, again in an identical manner to a steel-composite deck.

The only additional feature of this in-situ girder system is that the deck soffit formwork still needs to be safely and easily removed. Either overnight or during short weekend possessions or limited lane closures below, it is then possible to remove the formwork panels from below, using a small, mechanised crane or trolley system. The steelwork for the girder system itself is easily and safely removed from above the deck at any time. With all the PSC solutions, the concrete deck will strike itself from the formwork once the prestressing has been applied.

As noted at the start of this section, the only significant additional item of cost compared to a steel-composite deck or a concrete deck cast on a birdcage scaffolding (See Figure 4) is the temporary girder system – this item would need to be re-used at a number of locations in order to amortise its costs over several projects. In this case, the overall package of costs is certainly then competitive with any other solution.

Figure 4: Scaffolding birdcage.

Extensive programme and cost analyses were carried out for CBDG TG 14[3], including a direct comparison between a full birdcage scaffolding system and a comparable system of beams, girders and intermediate props, which did show that the overall costs are similar, once some re-use of the beams and girders is included. In essence, a well-considered formwork and falsework solution for an in-situ deck over these live traffic configurations can be comparable with an equivalent precast solution or steel-composite solution. Broadly, the additional costs of the falsework are offset by the much cheaper permanent works costs of the deck itself. A main contractor more comfortable with managing major sub-contractors may prefer a precast or steel-composite solution, but a more technically-skilled main contractor may well prefer the in-situ solution. This is certainly visible from the continental markets where such in-situ schemes do get built on a much more regular basis than in the UK.

3.3 Highway Bridge Precast Solutions

3.3.1 Standard Precast Beams

The UK is no different to many other countries in having a standard range of precast beams with simple cross-sections that suit these relatively small spans. They are all described in much greater detail in CBDG TG 14[3]. In summary, they are basically either a set of beams that are placed contiguously around which a solid slab is then formed, or a set of beams spaced at 1.0-3.5m upon which a thin in-situ deck slab (generally 200mm) is poured, generally using permanent formwork. In all cases, the span/depth ratio is about 18 for these highway schemes.

These standard precast sections are cast in proprietary factories off site and are then usually erected by mobile cranes. Figure 5: Shows Precast Concrete factory showing a typical pre-tensioning bed set up in this case to make W-Beams, and Figure 6 the casting of a typical precast U-beam.) They are ideally suited to these small to medium spans, ranging from 5-50m. The precast beams are always straight and pre-tensioned with individual 15.7mm low relaxation superstrands having an area of $150mm^2$ and an f_{pk} of $1,860N/mm^2$. As noted previously, the critical condition for the prestressing is the decompression of the bottom fibre under the SLS frequent traffic combination, with the concrete strengths at key intervals being determined by the stress checks under the SLS characteristic combinations. ULS combinations tend not to be critical.

Figure 5: Precast Concrete factory bed.

Figure 6: Precast Concrete factory casting.

Solid slabs are typically formed using TY beams placed contiguously and then infilled with concrete giving a solution that can accommodate 5-25m spans. Beam and slabs are typically formed using either Y/SY beams placed at about 1-2m centres for 15-45m spans, or U/W beams placed at 2.0-3.5m centres for 15-50m spans. Some transportation restrictions may apply with beam lengths beyond about 30m, but beams up to 40m can generally be accommodated on the road network without great difficulty. Calculations for a two-span, integral, precast beam, highway bridge designed in accordance with EC2[8] can be found in CBDG TG 13[11].

Figure 7 shows the range of typical UK precast beams for the highway.

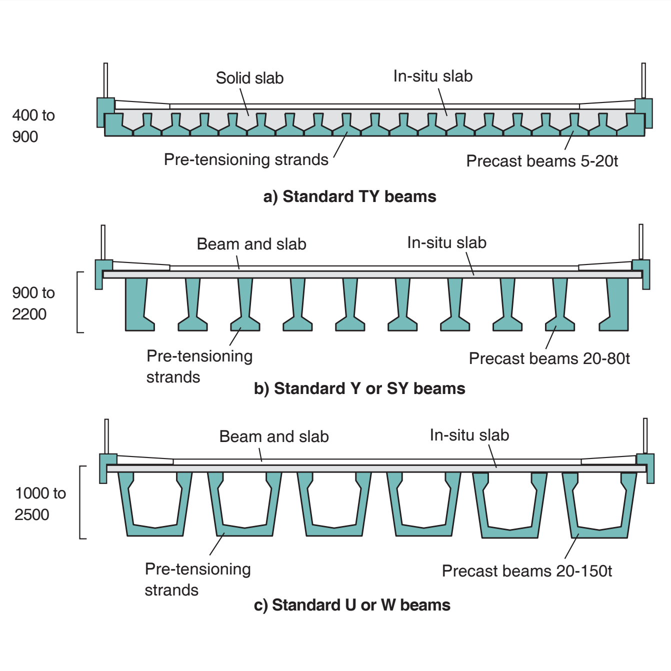


Figure 7: Shows the range of UK precast beams for the highway.

The lighter TY beams all weigh less than 20t, whereas the Y/SY beams range from 20-80t, and the largest U/W beams can get up to 100t for 40m spans or 150t for 50m spans. They would all be erected by mobile crane – typically and very roughly, it is possible to say that for each of the following lift weights (at a reasonable lifting radius), it is necessary to use the following crane size:

up to 30t	200t mobile crane
up to 60t	400t mobile crane
up to 90t	600t mobile crane
up to 120t	800t mobile crane
up to 150t	1,000t mobile crane

1,000t mobile cranes are now widely available in the UK, at costs that are certainly competitive for these markets.

Figure 8 shows the Afon Hydfron Bridge with the transportation of a 42.5m precast W18-beam.

Figure 9 shows the Limerick Southern Ring Road with the lifting of a 45m long W19 precast beam.

Figure 8: Afon Hydfron Bridge.

Figure 9: Limerick Southern Ring Road.

Various standard and very simple connection details are used to join these precast elements together. Where the smaller precast beams are placed adjacent to each other, transverse reinforcement is passed through preformed holes in the beams, and the space between the beams filled with in-situ concrete to form the solid slab. For the larger precast beams, the top surface of the beams is suitably prepared and has projecting reinforcement so that the in-situ deck slab and beams act together. Finally, at integral abutments or over continuous piers, the ends of the beams are cast in to in-situ concrete diaphragms that form part of the abutment (or pier).

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. Overall, bridges of this nature do have low construction costs, as long as there is good access for crane erection.

3.3.2 Whole Span Precast

It is also possible to combine these in-situ and precast options by precasting the whole span off-line. Such spans could weigh 150-1,200t, which means that except for the very smallest spans, it would be necessary to slide the completed deck in to place or to use a Self-Propelled Modular Transporter (SPMT) to lift the deck. The deck sections would be as those described for the in-situ options, i.e. the simplest possible cross-sections using solid slabs, voided slabs or twin-ribs.

These solutions are more like what might be seen in the railway environment, but where the traffic management impact and costs are of a similar magnitude, then such solutions can make good sense in the highway environment as well. In these cases, the slide track or SPMT would firstly be used to remove the existing deck (See Figure 10 which shows the SPMT method used to remove the old Moreton South Bridge), and then secondly be used to transport and install the new deck, all within night or short weekend possessions. SPMTs can be significantly more costly than even the very largest mobile crane, but as noted in the in-situ section above, the additional costs of the temporary works can be offset by the reduced permanent works costs of the deck itself. Again, a main contractor more comfortable with managing major sub-contractors may prefer a precast beam or steel-composite solution, but a more technically-skilled main contractor may well prefer this sort of in-situ/precast solution with a greater level of temporary works.

Figure 10: Moreton South Bridge.

3.3.3 Modular Precast Concrete Bridges

The CBDG developed a modular precast concrete bridge system for highways (Figure 11) that is described fully in CBDG TG 11[1] and TG 14[3]. Essentially, it is a precast segmental version of the classic PSC in-situ, twin-rib deck. It combines the best features of in-situ and precast construction in to a standard set of short, precast shell units that are assembled on site. The deck is completed with an in-situ inner concrete core within each rib that is then post-tensioned. It was designed for these 15-50m spans, and indeed for sites having only one or two spans, on the basis that the precasting and erection costs are amortised over a number of projects, in the same way that a precast beam manufacturer would spread his precasting costs over a number of schemes.

The precast U-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 a series of beams and props, or launching, or lifting of the whole pre-assembled rib using large mobile cranes (the *span-lift* method).

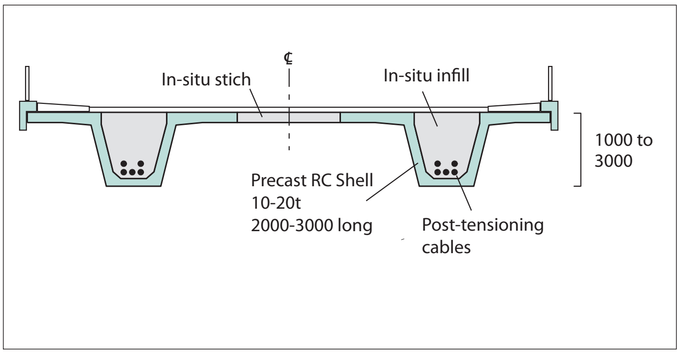


Figure 11: Highway Modular Precast Section.

3.4 Highway Bridge Arch/Portal Solutions

All the bridge replacement options shown tend to describe schemes where a proper bridge deck is being replaced or widened, with spans from about 10-40m. In reality, the schemes can all include spans down to about 5m as well. In this area of shorter spans (5-20m), it is also then possible to consider the culvert-type options. These options include the classic precast box culvert for 1-6m spans and the various precast arch or portal schemes for 5-25m spans. All options could be made from in-situ concrete, but with the good availability of various precast concrete solutions in the market, the precast version seems more obvious. All solutions are made from RC.

In the highway environment, it is generally assumed that the replacement scheme would be build it stages with a sequence such as – cut embankment and remove backfill; remove old culvert; prepare new foundations or supports; place new precast units and then complete backfill.
Many more details for these in-situ or precast arches and portals are shown in CBDG TG 12[2], along with further details and data in CBDG TG 14[3].

4. Railway Bridge Replacement

4.1 Issues

4.1.1 General

The railway bridge solutions illustrated typically cover the 10m to 24m spans that are most common, although it is noted where solutions can extend to 30-40m. Typical railway bridges carry either single or double track railways. Overall widths are about 5-6m for single track bridges and 9-13m for double track bridges. The same system of solutions can readily accommodate wider scenarios with more tracks. There will always be live railway traffic on the bridge itself, but diversions of the railway tend not to be common as the available space will not usually allow this solution. So, the typical solution is to build the new bridge off-line (or to have it ready off-line) and to then install it during a long weekend possession of the whole railway. Alternatively, for double track bridges, it can be possible to replace the existing bridge in two stages, using single track working. There will often also be live traffic under the replacement bridge (as a footway, highway, railway or waterway) – the construction methods outlined for all the various solutions shown allow for the works to progress safely, easily and quickly above such live traffic below. As with any solution where live traffic is involved, safety is paramount, but speed is the main motivation afterwards, as traffic diversionary and possession costs can be substantial. The most common scenario described here is with the railway bridge replacement over a live highway below.

All the solutions shown describe the ballasted option for track and sleeper support, which is the most common in the UK and indeed globally too. Track slab solutions readily work though with any of the schemes – they can often be the preferred solution on many bridge structures, as they give lower weights and lower structural depths. However, all the described concrete solutions have an equal or very similar structural depth to any comparable steelwork option. So, if the concrete scheme works well with a ballasted track, it can only work better with a track slab.

The solutions described below cover both in-situ and precast options. It is more obvious with the precast options as to how the works can progress easily over live traffic, but the in-situ options are also very valid. In-situ schemes (either built alongside or built on-line in a two-stage scheme) therefore use full span temporary falseworks, or a series of long-spanning girders/beams with widely-spaced temporary props, as the temporary means of supporting the formwork and the in-situ concrete pours – these are all easily removed after the in-situ concrete has developed sufficient strength. Birdcage scaffolding solutions are not therefore shown as they would inhibit any live traffic movements below the bridge replacement. The innovative plate girder falsework system described under the highways section can also be adapted for use here in the railway. Even when the in-situ deck is built alongside the railway, it will still generally be necessary to maintain the traffic flows beneath the bridge – the twin-plate girder system placed above the deck allows the in-situ works to progress with little impact on the traffic below.

All the railway methods, using in-situ built alongside or precast pieces, described below allow decks to be completed within 2-3 days, i.e. normal to long weekend possessions of 54-72 hours.

Traditionally, all railway bridges are based on simple spans with joints between the structures. This allows the railway track itself to pass straight over and to therefore be un-jointed, i.e. continuous. RC solutions could be used for spans <15-20m, i.e. for 10m to 15-20m spans (or indeed for 5m to 15-20m spans). However, PSC solutions can be used for all spans, as a new PSC precast beam system has been developed here, allowing all spans to be accommodated, i.e. for 10-40m spans. PSC solutions are normally better value than the equivalent RC section, both due to material savings and savings as a result of the easier and faster construction methods that are suited to PSC.

4.1.2 Loads and Stresses

Typical railway bridge loadings were described by the RU loads – Eurocodes now describe very similar loadings as the new LM 71 loads. These loads (of 80kN/m per track plus a concentrated set of heavier engine loads) are the ones used by Network Rail in the UK, and by all other mainline railway authorities around the world. These track loads are increased by route factors - 0.75 to 1.46 is quoted in the Eurocodes and 1.1 is given in the UK National Annex, but Network Rail Standards[12] increase this route factor to 1.21 to accommodate possible future uses; this is the figure used throughout this guide. Dynamic factors (of around 1.5 to 1.1 for these 10-30m spans) and lurching effects are also added.

It is these *heavy rail* loads that are used to size the various solutions shown in this guide. However, other railway loads also exist in other situations. The SW/0 loading applies to continuous structures, but is not used here for these shorter, simple spans. A *very heavy rail* loading (SW/2) is specified for some massive freight lines worldwide, but is not used in the UK. A *metro rail* loading (the old RL loads – of about 50kN/m) might be used by London Underground, for example, and a *light rail* loading (~50% of the old RL loads – of about 25kN/m) might be used by the Docklands Light Railway, for example. Both these loadings are lighter and are not explicitly covered here, but the same principles apply, with correspondingly smaller section sizes. High-speed lines tend to use the same LM 71, i.e. the vertical loads are no higher than normal *heavy rail* loads, even though there will be some greater dynamic effects, especially for larger spans.

As noted in the general section, all the PSC sections (being pre-tensioned or internally post-tensioned) will tend to be governed by decompression of the extreme bottom fibre, i.e. the SLS frequent traffic combinations, which are the quasi-permanent and prestressing actions plus 70-80% of the LM 71 loading (80% if only one is track loaded and 70% if both tracks are loaded). Stress checks are then made for the SLS characteristic combinations, but these checks are unlikely to be critical for the prestressing, although they will determine the concrete strengths required at different stages. ULS combinations are also checked, but again, these checks will not determine the prestressing sizes. If any increase in ULS capacity were required, then it would be best provided by additional passive reinforcement.

RC sections will tend to be governed exclusively by the ULS combinations, although both stresses under the SLS characteristic combinations and crack widths under the SLS quasi-permanent combinations do also need to be checked.

4.1.3 Details

All the solutions can readily accommodate the typical feature of many railway bridges, i.e. skew – details of these skew solutions are shown later. As noted in the general section, the solutions shown are all suited to railway bridge replacements, but can equally apply to the construction of new railway bridges.

The concrete solutions shown are all based on having either concrete girders below the track or concrete through-girders. The concrete through-girders maintain an overall depth and a deck depth below the track that is comparable to any steelwork option. In addition, the precast through-girder solution shows a brand new suite of standard railway edge-beams (U-Girders) offering a low profile and reduced deck depth giving the same depth as any steelwork version or existing structure. These new precast U-Girders are known as the '*UU-Bridge*'. Many other solutions, including precast Z-Girders and J-Girders, were also considered but were not preferred, as the precast U-Girders perform better in all regards.

Transverse slab depths can closely match any steel railway bridge – typically, narrow double track bridges have transverse decks that are about 375mm thick, while wider decks are about 450mm thick. Normal RC slabs for these 8-10m spans would be expected to be 500-600mm thick. However, with the use of higher strength precast concrete at strength class C50/60 and carefully detailed rebar (and where slab weight and depths are at a premium), the transverse slabs can indeed also be made 375-450mm thick. However, this may need the maximum reinforcement to be more than B40s at 125mm, which is close to the absolute maximum possible and then gives little room for change. So generally, it is better to show the transverse slabs being a little thicker than this absolute minimum – at 400mm for narrow decks and 500mm for wider decks. Typical reinforcement is then somewhere between B32s and B40s at 125mm pitch. Single track bridges have transverse slabs that are about 250mm thick, which is comparable to any other solution.

All these concrete solutions use layouts where there is a much more robust concrete edge beam to address any issues concerning vehicle impact from below, thus obviating the need for any additional steel side impact beams. This feature alone gives all the concrete solutions a distinct advantage over any of the steel solutions.

Railway bridges do also need to be designed for issues that tend not to greatly affect highway bridges, i.e. deflections, dynamics, vibrations, noise and fatigue. However, these issues are not hugely important for these modest 10-30m spans and in fact concrete options (with a greater mass and stiffness) all perform better in these matters than steelwork options. Fatigue is not really a major issue with RC as the reinforcement is all unwelded and simply lapped, both of which generate high fatigue lives. Fatigue is also not a major issue with PSC as the concrete is fully compressed throughout and the prestressing steel has a very low stress range (<50 N/mm^2) – again, fatigue lives are high and fatigue will not be critical.

A wider discussion of the advantages of concrete construction, and of the more particular details concerning programme and costs, can be found in CBDG TG 14[3].

4.2 Railway Bridge In-Situ Solutions

4.2.1 Standard Sections

If clearances allow, then the optimum solution would always be to put the structure beneath the railway. In these cases, the same in-situ solutions apply as would be used for highway bridges. However, most railways cannot be diverted and therefore railway schemes cannot generally be built on-line, unless the solution is for a new railway. In some double track cases though, it might be possible to build the section in two stages with the use of single track working, as would often be done for road bridges. The most common scenario though would be for the scheme to be built off-line, i.e. alongside the existing tracks – ready to be lifted, slid or transported across with an SPMT system.

So, there are a number of simple cross-sections that suit these relatively small in-situ spans that sit underneath the railway. They are all described extensively in CBDG TG 14[3]. In summary though, they are basically either a simple slab (which may or may not be voided) or a simple twin-rib section that uses two wide concrete ribs beneath a transverse deck slab. The span/depth ratio for these railway schemes is about 15 for slabs and about 13 for twin-ribs.

Solid slabs can accommodate 10-15m spans and might often be made of RC, although they can just as easily be formed using PSC. The sections tend not to be more than about 1m deep. For longer 15-30m spans, it becomes better to use a voided slab and in these cases, PSC is then required. These sections then tend not to be more than about 2m deep. It is generally more sensible with the longer 15-35m spans for double track bridges to reduce the concrete volume by moving away from a simple slab deck towards a more efficient deck cross-section. The very simplest version of this solution is the classic PSC twin-rib deck, which can get up to about 2.5m deep – the ribs would be positioned beneath the tracks. The simple soffit of both these types of deck makes the formwork, fixing and concreting easy, and overall, simple bridges of this nature do have low construction costs, as long as the access is good. Figure 12 shows the various in-situ sections for the railway.

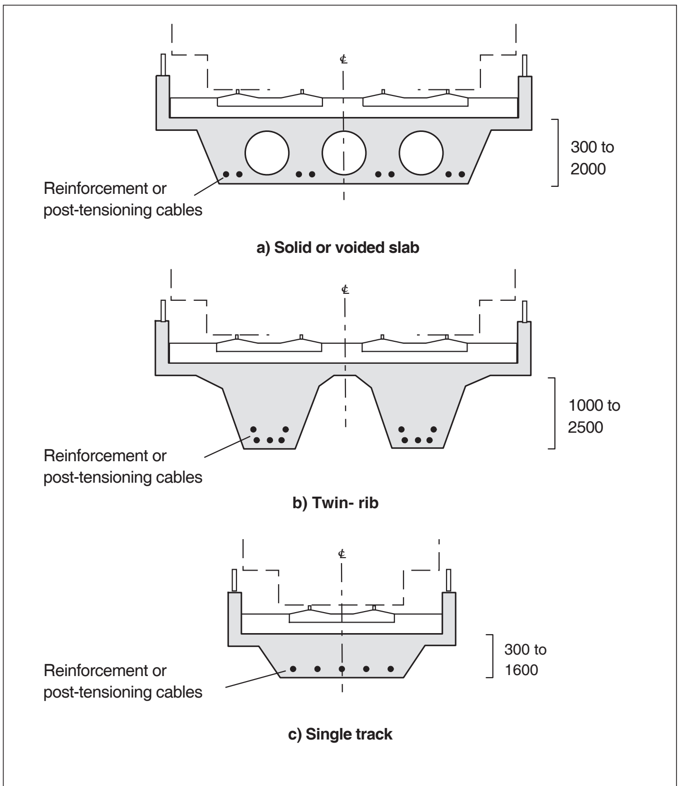


Figure 12: Railway in-situ sections.

The construction issues are exactly as described for the in-situ highway solutions, where it is suggested that the optimum solution, to avoid a birdcage of scaffolding, is to use a twin-plate girder falsework system that sits above the deck. This system keeps the area clear beneath the deck allowing free movement of traffic throughout the majority of the construction phases.

In essence, a well-considered formwork and falsework solution for an in-situ deck over these live traffic configurations can be comparable with an equivalent precast solution or steel-composite solution. Broadly, the additional costs of the falsework are offset by the much cheaper permanent works costs of the deck itself. A main contractor more comfortable with managing major sub-contractors may prefer a precast or steel-composite solution, but a more technically-skilled main contractor may well prefer the in-situ solution. If the in-situ section is indeed built alongside the railway, it can then be lifted (if the weight is less than 150t, which it is for all single tracks and double tracks with spans less than 10m), slid across on slide tracks or moved across with SPMTs, all during a short possession.

4.2.2 New Z-Girders

4.2.2.1 Development

If clearances below the deck do not allow a bridge to be built beneath the railway, then the only option is to design a through-girder solution. Steel versions of this option dominate the UK market, but almost no concrete versions are seen here, although they are relatively common overseas. In these cases, the main girders sit adjacent to the railway tracks with the lower transverse slab that connects the two girders being the only structure that sits beneath the railway itself. This solution then provides a total structural depth and a structural depth beneath the railway that is identical to any equivalent steelwork option.

As for the standard in-situ section described above, most railways cannot be diverted and therefore railway schemes cannot generally be built on-line, unless the solution is for a new railway. It might be possible to build the section in two stages with the use of single track working, but the most common scenario would be for the scheme to be built off-line, i.e. alongside the existing tracks – ready to be lifted, slid or transported across with an SPMT system.

The standard depths for these twin Z-Girders vary from 1.6m to 2.6m in 500mm increments, accommodating all spans from 10-40m. For all spans from 10-24m, the Z-Girder depth is a constant 1.6m, allowing it to sit under the platform gauge, forming the narrowest overall width and thus the smallest span of the transverse RC slab. At this depth, the top of the girder is also more than 300mm above the rail level, allowing it to act as a robust kerb in the derailment conditions. The safety walkway is then conveniently positioned on the top of the Z-Girder. For the longer spans, the Z-Girder becomes progressively deeper, which also forces it to become wider to avoid the structure gauge of the railway. In these cases, the safety walkway is positioned alongside the track. For spans from 25-33m, the depth becomes 2.1m, while for spans from 34-40m, the depth is 2.6m.

There is no obvious need for a standard solution, as the in-situ option can be readily designed to suit each individual location using the same basic parameters that are described here.

For 10 to 15-20m spans, these in-situ Z-Girders might often be made of RC, although they can just as easily be formed using post-tensioned PSC. For the longer 15-40m spans, it becomes necessary to only use post-tensioned PSC. The details described below are to suit the PSC versions. The span/depth ratio is about 15 for all these railway through-girders.

4.2.2.2 Double Track Details

Figure 13 (a and b) shows the in-situ Z-Girder for the double track railway and (c) for the single track railway. The 400m thick top flange of the Z-Girder stands out by 1m for the 10-24m spans and by 1.5m for the longer 25-40m spans. The webs are a constant 600mm thickness throughout – this is to suit the shear and bending stresses, to form a robust Z-section, and to allow two 27/15mm prestressing cables to be located within their width. The bottom flange, which is also the transverse slab, is 400-500mm thick depending on the exact width of the double track railway.

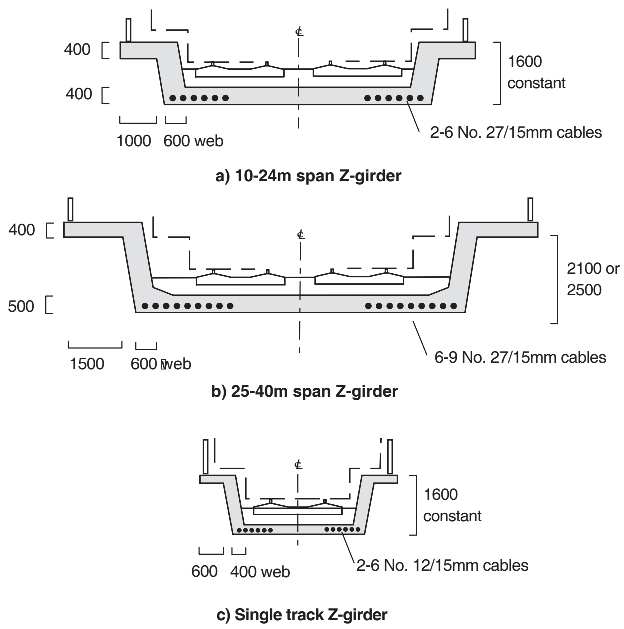


Figure 13: Railway Z-Girder sections.

Much of the section is sized to suit the typical prestressing layouts. The most suitable post-tensioned prestressing size has been determined to be a 27/15mm cable, which consists of 27 No. 15.7mm low relaxation superstrands, each having an area of 150mm^2 and an f_{pk} of 1,860N/mm^2. As noted previously, the critical condition for the prestressing is the decompression of the bottom fibre under the SLS frequent traffic combination, with the concrete strengths at key intervals being determined by the stress checks under the SLS characteristic combinations. ULS will not be critical in these circumstances. Depending on the span, there are 2-9 cables per side. They are anchored at the ends of the span on the web, which is made 1.1m wide locally to accommodate the cable anchorages. The 500mm step in height of the Z-Girders is solely to suit the cable anchorage geometry.

4.2.2.3 Single Track Details

Figure 13c: shows the in-situ Z-Girder for the railway.

For all spans from 10-24m, the Z-Girder depth is a constant 1.6m. Deeper sections become wider overall needing wider beams – in the rare cases of these 25-40m spans, the solution would be to use the double track system. The top flange of the Z-Girder is now made 200mm thick, standing out by 600mm from the web, both to control top fibre stresses and to provide a position for the safety walkway on top of the girder. The webs are a constant 400mm thickness throughout – this is sized to suit the placing of the in-situ concrete, control the shear and bending stresses, form a robust Z-section, and to allow two 12/15mm prestressing cables to be located within their width. The bottom flange, which is also the transverse slab, is made 250mm thick.

Much of the section is sized to suit the typical prestressing layouts. The most suitable post-tensioning size has been determined to be a 12/15mm cable, which consists of 12 No. 15.7mm low relaxation superstrands. The critical condition again for the prestressing is the decompression of the bottom fibre under the SLS frequent traffic combination. Depending on the span, there are 2-6 cables per side that are anchored at the ends of the span on the web, which is made 750mm wide locally to accommodate these anchorages.

4.2.2.4 Details

There are no post-tensioning issues in these modern PSC bridges as all the areas related to good grouting practice and good anchorage design and detailing are resolved by good construction practices, see TR 72[10]. This provides a three-layer protection system comprising the high-performance grout, continuous plastic ducts and the high-quality concrete section. End anchorages are also all covered in a proper thickness of bonded RC, suitably waterproofed. There are no major issues with any compressive stresses in the section with the critical case being the long-term stresses in the top fibre. It is therefore possible to just use a regular C40/50 strength class concrete mix throughout most spans, although some of the more slender, double track spans do need an increase to the strength class to C50/60.

A more detailed grillage assessment could be carried out to confirm whether it might be better to have thicker webs (with more torsional stiffness) and a correspondingly thinner bottom flange/slab (with greater end fixity), but is unlikely to offer any significant savings. The prestressing cables do also provide a significant shear relief to the webs, allowing both thinner webs and reduced amounts of web reinforcement. In any event, the thinnest web would be controlled by concrete placing requirements, which would determine a minimum thickness of 400mm. In reality, 600mm webs suit the double track bridge and 400mm is the minimum web thickness for the single track bridge. The whole, monolithic, single span deck unit (comprising the PSC Z-Girders and bottom slab) sits in a traditional manner on four pot bearings – one will be fully fixed, one guided longitudinally, one guided transversely and one free sliding. For further details about post-tensioned solutions, the reader is referred to CBDG TG 14[3] and TNs 1-12[4].

The construction issues are exactly as described above for the other in-situ railway solutions, using a twin-plate girder falsework system that sits above the deck. This system keeps the area clear beneath the deck allowing free movement of traffic throughout the majority of the construction phases. Again, a main contractor more comfortable with managing major sub-contractors may prefer a precast or steel-composite solution, but a more technically-skilled main contractor may well prefer this kind of in-situ solution, and indeed make it quick and competitive. When this in-situ Z-Girder section (weighing 50-1,000t) is built alongside the railway, it can then be lifted (if the weight is less than 150t, which it is for all single tracks and double tracks with spans less than 10m), slid across on slide tracks or moved across with SPMTs, all during a short possession. Figure 14 shows the Bramley Bridge with the use of the SPMT method to install the new bridge. The same equipment that is used to remove the existing deck would be used to install the new deck.

Figure 14: Bramley Bridge.

4.3 Railway Bridge Precast Solutions

There are a number of precast options available, including existing standard precast beams and a new suite of precast girders.

4.3.1 Standard Precast Beams

If clearances allow, then the optimum solution would always be to put the structure beneath the railway. In these cases, the same precast solutions apply as would be used for highway bridges. The UK has a standard range of precast beams with simple cross-sections that suit these relatively small spans. Figure 15 shows the range of typical UK precast beams for the railway. They are all described in much greater detail in CBDG TG 14[3]. In summary, they are either a set of beams that are placed contiguously around which a solid slab is then formed, or a set of beams spaced at 1.0-1.2m upon which an in-situ deck slab is poured, generally using permanent formwork. In all cases, the span/depth ratio is about 15 for these railway schemes.

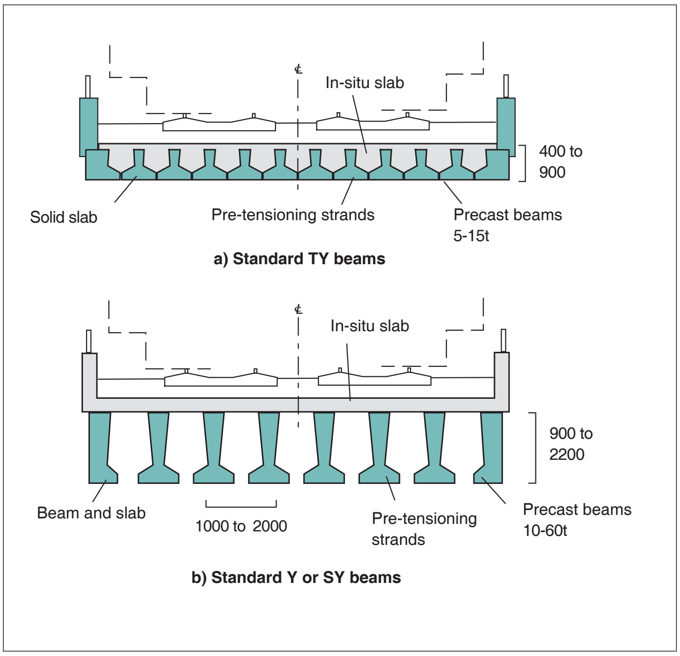


Figure 15: Railway Standard Precast Sections.

These standard precast sections are cast in proprietary factories off site and are then erected by mobile cranes. As noted previously, the critical condition for the prestressing is the decompression of the bottom fibre under the SLS frequent traffic combination, with the concrete strengths at key intervals being determined by the stress checks under the SLS characteristic combinations. ULS combinations tend not to be critical.

Solid slabs are formed using TY beams placed contiguously and then infilled with concrete giving a solution that can accommodate 5-15m spans. Beam and slabs are typically formed using Y/SY beams placed at about 1.0-1.2m centres for 15-35m spans. The beams should be positioned beneath the rails. U beams are not best suited to the railway as their webs are too far apart and they cannot generally accommodate the significantly larger numbers of strands required, especially for double track railways. However, U beams can be sensibly used in pairs beneath a single track railway, where there is a little more space.

The TY beams all weigh less than 15t, whereas the Y/SY beams range from 10-60t. They would all be erected by mobile crane – typically and very roughly, it is possible to say that for each of the following lift weights (at a reasonable lifting radius), it is necessary to use the following crane size:

up to 30t 200t mobile crane
up to 60t 400t mobile crane

Various standard and very simple connection details are used to join these precast elements together, as described in the highways section.

Figure 16 shows the Roby Bridge with the completed structure over the railway.

Figure 16: Roby Bridge.

For construction, the old deck needs to be removed, followed by the erection of the precast beams, installation of the deck slab formwork panels, fixing of the deck reinforcement, and finally, the casting of the deck. These operations could be quite slow and will generally take longer than a normal weekend possession. Most railways cannot be diverted and therefore railway schemes cannot generally be built on-line, unless the solution is for a new railway or the railway is closed for some longer period. In some double track cases though, it might be possible to build the section in two stages with the use of single track working, as would often be done for road bridges.

To further speed up the construction though, it is also possible to precast large sections of the deck slab, generally in lengths of 2-3m to make them easily transportable. The whole width of the railway slab can be precast with slots provided in the slab to enable a proper shear connection to be formed with the precast beams below. The slab panels are then simply lifted in to position and stitched together with in-situ concrete. Figure 17 shows the Underbridge 92 with the trial erection of precast deck panels and Figure 18 shows a finished bridge on the border project.

Standard precast beams, produced in a factory, can be of high-quality with a proven record of durability. They can also be quickly erected on site and be particularly useful when bridging over live traffic.

Figure 17: Underbridge 92.

Figure 18 Finished Border Project Bridge.

4.3.2 New Precast U-Girders – 'UU-Bridge'

4.3.2.1 Development

Having shown the in-situ Z-Girders above, it is obvious to develop a precast version of the same section. This solution fits under and around the railway at no greater depth than existing schemes, but is shaped to suit a 150t lifting weight limit. The corresponding precast section is then in-filled with in-situ core concrete on site and stitched together across the whole width with precast RC transverse slab panels. However, the precast unit is then around 3.5m wide, making it too wide for easy road transport. Together with the more difficult precasting operations, the solution does not work as well as the later set of U-Girders, and is therefore discounted.

So, it has therefore been determined that the best precast solution is the one shown using U-Girders to form a through-girder scheme. This option is easier to cast and transport, and faster to erect than the others precast options considered.

In general, these U-Girders are all PSC, allowing both single and double track options for all spans from 10-39m. It is possible to show an RC option too, using the same U-Girder shape but infilling it entirely to make it in to a solid beam, or a shaped J-Girder. This is only viable for 5-20m spans – it seems an unlikely option when there will be a standard, better value and easier PSC option available for all spans from 10-39m. As in the highway environment, once a standard set of PSC beams/girders exist, then there is little demand for any RC precast options.

This design has been carefully crafted over the last year by the author and will now be known as the '*UU-Bridge*'. The unique features of this new railway design have been developed on the basis of both the prestressing analysis and details, and all the construction considerations.

These new precast concrete through-girders fit under and around the railway at no greater overall depth or clearance depth than any existing schemes or any equivalent steel schemes. The span/depth ratio is about 15 for all the railway schemes.

The system uses the precast U-Girders as edge beams, which are then in-filled on site with in-situ concrete to form solid edge girders. These girders are then stitched to transverse, precast RC slab panels, forming an overall U-shape – hence the '*UU-Bridge*' name. This stitch detail (See Figure 20, page 21) is formed using a temporary soffit shutter and HSC of C85/100 strength class, which gets up to 20 N/mm^2 (about 20% of its strength) in 6 hours and up to 50 N/mm^2 (about 50% of its strength) in 18 hours. It may also be possible to use lower strength, more specialised mixes (e.g. strength class C65/80) that reach higher strengths much more quickly. Half-joints at this location between the U-Girder and the transverse slab were considered in great detail using either concrete or steel sections, as they offer good speed advantages, but after much analysis, it was concluded that half-joints were too complicated to implement and were also unlikely to gain widespread approval from client authorities, as their potential to contain hidden defects might be larger.

For the most efficient section and prestressing design, it would be best to incorporate a void within the in-situ, infill concrete. However, given the available width and depth, and the relatively small benefits, it was decided to avoid this additional and rather fussy detail, which is actually just as expensive as the concrete it replaces. The U-Girders are pre-tensioned with individual 15.7mm low relaxation superstrands having an area of 150mm^2 and an f_{pk} of 1,860N/mm^2. As noted previously, the critical condition for the prestressing is the decompression of the bottom fibre under the SLS frequent traffic combination, with the concrete strengths at key intervals being determined by the stress checks under the SLS characteristic combinations.

The key sequence is determined by the fact that the U-Girder needs to be infilled with in-situ concrete before the RC transverse slabs are erected. There is therefore a significant impact of creep as the stresses within the precast U-Girder move towards the infilled composite section and to a lesser extent, towards the composite section formed by the addition of the RC transverse slab and stitch. Even though the overall prestress axial stresses will creep in to the whole section that includes the transverse slab, there will actually be very little creep of the bending stresses due to the fact that the shear lag is very limited because the transverse slab is relatively soft in tension. In effect, the conclusion is that the vast majority of the longitudinal stresses stay in the U-Girder and infill, and no significant longitudinal bending stresses appear in the transverse slab.

The main factor determining the grade of the precast concrete in the U-Girder is the bottom fibre compression in the short-term, i.e. in the factory after pre-tensioning. A balance has been struck between wanting a thicker bottom flange to control stresses, and needing a thinner area to control lift weights. The outcome is that relatively high strength concrete (HSC) needs to be used, especially for the longer spans (HSC has been previously outlined page 2). These strength classes are readily available from a competent precast manufacturer nowadays. The top fibre compressions in the long-term are also significant and produce requirements that are not too far behind those for the bottom fibre – hence the need to pour the infill concrete prior to any more loads being applied.

A new suite of bespoke edge beams has thus been created. These low-profile U-Girders are precast with HSC and then in-filled with in-situ core concrete on site. The aim throughout has been to keep the weight of all the most typical lifts to less than 100t and to keep the maximum weight to generally below 150t. All the single track options that cover spans from 10-24m have lift weights no more than 40t. All the double track options that also cover these smaller spans from 10-24m have lift weights no more than 75t. For the less frequent larger spans from 27-39m, the maximum lift weights for the double track options vary from 95-165t. In summary, all span and track configurations up to 27m spans have lift weights less than 100t, and up to 36m spans have lift weights less than 150t.

The transverse RC panels are precast with C50/60 strength class concrete. For the single track options, the slab is formed as a single piece that is about 2.6m wide, a span length no longer than 24m and around 250mm thick. These weigh 15-

40t and can thus be lifted by the cranes already on site for the girders. For the double track options, the slabs are split in to 2.5m lengths for precasting and transporting – they are about 5.7-7.5m wide and 400-500mm thick. These precast slabs only weigh 15-25t and can thus be easily lifted by the cranes already on site for the girders.

The PSC U-Girders are precast and pre-tensioned in a factory, alongside the RC transverse slabs. All pieces can be readily transported on the road network with maximum widths of about 2.5-2.6m. Clearly, the longer span U-Girders over about 30m will need special road provisions and/or escorts, but none of these issues are hugely significant, even up to the maximum span lengths of 39m. The new system has been predominantly sized for the most typical 10 to 20-30m spans, but the solution is also easily able to expand up to the 39m spans shown. The whole, monolithic single span deck unit (comprising the PSC U-Girders and the RC transverse slabs) sits in a traditional manner on four pot bearings – one will be fully fixed, one guided longitudinally, one guided transversely and one free sliding. During construction, the U-Girders are each temporarily propped with 4 small jacks (at their edges and at their ends) to provide lateral stability – once the precast deck panels are fully stitched and up to enough strength (after 12 hours), these props or jacks can be removed.

As noted in the introductory sections, all the solutions shown describe the ballasted option for track and sleeper support, which is the most common in the UK and indeed globally. Track slab solutions readily work with any of the schemes – they can often be the preferred solution on many bridge structures, as they give slightly lower weights and lower structural depths. Either way, the same principles apply to all the variants. Any lower loads due to track slab, or route factors less than 1.21, will simply use the same concrete sections but with fewer strands and/or lower concrete strengths, as happens with all standard precast beams.

4.3.2.2 Double Track Details

Figure 10 (a and b) shows the double track 'UU-Bridge'. The standard depths vary from 1.6m to 2.6m in 200mm increments, accommodating all spans from 10-39m.

For all spans from 10-24m, the U-Girder depth is a constant 1.6m, allowing it to sit under the platform gauge, forming the narrowest overall width and thus the smallest span of the transverse RC slab. At this depth, the top of the girder is also more than 300mm above the rail level, allowing it to act as a robust kerb in the derailment conditions. The safety walkway is then conveniently positioned on the top of the infilled U-Girder.

For the longer spans, the U-Girders become progressively deeper, which also forces them further apart to avoid the structure gauge of the railway. In these cases, the safety walkway is positioned alongside the track. At the 27m, 30m, 33m, 36m and 39m spans, the overall depths increase to 1.8m, 2.0m, 2.2m, 2.4m and 2.6m respectively.

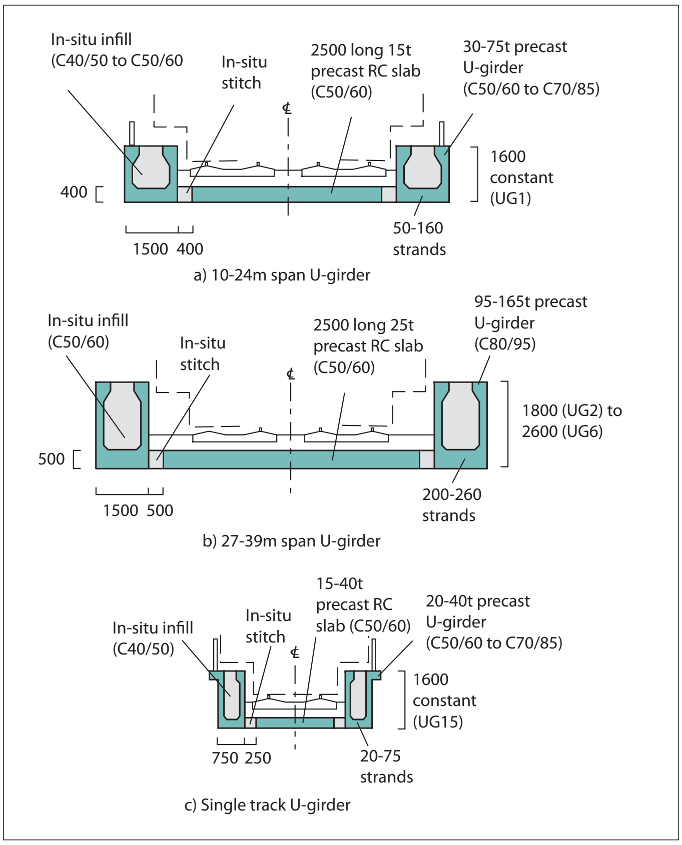


Figure 19: Railway 'UU-Bridge' Sections.

The overall width of the U-Girder is required to be as small as possible to reduce its weight, to reduce the span of the transverse slab and to sit easily on any existing abutments. However, the concrete stresses can be very large and therefore the optimum width has been determined to be 1.5m. The webs of the U-Girder are made 175mm thick for both robustness and to fit two legs of shear reinforcement and two lines of strands, if required. The bottom flange is made the same thickness as the transverse slab at 400-500mm.

These six sizes of new U-Girder are designated UG1 to UG6. They are similar to existing precast manufacturers large U-Beams, sometimes called W-Beams, but they are much bulkier to suit the railway and are in-filled with in-situ concrete to control the very large stresses. The whole solid section acts as a composite unit for both bending and shear – this will entail some vertical reinforcement coming out of the top of the bottom flange for interface shear. The number of strands positioned within the bottom flange varies from 50 to 260, which is close to the maximum possible within that space.

For the 10-24m spans, the U-Girder needs a concrete strength class varying from C50/60 to C70/85, while for the 27-39m spans, the strength class needs to be C80/95. The infill concrete also experiences large stresses and is required to be between C40/50 and C50/60 strength class. The infill concrete on site could weigh up to 200t - hence the need to avoid lifting it. It does need to be cast soon after the girders are erected and then to be achieving reasonable strength (10-12N/mm^2, i.e. about 20% of its strength, in 6 hours) to enable the transverse deck panels to be added. It also needs to achieve a strength of 20-24N/mm^2 in 24 hours to allow the ballast to be added. The top of the U-Girder may need to be clamped or tied temporarily to control the initial wet concrete stresses in the webs. The ends of the U-Girder can either be shuttered or an end panel could be cast in the factory area.

The U-Girders vary in weight from 30-75t for the 10-24m spans, from 95-145t for the 27-36m spans, and reach 165t for the 39m span. They would all be erected by mobile crane – typically and very roughly, it is possible to say that for each of the following lift weights (at a reasonable lifting radius), it is necessary to use the following crane size:

up to 30t	200t mobile crane
up to 60t	400t mobile crane
up to 90t	600t mobile crane
up to 120t	800t mobile crane
up to 150t	1,000t mobile crane
up to 180t	1,200t mobile crane

1,000t mobile cranes are widely available in the UK, whereas a 1,200t mobile crane may need to come from Europe, but its use would still be viable for some special cases. Tandem lifts might also be possible using two smaller cranes.

The 400-500mm thick transverse slabs are precast and transported in 2.5m lengths. As well as the longitudinal stitch between the U-Girders and the slabs, there will also be transverse stitches between the slab panels. These will also be formed with in-situ RC stitches cast on site at the same time as the longitudinal stitches. However, the moments across these joints are relatively nominal and a much simpler solution can be used with the precast panels themselves forming the bottom shutter.

4.3.2.3 Single Track Details

Figure 19c shows the single track 'UU-Bridge' for the railway.

The standard depth is 1.6m for all spans from 10-24m. Deeper sections become wider overall needing wider beams – in the rare cases of these 27-39m spans, the solution would be to use the double track system.

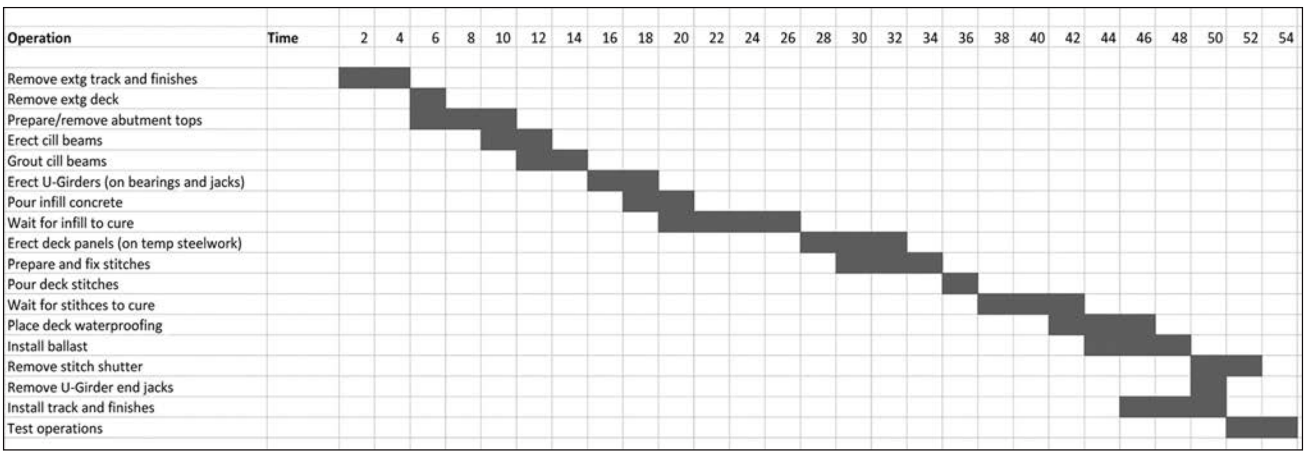
The optimum width for these 10-24m span situations has been determined to be 0.75m. The webs of the new U-Girder (designated UG1S) are now made just 125mm thick to fit one leg of shear reinforcement and one line of strands. The bottom flange is made the same thickness as the transverse slab at 250mm. The number of strands positioned within the bottom flange varies from 20 to 75. The U-Girder needs a concrete strength varying from C50/60 to C70/85, while the infill concrete can just be C40/50. The U-Girders now vary in weight from 20-40t and would all be erected by modest mobile cranes.

The 250mm thick transverse slab is only about 2.6m wide, allowing it to be precast and transported as a single whole-span piece, only needing the longitudinal stitches between the U-Girders and the slab to be created. Care would be needed to ensure that the slab was precambered in a similar fashion to the U-Girders in order to facilitate the construction of these stitches.

4.3.2.4 Programme

A detailed construction programme is shown in Table 1 for a typical '*UU-Bridge*' solution. It incorporates the removal of an existing deck, the installation of the U-Girders and deck slabs, waterproofing of the deck, as well as the installation of the ballast and track. It allows for the fact that the in-situ infill concrete to the U-Girders must be poured, and achieving reasonable strength (10-12N/mm^2) within 6 hours, before the bottom slab deck panels are erected. It also allows for the deck in-situ stitch concrete to be poured and up to reasonable

Table 1: Shows a typical 54-hour programme for the 'UU-Bridge'.



strength (20 N/mm^2) within 6 hours. The ballast can then be added after this short period – the temporary steelwork support to the RC deck panels has been sized to carry both the weight of the precast slab and the ballast. At the end of the possession, or at least 12 hours after the stitch has been poured, the temporary jacks to the U-Girders are removed, which then puts the full transverse bending in to the slab and its new stitch. In summary, the whole series of operations can be completed within a short weekend possession of 54 hours, running from closure at midnight on a Friday to re-opening at 6am on the following Monday morning. The operations could therefore all also be carried out more comfortably within a longer weekend possession of 72 hours. So either way, this railway method using precast U-Girders and deck slabs can be satisfactorily completed within 2-3 days.

4.3.2.5 Details

As well as the single and double track configurations described above with just two girders, there is also a common situation using a double track and three girders (See Figure 20), which is effectively two single tracks side by side. This layout is only ever used for 10-24m spans, i.e. where the 1.6m deep girders sit beneath the platform gauge.

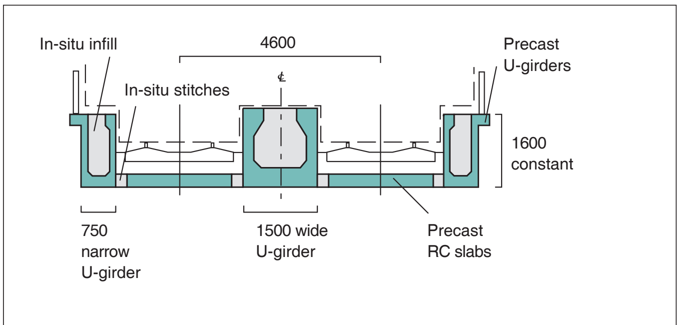


Figure 20: Railway 3-girder 'UU-Bridge'.

The traditional arrangement of the *six-foot* gap between two tracks places the track centres at 3.4m. This space is too narrow to even fit a narrow steel plate girder. For all the typical steel solutions therefore, the tracks centres are increased to about 3.8m. The central girder of the three clearly carries twice the load of the outer girders – so, in this new configuration of U-Girders, the outer girders will be 0.75m wide and the central girder will be 1.5m wide. This layout needs the track centres to increase to 4.6m in order to fit the 1.5m wide central U-Girder. This new geometry would need to be considered at each location.

Skew layouts are very common with many railway bridges and this U-Girder system can incorporate skews without any difficulty (See Figure 21 which shows a typical skew plan layout for the 'UU-Bridge'.). For the single track options, the transverse slab is a single piece of precast concrete that can be reinforced with either square or skew reinforcement as the designer and contractor prefer. Square reinforcement at the longitudinal stitch between the RC slab and the PSC U-Girder will certainly be easier to interlock and cast. For the double track configurations, the easier casting and construction option would be to use skew slabs with skew reinforcement. This requires the longitudinal stitch to be reinforced with skew bars too, which is a little more awkward, but not too significant. However, as the main loads in the slab are truly transverse, the design would need to include significant longitudinal reinforcement across all the transverse/skew stitches, which is not easy to accommodate. The better option therefore would be to use square slabs and square reinforcement, which is very easy for the central sections of the span. At the skew ends though, the design would then need to incorporate precast trimmer beams that become stitched to the U-Girders at the same time that all the RC slabs are stitched. The end stitch would be detailed more like the main longitudinal stitch. For the most extreme skews, this trimmer beam can be made a little deeper or a further central bearing could be incorporated, as would be seen on a steel railway bridge.

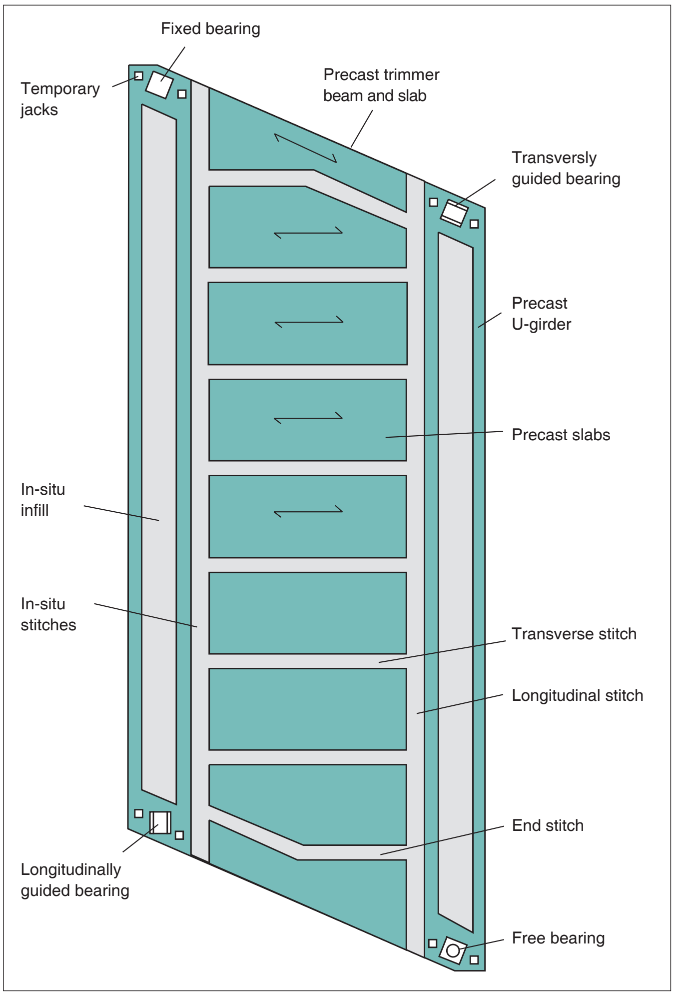


Figure 21: Railway 'UU-Bridge' skew.

The creation of a single, monolithic piece of deck concrete requires there to be stitches formed between the precast pieces. There are nominal transverse stitches between the RC deck panels and main longitudinal stitches, carrying significant moments and shears, between the RC deck panels and the PSC U-Girders. These would all be formed in HSC (of around strength class C85/100) not so much for long-term strength, but to get up to enough short-term strength (at least 20 N/mm^2 in 6 hours and about 50 N/mm^2 within 18 hours). Speed is of the essence for these stitches as they are all on the critical path of the programme during the weekend possession periods.

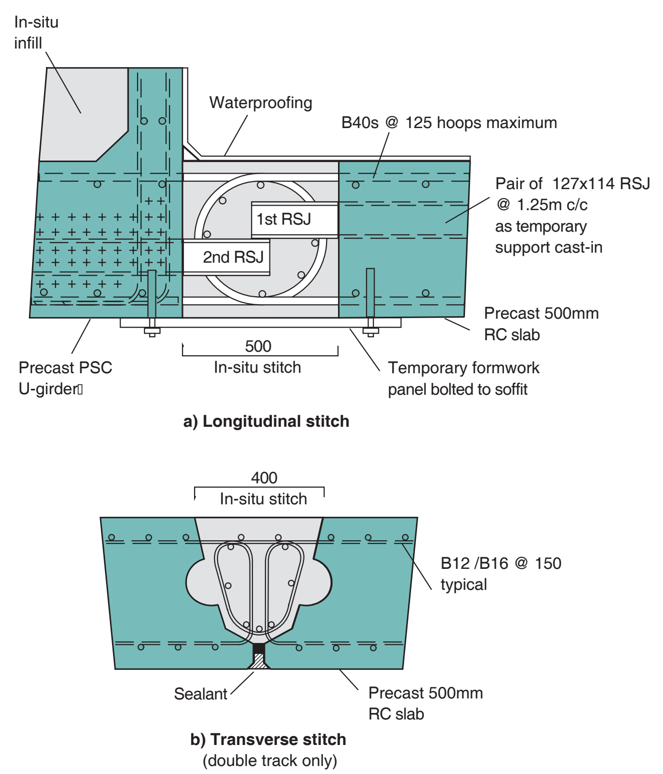


Figure 22: Railway 'UU-Bridge' stitches.

This longitudinal stitch detail is formed using a temporary soffit shutter, which is bolted to the underside of the U-Girder and the precast slab, allowing it to be readily removed at the end of the possession. Alternatively, a temporary falsework could be hung from the bottom of the U-Girder to perform the same sort of role. The stitch carries significant moments and is designed on the basis of overlapping hoops. The stitch width is the same as the stitch depth, and in this case, the bars can all be seen to be fully anchored in tension at all positions. In addition, recent research (which will be incorporated within the new EC2) by Joergensen and Hoang[13] shows that a stitch of this form can indeed carry the full tension capacity of the bars as long as there are sufficient longitudinal bars placed within the overlapping hoops, as any sensible detailing would require anyway. A temporary support to the RC deck panels has been sized using overlapping pairs of RSJ steel sections, which are cast in to the U-Girders and the precast deck slabs.

These can carry both the weight of the precast slab and the ballast – however, the ballast should not be added until 6 hours after the stitch (See Figure 22 which shows the typical details for the stitches on the 'UU-Bridge' deck.) has been poured to guarantee the overall stability of the U-Girder. Towards the end of the possession, or at least 12 hours after the stitch has been poured, the temporary jacks at the ends of the U-Girders can be removed, which then puts the full transverse bending in to the slab and this new stitch.

The transverse stitch between RC deck panels is only needed for the double track railways. It is a nominal RC stitch poured in to an area formed by the precast panels themselves, i.e. it does not need an additional shutter. It mainly acts as a shear key between the precast panels although it does have some nominal bending capacity too.

4.3.3 Modular Precast Concrete Bridges

The CBDG developed a modular precast concrete bridge system for the railway (Figure23) that is described fully in CBDG TG 11[1] and TG 14[3]. Essentially, it is a precast segmental version of the classic PSC in-situ, twin-rib deck. It combines the best features of in-situ and precast construction in to a standard set of short, precast shell units that are assembled on site. The deck is completed with an in-situ inner concrete core within each rib that is then post-tensioned. A railway version was also designed for these 15-40m railway spans.

The precast U-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 alongside the railway on a series of beams and props, before lifting (if the weight is less than 150t, which it is for all single tracks and double tracks with spans less than 10m), sliding, or using an SPMT to move the whole deck (weighing 100-1,000t) across to its final position.

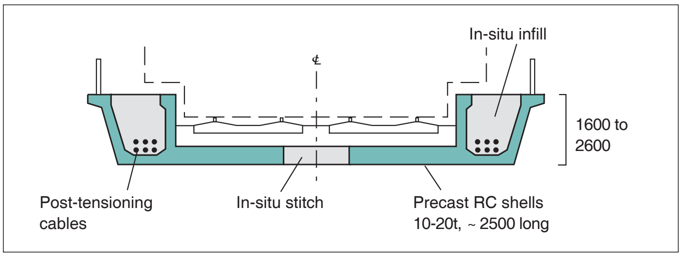


Figure 23: Railway Modular Precast Section.

4.4 Railway Bridge Arch/Portal Solutions

All the bridge replacement options shown tend to describe schemes where a proper bridge deck is being replaced or widened, with spans from about 10-40m. In reality, the schemes can all include spans down to about 5m as well. In this area of shorter spans (5-20m), it is also then possible to consider the culvert-type options. These options include the classic precast box culvert for 1-6m spans and the various precast arch or portal schemes for 5-15m spans. All options could be made from in-situ concrete, but with the good availability of various precast concrete solutions in the market, the precast version seems more obvious. All solutions are made from RC.

In the railway environment where track diversions are not possible, the replacement scheme would generally be built alongside the railway with a sequence such as – construct new precast units and supports alongside; cut embankment in a possession and remove backfill; slide or lift out old culvert; slide or lift in new culvert; and then complete backfill in the possession. Sliding or rolling can take place upon pre-assembled tracks. It is also possible to use an SPMT to both remove the old bridge and to install the new one. Such schemes would include the sliding or lifting of the ballast and track, in order to minimise the possession time.

Figure 24 shows the use of a small low arch to create a replacement bridge in 8 hours.

Many more details for these in-situ or precast arches and portals are shown in CBDG TG 12[2], along with further details and data in CBDG TG 14[3].

Figure 24: 8 Hour Bridge,Holm Farm.

5. Substructure Solutions

This topic is huge in its own right, but in the context of this guide, the issues are not particularly complicated and are generally well understood by the wide community. Only a brief flavour will therefore be given here of some of the key issues.

In the highway environment, most abutments should be made integral, which is commonly achieved with in-situ concrete diaphragms connecting the in-situ or precast decks to the existing abutment walls and foundations. There are no difficulties in casting these works as the abutment area is usually well away from the live traffic beneath the bridge. If bearings were still being used, as might be the case for a deck sat upon an existing masonry abutment wall, then either just the bearings might be replaced or some of the supporting structure beneath the bearings might need replacing too. In this case, there is a cill beam between new deck and bearings, and the supporting wall. This cill beam can simply be cast in-situ, in stages to suit the deck construction. If speed were required, then the cill beam might also become a precast unit, as would be common in the railway environment (Figure 24).

On the railway, the most common scenario would indeed be a single span deck sat on bearings, which are then supported on a masonry abutment wall. Again, this area is generally well away from the live traffic beneath the bridge, allowing works to take place in a relatively unrestricted manner. However, the railway deck itself needs to be replaced within very tight time restrictions, which puts the replacement of the cill beam on the critical path of the programme as well. The typical construction programme shown in Table 1 highlights all the key operations, including those related to this type of cill beam. Basically, once the existing deck has been removed, the top of the existing abutment wall needs to be removed too, allowing a new precast cill beam to be lifted in to place. The cill beam is bedded on to the masonry wall with high strength concrete grout, which enables the new deck to be installed very shortly afterwards. Such precast cill beams are formed as solid RC sections, typically weighing 10-40t, which makes them readily installed by the existing cranes on site for the deck beams. Some of the precast concrete railway decks proposed in this guide are 300-500mm wider on each side of the abutment than an equivalent steel deck, but all these geometric differences can be readily absorbed within a reasonable cill beam design, leaving the existing abutment unaffected. Whereas many steel or steel-composite railway decks also require an additional side impact beam for protection, all the concrete decks shown are much more robust, particularly for such lateral impact loads. No additional protection is therefore needed for any concrete bridge. This feature alone gives all the concrete solutions a distinct advantage over any of the steel solutions. Figure 25 shows a typical cill beam layout for the railway.

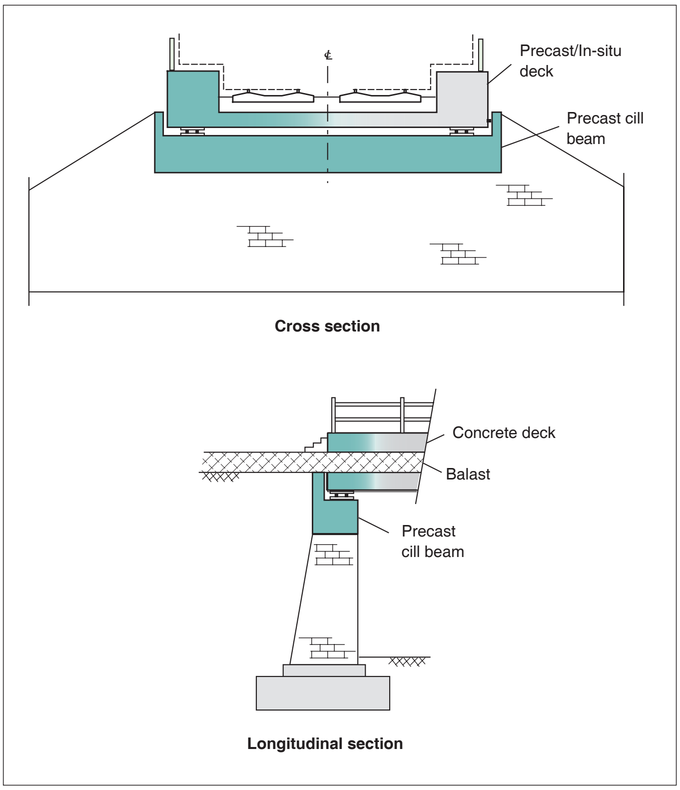


Figure 25: Railway cill beams.

It is also necessary to consider the load effects of any new deck upon existing abutments and foundations, particularly for older masonry walls. Similar deck replacements would cause no issues, but there may be some concerns if a steel or steel-composite deck were replaced with a heavier concrete deck. Of course, for overall stability and lateral sliding of the abutment, a heavier deck would only improve the situation. However, a heavier deck will usually increase the ground bearing pressures beneath the front of the wall and its foundation, and this condition should always be thoroughly investigated. From a simple analysis of several typical spans and abutment configurations though, it can quickly be seen that even though the deck weight might increase significantly, the increase in overall weight at the foundation level is less than about 10%. This is due to the fact that most of the weight comes from the highway or railway traffic, the surfacing or the ballast, the abutment wall, the backfill and the foundation itself, i.e. the effect of the actual weight of the deck is relatively small. Looking at the highest front bearing pressures, the increase in overall pressure at the foundation level is then less than about 5%. This is due to the weight comparison quoted above and the fact that the lateral loads (from the traffic and backfill) are virtually unchanged. In most cases, this would suggest that a heavier concrete deck is not an issue for the abutments.

6. Conclusions

The purpose of this technical guide has been to address the many small to medium-span bridge replacement situations, in the UK especially, i.e. spans of 10-30m that are often either single-span or two-span structures. Such schemes need to be built safely, simply, quickly and effectively across a live roadway, railway or waterway. The solutions shown cover best practices for both the design and construction of replacement road and rail bridges. Speed and ease of construction is very important in order to limit possession and/or traffic management costs and delays. As well as these typical bridge replacement schemes, the guide equally addresses the creation of new concrete bridges of this type.

Both in-situ and precast solutions are examined and shown, together with both reinforced concrete (RC) and prestressed concrete (PSC) schemes. An innovative new system for casting these simple spans in-situ is described in some detail, allowing such options to become much more common in the UK. An innovative precast railway scheme is also examined in depth (the new '*UU-Bridge*'), and the precasting of whole spans is demonstrated too. All these railway methods using precast concrete pieces allow decks to be fully completed within 2-3 days, i.e. normal to long weekend possessions.

The CBDG's Modular System is briefly included, although much of this system is already described in detail in CBDG TG 11[1]. This technical guide also covers precast arches and portals, although these are also described in greater detail in CBDG TG 12[2].

CBDG TG 14[3] is widely referenced as it outlines the critical importance of the construction method in the choice of all concrete bridge decks, and it goes on to give detailed data relating to production rates, programme and cost breakdowns for every available concrete bridge deck solution, including most of those shown in this guide.

The target audience is consultants, designers, contractors, sub-contractors, suppliers and owners. This guide will generate a significant additional area of expertise that owners, consultants and contractors can call upon when investigating bridge replacement schemes, or indeed new schemes of this size and type. The greater use of high quality, good value, robust, durable and sustainable concrete options with a high aesthetic content should result.

Overall, concrete gives safe, easy and quick solutions with good value, aesthetics and impact resistance, with very low maintenance for all bridge replacement scenarios, and no greater depth than any steel version.

It is hoped that, using the information provided in this guide, many more in-situ and precast road and railway bridges will be used in the UK (and globally) at the increasing number of bridge replacement locations, proving that with some careful consideration about the best construction methods, concrete bridges do indeed provide competitive options.

Figure 26 shows a seven span precast U beam and in-situ concrete slab replacement viaduct carrying both road and rail.

Figure 26: Multi-span replacement viaduct.

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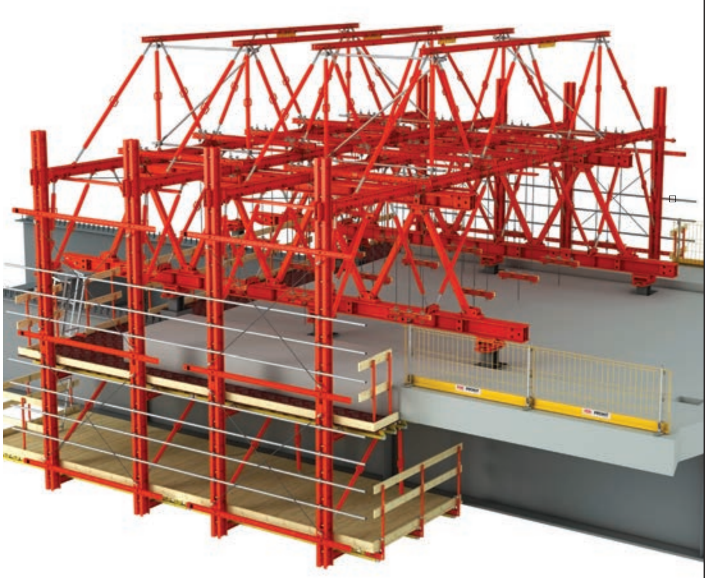

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CONCRETE BRIDGE DEVELOPMENT GROUP

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 challenges to bridges and to maximise opportunities to develop the wider and better use of concrete.
- Provide a focus for all those involved in concrete bridge design, construction and management, temporary works, maintenance, inspection and monitoring and materials.
- Promote an integrated approach and the use of best practice in design and construction.
- Encourage the development of innovative ideas and concepts.
- Support and encourage education and training initiatives.
- Identify and support future research and development needs.

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
- Students

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

Bridge Replacement Guide: A state-of-the-art report

This technical guide addresses the many small to medium-span bridge replacement schemes. Such schemes need to be built safely, simply and quickly across live traffic. The solutions shown cover best practices for both the design and construction of replacement road and rail bridges. Both in-situ and precast solutions are shown. An innovative new system for casting spans in-situ is described in some detail, allowing such options to become much more common. An innovative precast railway scheme is also examined in depth. The railway methods described using precast concrete also allow bridges to be fully completed within normal weekend possessions.

This technical guide will generate a significant additional area of expertise that owners, consultants and contractors can call upon when investigating bridge replacement schemes, or indeed new schemes. Overall, concrete schemes are shown to give safe, easy and quick solutions with good value, aesthetics and impact resistance, with very low maintenance and no greater depth than any steel version.

Using the information provided in this technical guide, many more concrete road and rail bridges should be used at the increasing number of bridge replacement locations, proving that with some careful consideration about the best construction methods, concrete bridges do indeed always provide competitive options.

Simon Bourne, Bridge Consultant and former owner of Benaim. Benaim specialised in the design of major bridges for contractors, working with alternative designs, value engineering commissions, or design and construct projects. Simon was the Chairman of the CBDG from 2012-15 and has worked extensively on 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. 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.

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