Concrete Bridge Design and Construction series

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

The group aims to promote excellence in the design, construction and management of concrete bridges. With a membership that includes owners, designers, academics, contractors and suppliers, it provides a focus for the use of best practice, innovation, training initiatives and research and development. Further information on the CBDG can be found at: www.cbdg.org.uk

No. 1: Introduction to concrete bridges

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

Introduction

This is the first in a series of articles prepared by the CBDG's Technical Committee. The series will summarise all the key areas concerning concrete bridge design and construction. This article demonstrates the key benefits of using concrete. Subsequent articles will focus on bridge types and choices, prestressing and reinforcement details, formwork types, construction methods, high performance concretes and managing the asset. The series will encourage early participation between the owners, designers and contractors who are intending to construct a bridge.

Benefits of concrete bridges

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

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

Four key benefits are described here – aesthetics, sustainability, durability and buildability. As the series progresses, articles will describe the extensive versatility of concrete bridges, with references to the best choice of bridge type for each location; much of which will be determined by programme, speed of construction and the availability of materials and skills. A new CBDG Technical Guide is also being finalised for publication this year that will give extensive details regarding costs and programme for all concrete bridge types.

Aesthetics

A bridge engineer has twin obligations – to use his client's money wisely and to produce a structure for society that will enhance the built environment. These two elements are the classic balance between form and function. The structural forms that can be achieved with concrete are only limited by the imagination of the designer, but it clearly requires an experienced engineer with good judgement and expertise to control this balance between form and function. Aesthetics is a central feature of the design development, but solutions designed to suit the flow of forces in the bridge will

Figure 2a Broadmeadow Estuary Bridge (from distance)

Figure 2b Broadmeadow Estuary Bridge (close up)

Figure 3 Typical ready-mix concrete plant

tend to have a natural elegance[1]. Bridges often need little more to improve their form, though the collaboration with experienced bridge architects can certainly be a welcome addition, as they can also add a much broader understanding of the social impacts. Nevertheless, a good appreciation of context, scale, lines and balance is still vital for the engineer.

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

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

Sustainability

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

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

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

Concrete should be placed as near to its point of production as possible, in order to minimise the need for transport to site, support the local economy and prevent the export of environmental impact to other locations. The UK is highly self-sufficient in this regard and there is generally a ready-mix plant within 8km of every site, or within the precast factory, and more remote sites can set up their own batching plants.

Embodied energy and CO_2 emissions have been shown to be at their minimum, both during construction and in use, with concrete bridge solutions[2]. Up to 95% of the concrete and steel reinforcement in a concrete bridge can also be recycled once the structure has reached the end of its viable life.

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

Durability

Concrete has been in use since 7,000BC and there is significant evidence to show that it is a very durable construction material (Figure 4). Most bridges in the UK are specified to have an intended

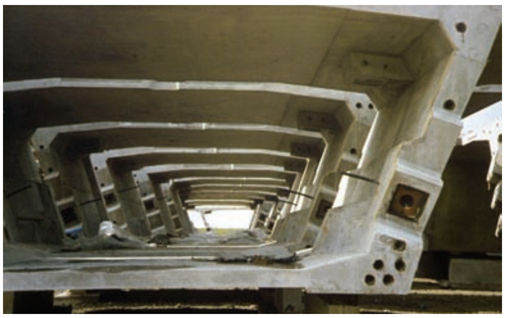

Figure 4
Maillart's stunning Salginatobel Bridge - opened in 1930

Figure 5
East Moors Viaduct - stored precast units

working life of at least 100 years and so durability is a primary objective. It is therefore essential to consider the overall layout of the bridge, the detailing of the elements and the specification of the component materials. A significant reduction in the number of joints and bearings, or their elimination, will be a major feature of such considerations, as will the careful specification of concrete types and cover to reinforcement. All external areas of the concrete surface need to be carefully detailed with dedicated routes away from the structure (for the flow of salt-laden water, and the incorporation of suitable drips, channels and pipes) where necessary[3].

Waterproofing of bridge decks is recognised in the UK as a necessary operation to enhance the longevity and durability of the structure. The most common form of waterproofing is a liquid sprayed system applied in several coats[4].

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[5-7]. Following these recommendations will ensure that the concrete is resistant to carbonation and chloride ingress, providing a full working life. The partial substitution of Portland cement with fly ash or blast furnace slag, for example, results in concretes with high resistance to chlorides from de-icing salts or sea water. Concrete is also entirely appropriate for use where structures are subjected to other aggressive actions (such as acids) or ground conditions (such as sulfates). Construction methods that also use precast elements will tend to have higher concrete strengths, thus enhancing the long-term performance of the bridge (Figure 5).

The durability of concrete is highly dependent on the attention that is paid to detailing. Best practice is described in two notable documents: Highways Agency BD 57[8] and CIRIA C543[9]. Ready access to sensitive areas, such as pier tops, abutment shelves, the inside of box girders, bearings and joints, will allow inspection and any maintenance work to be safely carried out.

Well designed and constructed concrete bridges require only minimum maintenance to keep them in good working condition. As a result, their competitive initial construction costs coupled with reduced inspection and maintenance, ensure a very attractive whole-life cost. High quality, low permeability concretes with the correct covers, low water/cement ratios and the appropriate cementitious material will provide durable bridge structures in all environments[10].

Buildability - precast versus *in-situ*

Buildability and the various construction methods available for concrete bridges will be discussed in future articles in this series, but the particular issues around the use of precast or *in-situ* construction are outlined here.

The general parameters of the scheme (such as the typical spans, the overall deck area, width and length, the clearance requirements, alignment and the overall aesthetic) will start to suggest which bridge types and which construction methods might be appropriate (Table 1). However, the final choice will then depend on many other particular parameters such as:

- site access, layout and availability
- geotechnical issues
- environmental issues
- construction programme and phasings
- labour rates
- resource requirements
- material quantities and costs
- plant supply
- traffic management
- temporary works layouts

as well as the overall casting, transportation and craneage or erection issues. The owner should try to leave as many of these parameters as flexible as possible, such that the designer and contractor can consider as many of the available construction methods as possible – this strategy is likely to lead to the optimum solution for the owner.

Many of these parameters are controlled by the need to increase the speed and ease of the construction process, and while fast construction is not necessarily an objective in itself, it can generally be seen that the best construction methods are indeed driven by speed. Although precasting is often the preferred method of achieving these speed objectives, *in-situ* concrete can also deliver the same results (Figure 6). In practice, a combination of the two (*in-situ* piers and precast decks) is typical. The appropriate use of labour, materials and plant to create the best construction method can assure the successful delivery of a wide range of bridge deck structures within tight programmes and across the spectrum of environmental and site conditions.

Precasting and factory production methods can significantly improve the safety regime by shifting the works to a more regular and controlled series of operations, with a workforce who have become

Figure 6
River Dee Viaduct - *in-situ* balanced cantilevering

Table 1: Bridge types vs span (all dependent on total deck area, alignment, depth and local conditions)

Bridge Types	Span (m)						
	10 to 20	20 to 30	30 to 40	40 to 50	50 to 60	60 to 70	70 to 80
In-Situ Flat Slabs							
In-Situ Voided Slabs							
In-Situ Twin Ribs							
Standard Precast Arches/Portals							
Standard Precast Beams							
Bespoke Precast Beams							
In-Situ Boxes							
Modular Precast System							
Precast Segmental Span by Span							
Incremental Launching							
Whole Span Precast							
In-Situ Balanced Cantilevering							
Precast Segmental Balanced Cantilevering							
Bespoke Arches/Frames							
Stressed Ribbons							
Extradosed							
Cable-Stayed							

familiar with the production process. Precasting of elements can also significantly reduce risks and improve rates of production. The repetition created by a standardisation of details and dimensions helps to reduce construction time (Figure 7).

Bridge components that are manufactured away from the construction site (eg. Figure 8), in an efficient factory environment, can be made to very high standards and without any concerns about adverse weather. The quality of the concrete can be tightly controlled and the formwork, reinforcement and prestressing can be prepared and positioned to extremely high tolerances. After it has been poured, the concrete can be cured effectively to maximise its performance, durability and appearance. Importantly, precast concrete can be stored and delivered to site at precisely the right time in the construction programme. On larger projects, a precasting facility may be established on (or close to) site.

Precast elements, which can vary from several tonnes to several thousand tonnes, are much quicker and easier to erect too, though more sophisticated erection methods will generally be needed. These methods might use large mobile or site cranes (Figure 9), lifting frames or shear legs, gantries (some of which can become self-launching and very sophisticated pieces of mechanical/electrical engineering), falsework towers and a range of girders.

As such, precasting requires a greater degree of capital investment, with not only more complex erection methods, but also casting and storage areas, transportation, and more equipment than is needed for *in-situ* works. Therefore, it tends to need greater planning and more care in its execution. Nevertheless, there are significant benefits to precasting, but *in-situ* construction is still also very valid, in the right circumstances.

Typical range | Most competitive range in UK

	Span (m)					
	80 to 90	90 to 100	100 to 150	150 to 200	200 to 250	250 to 300

Figure 7
Kingsway Canal Bridge - standard precast beams

Figure 8
Banagher Concrete precast factory and yard

Figure 9
Limerick Southern Ring Road - precast beam lifting

Future articles will investigate these various forms of *in-situ* construction – slabs, twin ribs, box girders and balanced cantilevering (which can produce the largest concrete beam bridges in the world, with spans of over 300m). The many forms of precast construction will also be described – standard and bespoke beams, segmental, modular, whole span and incrementally launched.

Conclusions

Using local and recycled resources, teams are able to deliver sustainable concrete solutions for a wide range of bridge applications. Aesthetics, durability, versatility, economy and buildability make concrete an excellent material for any bridge project, whatever the size, form or use.

With over 100 years of history, concrete bridges are an established part of the world landscape. Looking ahead, concrete bridge construction will continue to lead the way, enabling aspirations embraced by the construction industry and society to be fulfilled as part of a sustainable future.

Subsequent articles will outline the versatility of concrete bridges, looking in detail at all bridge types, key details, formwork and falsework options, best construction methods and the use of a range of different high performance concretes.

References and further reading

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