ISSN 1562-3610
ISBN 2-88394-069-X

Precast concrete bridges

Contents

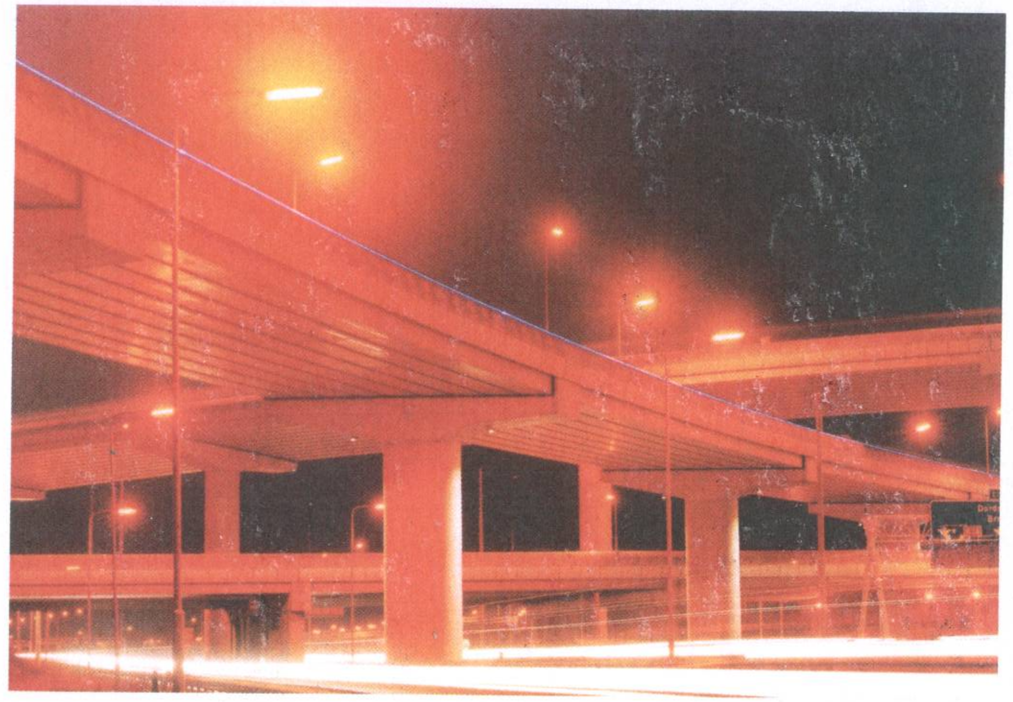
fib CEB-FIP

fédération internationale du béton
the international federation for structural concrete
created from the merger of CEB and FIP

bulletin 29

state-of-art report

fib CEB-FIP



Precast concrete bridges

Precast concrete bridges

State-of-art report prepared by

Task Group 6.4

November 2004

Subject to priorities defined by the Steering Committee and the Presidium, the results of *fib*'s work in Commissions and Task Groups are published in a continuously numbered series of technical publications called 'Bulletins'. The following categories are used:

category	minimum approval procedure required prior to publication
Technical Report	approved by a Task Group and the Chairpersons of the Commission
State-of-Art Report	approved by a Commission
Manual or Guide (to good practice)	approved by the Steering Committee of *fib* or its Publication Board
Recommendation	approved by the Council of *fib*
Model Code	approved by the General Assembly of *fib*

Any publication not having met the above requirements will be clearly identified as preliminary draft.

This Bulletin N° 29 was approved as a *fib* state-of-art report in April 2004 by *fib* Commission 6, *Prefabrication*

This report was drafted by *fib* Task Group 6.4, *Precast bridges*:

José Calavera (Convenor, Spain)
André De Chefdebien (CERIB, France), David Fernández-Ordóñez (Prefabricados Castelo, S.A., Spain, Secretary), Antonello Gasperi (Consulting engineer, Italy), Jorge Ley (INTEMAC, Spain), Fritz Mönnig (Prof. Bechert & Partner, Germany), Pierre Passeman (CERIB, France), C. Quartel (Spanbeton BV, The Netherlands), Ladislav Sasek (VPU DECO Praha, Czech Republic), George Tootell (Buchan Concrete Ltd., UK), Arnold Van Acker (Belgium)

Full address details of Task Group members may be found in the *fib* Directory or through the online services on *fib's* website, http://fib.epfl.ch.

Cover picture: Curved precast box beam bridges for the intersection on motorways (see Fig. 6.9)

The colour publication of this report has been made possible through the generous support of these sponsors:

FCC (Spain), Generale Prefabbricati S.p.A. (Italy), Ianus s.r.l (Italy), INTEMAC (Spain), Pacadar (Spain), Precompressi Centro Nord (Italy), Prefabricados Castelo S.A. (Spain), Spanbeton BV (The Netherlands)

First published in 2004 by the International Federation for Structural Concrete (*fib*)
Post address: Case Postale 88, CH-1015 Lausanne, Switzerland
Street address: Federal Institute of Technology Lausanne - EPFL, Section Génie Civil
Tel +41 21 693 2747, Fax +41 21 693 6245, E-mail fib@epfl.ch, web http://fib.epfl.ch

ISSN 1562-3610
ISBN 2-88394-069-X

Printed by Sprint-Digital-Druck Stuttgart

Foreword

Bridges and viaducts are an important segment within the construction activity. Most publications regarding realisations and guidance documents on design and execution are generally focusing the more spectacular bridge projects with extreme large spans and challenging execution conditions. However the bulk of the bridge market concerns ordinary bridges over motorways, railways and watercourses. They are characterised by smaller spans, limitation of traffic restrictions during execution and above all economy. This is the exquisite domain for prefabrication: high strength concrete, speed of construction, absence of scaffolding, industrialised production process, etc. However the knowledge of modern precast bridges among authorities and designers is often limited and a lot of prejudices exist with regard to aesthetic appearance, technical possibilities and innovations.

The present State of Art report is intended to give detailed information on modern precast bridges. The scope is restricted to industrially precast bridges, manufactured in permanent precasting plants. The document is for a greater part based on European experience, since most of the members of the Task Group are from Europe and the collection of information from other continents didn't succeed very well. The *fib* Commission on prefabrication intends to complement the present State of the Art Report by a future publication concerning guidelines on the design and execution of precast bridges.

The report has been prepared by the Task Group TG 6.4, headed by Prof. J. Calavera. Dr. David Fernandez and Arnold Van Acker have done the editorial work.

Prof. José Calavera

Convenor Task Group 6.4

Contents

1 Introduction

Publications on the subject of bridge construction deal mostly with spectacular structures, both with respect to design matters - span length and total length - as with regard to execution. They are constructed on site, often using a technique of site-prefabrication of large and extremely heavy bridge parts. However, an important part of the bridge market consists of simple projects, where speed of construction, cost and minimum disturbance of existing traffic are important parameters. This is the domain of industrially precast bridges, although also relatively large bridges can be made by this technique. In the following, the term "precast bridges" is used for this type of bridges, made in permanent precasting factories.

The development and application of precast bridges is very different in the various countries: in some like Belgium, Canada, Italy, Spain, the Netherlands, United Kingdom, USA, etc. precast bridges are routinely used, in other countries they are hardly known or even not used at all. Also in other continents like for example China, precast bridges are frequently used, but information is missing.

The development of precast bridges has been mainly done by the precast industry in collaboration with public authorities. Initially, the projects were based on beam systems with a cast in-situ deck. Later on, the developments went towards more completely prefabricated systems, for example with box beams. The recent developments are now focussing on:

- more emphasis on aesthetics,
- larger and heavier units,
- demands for special solutions,
- total tender projects, in which the precaster is responsible for the complete structure.

The development of cranes, launching cradles and assembly methods in general, along with the increased length and loading capacity of transport vehicles, have enhanced prefabrication potential enormously, both from the technical and economical standpoints. All this has led to the existence of prefabricated structures that can readily span up to 100 m.

The progress made during recent years in transversal deck construction using strut bracing and precast components in general have made it possible to build very wide decks with highly aesthetic single box beams.

Precast beam bridges are well suited for moderate span projects, where the realisation of classical scaffolding supported on the ground is difficult or prohibitively expensive and where the speed of erection is mandatory:

- watercourses,
- railways,
- roads and motorways in use, in order to limit traffic restrictions.

Prefabrication presents many advantages over traditional construction for bridges. They have resulted from the industrial approach and favourable working environment, protected from adverse weather conditions. For many years, the profession has been familiar with the principles and methods aiming at mastering the quality of the precast products. Each plant has a self-control system, defining the working procedures and modules for internal inspection and control. Among the many advantages, the following are of particular interest to bridge construction:

- Quality and regularity of the concrete strength.
- Elements with elaborated shapes designed to get a maximum benefit from the materials and the prefabrication. They require the use of relatively complex moulds, but at the same time enable high quality surfaces with respect to shape, texture, dimensional tolerances, etc., to be achieved.
- Absence of laborious and hindering scaffolding.
- Shorter construction time due to the fact that precast elements are made at the plant independent from the foundations and other preparatory works on site.

Precast bridges are not without criticism:

- The perceived opinion from some instances, that precast bridges are monotonous and ugly.
- The larger number of transversal joints in older realisations, especially in viaducts, causing discomfort and maintenance problems.
- Certain specific technical issues, such as earlier doubts with regard to the transfer length of prestressing strands, particularly for large diameters subjected to fatigue stresses in railroad bridges. Another question concerned the effectiveness of the shear transfer at the interface between cast-in-situ concrete and prefabricated elements, especially in relation to fatigue stresses.

The aim of this State-of-the-Art report is to give a detailed overview of the existing solutions and applications world-wide and recent developments in the domain of precast bridges. They should enable the authorities and designers to form a realistic opinion about the possibilities and advantages of this technique, and get away from some still existing prejudices.

2 Definitions

Abutment: Any end support of a bridge usually without rigid continuity with the deck. Rigid abutments and flexible abutments should be distinguished where relevant.

Pier: Intermediate support of a bridge, situated under the deck.

Bearing: Structural device located between the deck and an abutment or pier of the bridge and transferring loads from the deck to the abutment or pier, or allowing relative movements between the different parts of the structure.

Pre-tensioning: prestressing used in permanent precasting factories with strands pretensioned on long beds before casting and hardening of the concrete.

Post-tensioning prestressing with ducts and cables used mainly on site, but sometimes also applied in precast bridge construction in complement to pre-tensioning.

Headroom: Free height available for traffic.

Continuous bridge: Bridge with no expansion joints between adjacent intermediate spans, with or without structural continuity.

Partial continuity: Structural system with simply supported beams and continuous slab deck.

Full continuity: Structural system with continuous beams and slab deck.

Integral bridge: Bridge without expansion joints between adjacent intermediate spans and between end spans and abutments.

Diaphragm: Transverse stiffening action of the bridge, either by the deck or by transversal in-situ or precast beam(s).

Cross head: Transverse support beam at an intermediate deck support.

Sagging moment: Bending moment inducing tensile stresses in the bottom fibres (positive moment).

Hogging moment: Bending moment inducing tensile stresses in the top fibres (negative moment).

Skew bridge: Angular crossing of oblique bridge.

Expansion joint: Device between abutment and deck or between two deck sections to allow relative moving.

Sacrificial back wall: to allow longitudinal impact induced by an extreme earthquake. The longitudinal movements are not hindered by this part of the abutment back wall.

Safety stops and limit stops: Devices designed to restrict relative displacement between the deck and its support due to seismic action to secure the structure.

3 History and development of precast bridges

3.1 General

The development of precast concrete bridges goes back a long way in history. The first projects dating from the initiation of prefabrication in concrete itself. Solutions from the thirties can be found in most developed countries, mainly for short span bridges and generally restricted to small works.

The real break-through of precast bridges took place in the fifties and the sixties. It was driven by the large growth of road traffic and the construction of new motor ways, creating a need for fast and economic solutions for underpasses and overpasses with as little as possible disturbance of the ongoing traffic. On the other hand, the introduction of long-line prestressing techniques in precasting plants contributed substantially to the development of larger and more slender pecast units, which was beneficial especially for long spans and heavy loading for bridges.

Looking back over more than 50 years of building of prestressed concrete bridges, one can see a constant growth in the number of prefabricated bridges and also in the size and weight of the applied precast units. However, the development has not been the same in the different countries. In some countries, precast bridges are very widely used and accepted as a classical solution. This is for example the case in Belgium, Italy, the Netherlands, Spain, UK, but also in the USA and in Canada where precast bridges have a market penetration of 50% and more. Those countries dispose of an extensive range of technical solutions for small and large projects and the precaster is playing an important role in the design and execution of the projects. The decision whether a bridge is precast or not is taken at the initial design stage either by the authorities or by the consultant.

In other countries, precast bridges are accepted as a good variant solution to cast in-situ bridges. The market is dominated by big contracting companies and the decision whether to precast a bridge or not is often taken by the contractor himself on the basis of cost and availability of work. In periods of high economical activity, there are more precast bridges than in low economical periods. Examples of such countries are Canada, France, Germany, etc. The market share of precast bridges lies between 5 and 20%.

Finally, in a number of countries, precast bridges are seldom or never used. This is often due to a lack of knowledge and prejudices against prefabricated bridges, both on a technical and aesthetic level. Especially in the Scandinavian countries, there are little precast concrete bridges, although the climatic conditions would logically incite to an opposite attitude.

3.2 Technical development

Precast bridge systems and units have been and are still mainly being developed by the precasters themselves. When looking at a large scale, each precaster or local group of precasters has their own bridge profiles. However, the basic systems are rather similar, with a few exceptions. In some countries, like for example in UK, the influence of Government has been very great in the early days, with encouragement of the use of prestressed concrete because of shortages of steel, and Governmental technical input was used to progress design, casting and the planning of prototypes. In the USA standard cross-sections for bridge beams were developed by a "Joint Committee of the Prestressed Concrete Institute" and the

"American Association of State Highway Officials (AASHO)" for type I-IV beams in 1956 and for type V and VI beams in 1960.

The solutions from the first period were meant for rather small bridges. It is hard to say where the practice began, but it was very likely in England. Pretensioned precast bridge beams were cast before 1948, but that year marked the introduction of the first manufacturers advertising and producing ranges of precast bridge beams. In the US, the first precast bridge was constructed in 1950 in Tennessee. The following variants were used in the early period:

- The so-called match cast systems, whereby the bridge is composed of a series of rectangular beams placed side by side. After erection, the beams are transformed into a deck by transversal post-tensioning. The system is not applied anymore.
- Systems composed of small inverted T-beams placed each against each other. After erection, the space between and above the beams is filled with in-situ concrete.

Next came the girder bridges with precast beams and a cast in-situ deck slab. In the beginning, the height of the beams was rather small, for example 2ft 3 1/2 for a railway bridge of 50 ft span in UK, and 50 cm in some Italian projects. They became gradually higher and higher, up to 2.20 m. At the same time the maximum span length of the beams increased from 35 m in the sixties, till 50 to 60 m nowadays.

The prestressing of the large beams is often a combination of straight and relieved strands, to cope with the tensile stresses at the top of the beam endings during manufacture and handling. In some cases, the relieved strands are replaced by post-tensioning cables, which are tensioned either on the stockyard or on site after casting and hardening of the deck slab.

The bridge beams are mostly I-shaped or inverted T-shaped, and normally with end bloc. However, in the US the practice for the past 30 years has been to eliminate end blocs in all I-beams cross sections. Performance has been excellent even with thin webs. The beams are placed apart at a certain distance, although there are also solutions with large bottom flanges, where the beams are put against each other, to increase the resistance against lateral collision. In the latter case, the bridge has a flat underdeck. The deck slab is cast on concrete shuttering planks, placed in-between the bridge beams. There are of course also other types of beams used, for example V-shaped or trapezoidal beams in France and Italy.

The more recent developments are aiming at the complete precasting of the entire bridge deck. Also here, different systems exist:

- The box beam bridge, either with one large single box, or with multiple smaller boxes.
- Composite bridges with prefabricated deck composed of transversal units, with a length equal to the total width of the bridge. These units are normally supported on steel beams.
- Trough bridges have been developed for example in Belgium, especially for railway bridges.
- Segmental bridges, but with rather small segments, precast in a fixed factory. They are normally used for viaducts in cities and urban areas. However, in the US and in some countries in Europe, plant cast segmental bridges have been employed on river crossings with spans up to 80 metres.

At some time between 1975 and 1985 a giant change took place in the way in which bridge design was considered. From a period where concern was primarily with the economy of new build, there was a change to an appreciation of the importance of lifetime performance. The increase in road salting from 1955 onwards, and its detrimental effect on highway structures of all materials is well known. Precast bridge elements cast in permanent factories benefit both from protected weather conditions and certified quality assurance systems. Experience from many countries show better durability of precast bridges than cast in-situ ones.

The latest developments are inspired by market demands to improve the aesthetics of the precast bridges, to save time and costs and to manage the process of design and erection. Much progress has been made in the development of bridge solutions in the last fifteen years in a number of areas. In this regard, the first challenge for the bridge manufacturers was to adapt their products to curved bridges without having resort to polygonal-shaped floor plans. Today, curved box beams are currently applied in Spain, The Netherlands and UK, with a curvature radius as low as 120 m. The second problem to be solved was to produce members with variable depths, which are better adapted to structural requirements and aesthetic demands. Also piers and other supporting structures are sometimes in precast concrete.

In the early period, precast bridges were always designed as simply supported structures, even in the case of multi-span bridges. Because of problems with respect to traffic comfort and maintenance of the transversal joints, multi-span bridges are now mostly designed as continuous structures. There are two alternatives, either with partial continuity where only the slab is made continuous and the beams are simply supported, or with full continuity, both for the supporting beams and the deck slab. In Germany for example, the latest developments in the construction of precast bridges include continuous bridges, which are prestressed for transportation and made continuous by post-tensioning after erection.

In Spain, due to competition with cast in-situ solutions, precasters are constantly searching for new and competitive solutions. In the last decades, new and very complex precast bridge systems have been developed, for example continuous box beam bridges up to spans of 90 metres, continuous bridges with variable depth up to spans of 60 metres, systems with external post-tensioning, even precast cable stayed bridges with spans up to 260 metres.

In France, after about fifteen years of experience running its TGV high-speed rail lines, SNCF (French Rail), invited contractors and precast concrete products manufacturers to contribute to the future TGV line serving eastern France, with a view to reducing the cost and construction time for the rail line by means of a novel design of standard bridges. In 1996, after studying around thirty new design concepts, SNCF came to the conclusion that the most economic and reliable solution consisted of continuous rail bridges using pre-tensioned prefabricated beams. Fatigue tests were carried out to check that these beams would be able to withstand the applicable railway loading for the theoretical service lifetime of the works (100 years). These studies were carried out by CERIB (see chapter 11).

This new type of standard bridge, which SNCF has designated “Ra-PPAD”, should reduce investment and running costs as well as the line construction time, while still meeting all the technical and regulatory criteria in respect of safety and track evenness. The dual interest of this continuous structural solution lies in the reduced effect of climatic and geo-technical unknown parameters and the physical separation of track and bridge construction. In addition, the monolithic nature of this construction technique enables longer maintenance intervals since it helps to stabilise the ballast and reduces rail stresses above the supports.

3.3 Standardisation - Design guides

Standardisation of bridge systems and beams has been gradually introduced in most countries around the years 70-75. In the USA it started already in the 1950's. In the UK, a brochure from 1979 went as far as producing complete designs, manufacturing construction and specification materials for eight bridges. Of these, three were in-situ concrete, four using precast bridge beams and one with steel beams. In Belgium the real beak-through of precast bridges came in the sixties, during a vast construction program of motorways. Both the authorities and the precasters were convinced that a standardisation in the domain of precast bridges was needed, and that the technique of precast prestressed concrete had evolved sufficiently to enable a codification. In October 1966, a commission was installed to publish a guide on the standardisation of precast prestressed concrete beams for bridges. The commission was composed of members from the Bridge and Railway authorities and the Belgian Precast Concrete Federation. The Belgian Authorities took the commitment to design all new precast bridges according to the agreed standardisation.

The Belgian standardisation was focussing the type of precast bridges, the geometry of the beams including edge beams, the calculation method and quality control procedures. Also some production and erection characteristics have been standardised, e.g. arrangement of the prestressing tendons, deviation of the prestressing tendons in the beams, mild steel reinforcement etc. The given prescriptions enable draft standard reinforcement drawings both for reinforcing and prestressing steel.

In France, a first document related to the calculation of precast bridges, entitled "PRAD 73, was published in 1973 by SETRA (French national design agency for roads and motor ways)". It coincided with an official publication "Provisional instructions N° 2", prescribing the calculation of prestressed units according to the Ultimate Limit State method. However, little specifications were given concerning the design of the bridges. The document of 1973 has been complemented in 1996 by a design guide on "Road bridges with pre-tensioned prestressed bridge beams" also published by SETRA.

The idea of standardised precast bridges took hold in Norway as early as in 1964. In 1967 a committee was established to start the development. The committee was a joint venture with participants from the Norwegian Concrete Association and the Public Roads Administration. In the beginning the results were kept as internal reports in the Public Roads Administration, but in 1974 they were made official as Norwegian Concrete Association publications no. 1, 2, 3 and 4:

- no. 1 contains the design procedure for precast prestressed bridge beams;
- no. 2 is a detailed calculation example, with the beams in composite action with the deck;
- no. 3 contains the standardised beam sections and recommendations for design and production;
- no. 4 is an enlargement of the number of standardised beams.

A summary of the project was presented in the publication “Nordisk Betong” no. 5 in 1977. In the same publication, no. 2-4 in 1982 several examples of the use of the complete systems with pedestrian culverts, water culverts, retaining walls, several types of pedestrian bridges as well as several types of road bridges were presented. The bridges were extensively used up to the middle of the 1980’s. They lost their popularity mainly due to aesthetic reasons. This was not the fault of the system, though, but because the way the bridges were modelled into the terrain was not always very successful. The bridge handbooks have been revised in the period from 1999 to 2001, and a revival of the popularity of precast bridges is expected.

In Germany, guidelines for design and execution of bridges with precast beams were published in 1979: "Provisional guidelines for road bridges in prestressed and reinforced precast concrete" (R FT-Brücken) 1979, Forschungsgesellschaft für das Straßenwesen. The guidelines include design rules, examples and details specific for precast bridges. These recommendations are valid still to day and only some minor amendments were made in the context of the progress of the state of the art.

Like other countries, a normalisation of elements was also done in Spain, but was seldom used. The final design of every single bridge is done by the precaster on the basis of their own element types.

As noted in the USA, standard solutions for precast bridges were developed by PCI in 1956. A series of cross-sections for bridge beams were used by all precast concrete manufacturers. Of course, there were differences in the number of prestressing tendons, mild steel reinforcement, etc.

This early development of standardisation expedited the growth of the precast bridge beam market in the US. In some states, such as Texas, 50% of all bridges are of precast concrete.

4 Types of precast bridges

4.1 General

This chapter gives a general description of the most current types of precast bridges. Many partly or completely precast bridge systems have been developed during the past 30 to 40 years. In this document we are mainly dealing with the types which are still used today.

4.2 Solid deck bridges

Small bridge decks can be constructed with precast units and a cast in-situ topping, acting together as a composite structure. They are used for decks of bridges, viaducts, culverts, tunnel decks, etc. The type of solution leads to heavy but easy to erect structures. For this reason, it continues to be valid for short- and in some cases even for medium-span bridges.

For small spans up to ca 8.00 to 13m, a massive slab-beam solution can be chosen (Fig. 4.1). The precast slab has a modulated width, for example 1200 mm, and a thickness of 150 to 350 mm. The slabs are positioned side by side, and a structural topping varying from 150 to 200 mm is cast on site.

The precast slabs are mostly prestressed and protruding bars at the top ensure a good connection with the structural topping. The longitudinal joint faces of the slabs are provided with a longitudinal slot to form a shear key. The edge of the bridge is normally finished with a profile cast on site together with the topping.

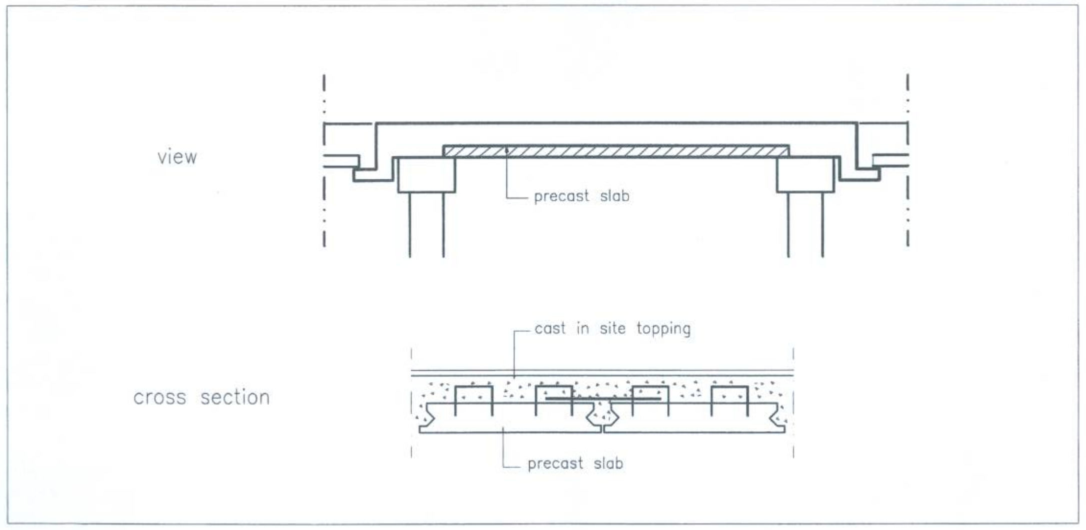


Fig. 4.1: Solid slab-beam bridge

In a more advanced solution, the deck is composed of I-shaped, inverted T-profiles or heavy double-tee units, placed side by side, and connected with a cast in-situ topping and infill concrete. The additional reinforcement of the cast in-situ part comprises a transversal reinforcement through openings in the webs of the beams and a top reinforcement above the beams. The system is suited for bridges with a span length between approximately 6 and 20 m. The edge of the bridge can be realised with a precast side profile or a cast in-situ cantilevering slab.

Figure 4.2 shows systems, which are used in UK, Spain, the Netherlands etc. The solution results in heavy, but very durable bridges.

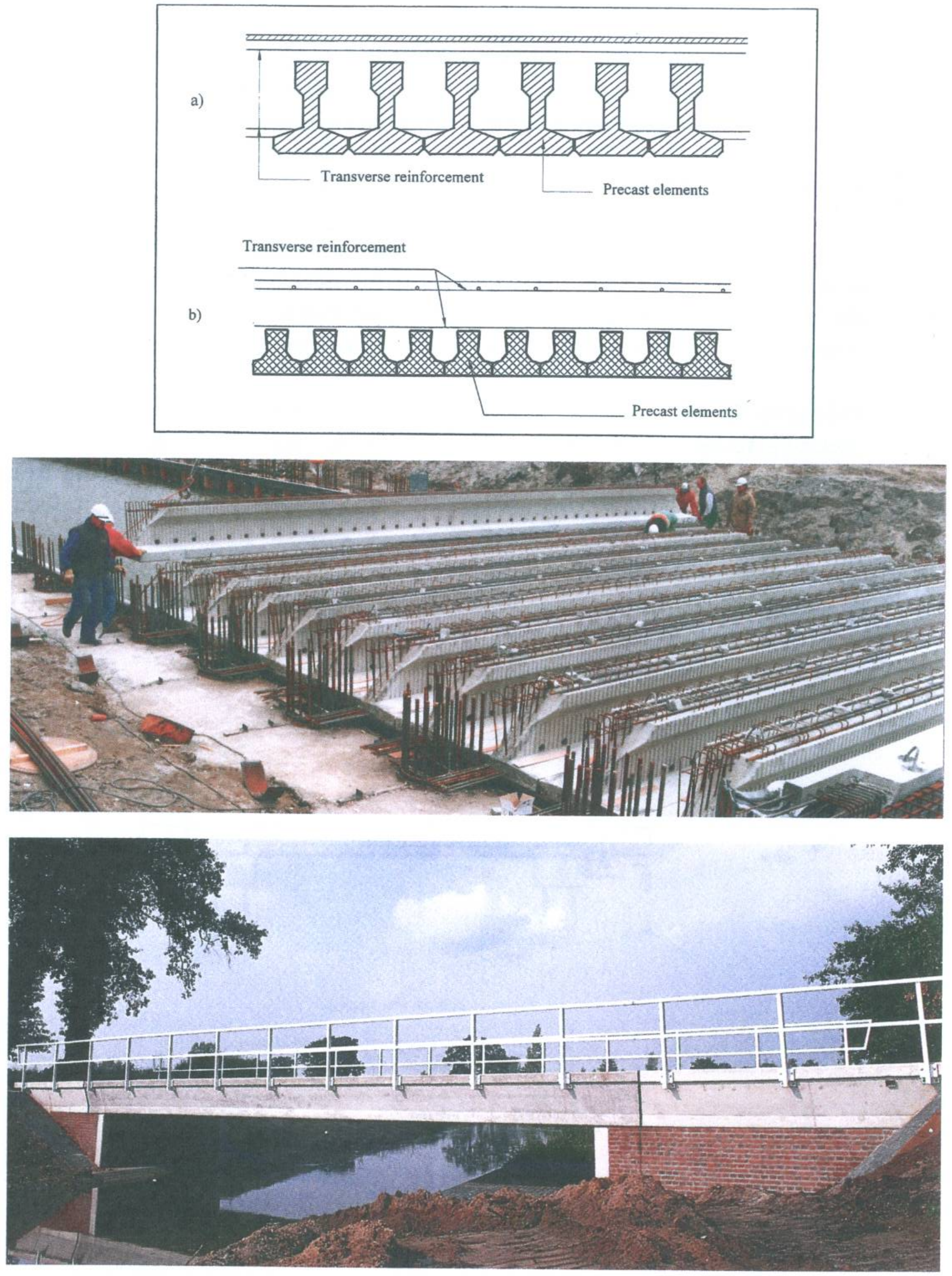


Fig. 4.2: Precast slab bridge with cast in-situ infill

A new series of precast prestressed elements up to 1.0 m height and a modular width up to 1200 mm are now currently manufactured in Italy, Spain and Portugal with slipforming machines on long line casting beds. These kinds of elements are produced with shear reinforcement included in the webs.

Figures 4.3 to 4.5 show sections and examples of multi-span bridges composed of precast beams, with inverted double T-profile, or box shaped units similar to hollow core slabs for bridges with span length between 12 and 20 m.

The main advantages of the system are massive production potentiality and limited factory labour input, typical of hollow core slab manufacturing plants. The multi-span bridges can be designed with partial or full continuity and transversal beams at supports and in the middle of the span are possible.

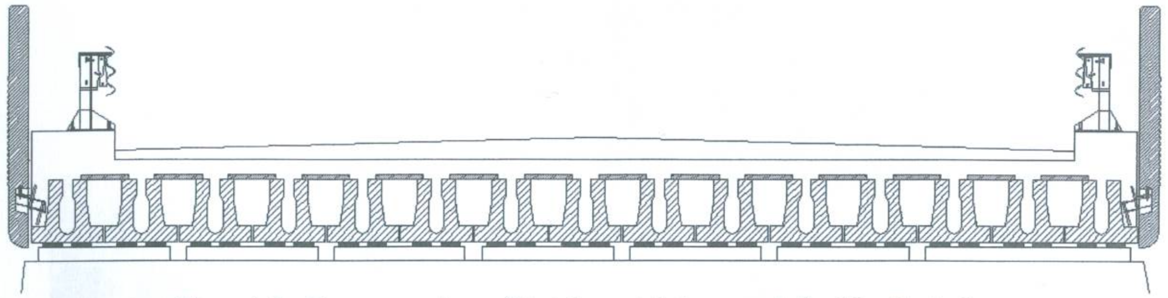


Fig. 4.3: Cross-section of bridge with inverted double-T girders

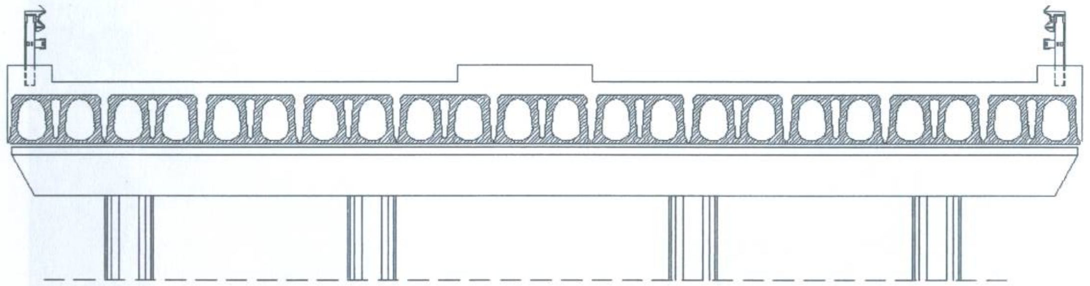


Fig. 4.4: Cross-section of bridge with hollow core beams

Fig.4.5: Examples of inverted double-T girder bridges

4.3 Girder bridges

Large girder bridges constitute the main solution for precast bridges built from the sixties on. The bridge deck is composed of several inverted T- or I-shaped beams positioned at a certain distance. The beams are connected by a transversal diaphragm beam at each support and sometimes also in the middle of the span, depending on the length. After erection of the beams and casting of the diaphragm beams, a deck slab is cast on site, mostly with concrete shuttering planks positioned on a notch at the top of the beams. The top of the beams has protruding reinforcement for the connection with the deck slab. The system is used both for simply supported and continuous bridge structures. The system with inverted T-beams is suitable for span lengths between approximately 15 to 45 m (Figures 4.6 and 4.7). The system enables bridges with closed underdeck.

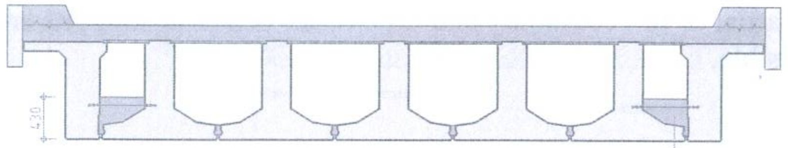


Fig. 4.6: Cross section of a beam bridge with inverted T-beams

Fig.4.7: Example of multi-span road bridge with inverted T-beams

The bridge system with I-shaped beams is suitable for span lengths between approximately 15 to 55 m. The distance between the units is variable and function of the needed span/load capacity. Examples of I-beam bridges in various countries are given in Figures 4.8 to 4.13.

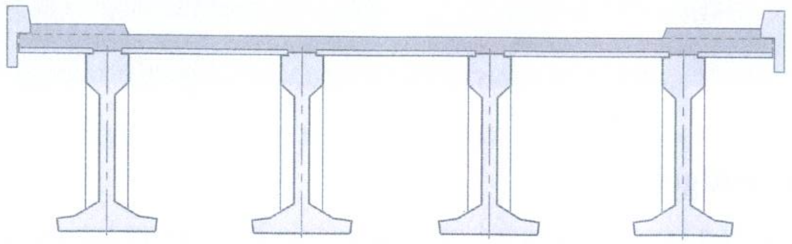


Fig. 4.8: Cross section of beam bridge with I-shaped girders

Fig. 4.9: Precast motorway girder bridge under construction

Fig. 4.10: Girder bridge over motorway during construction, without traffic interruption

Fig. 4. 11: I-beam bridge over watercourse

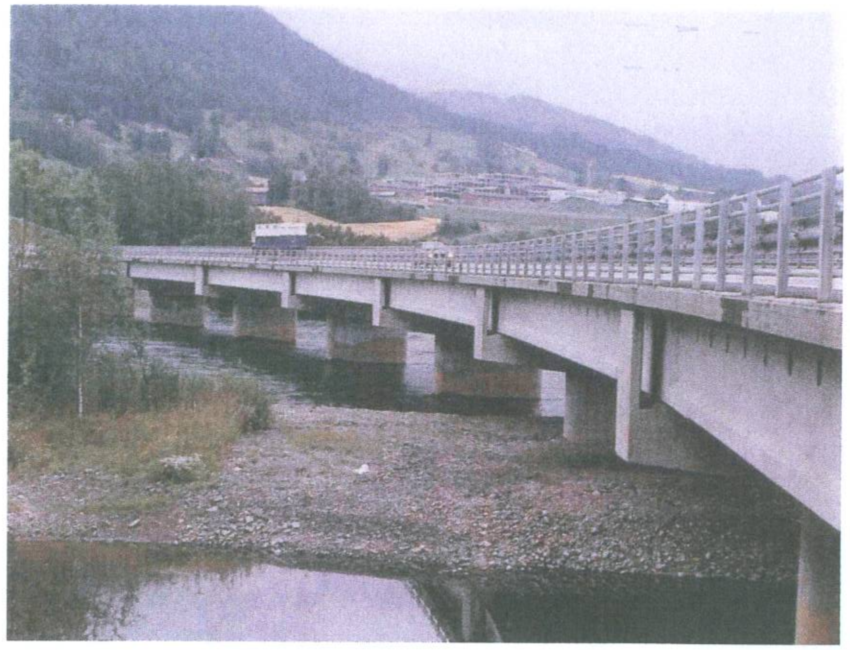


Fig. 4.12: Precast bridge over watercourse with polygonal longitudinal profile

Fig. 4.13: I-beam bridge during erection

4.4 Box-beam bridges

The system consists of prestressed box-shaped beams. The bridge deck is composed of a series of box beams placed side by side or at a small distance. After erection the site work is limited to the filling of the longitudinal joints and the transversal post-tensioning of the bridge. The slenderness ratio is in the order of 30; however, spans of 50 m have already been realised with box-beams of 1.50 m height. Protruding reinforcement is available in the beams for connections to cast in-situ edge profiles, joint constructions, screeds, etc.

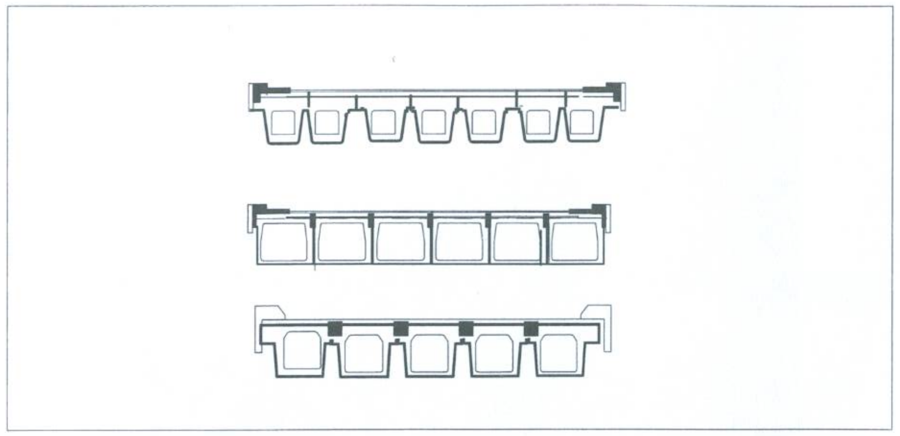


Fig. 4.14: Precast box-beam bridge without structural topping

Fig. 4.15: Box-beam bridge

There exist also a type of box-beams with top flanges to construct the bridge deck. The system is widely used in Australia for bridges to about 45 m span. They call the units "super Tee beams". Details about elements, erection and finished bridges are given in Figures 4.16 and 4.17.

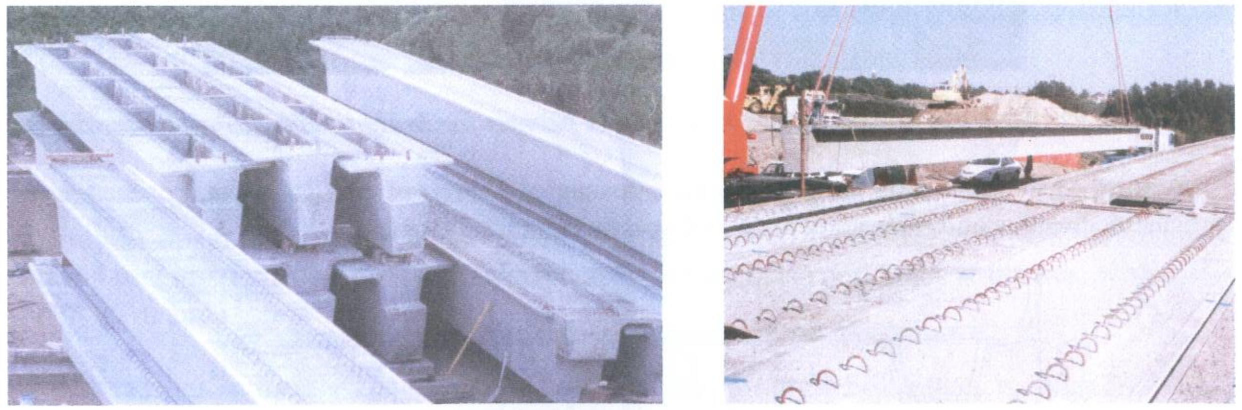


Fig. 4.16: Super Tee beams on the stockyard and during erection, prior to casting of the bridge deck

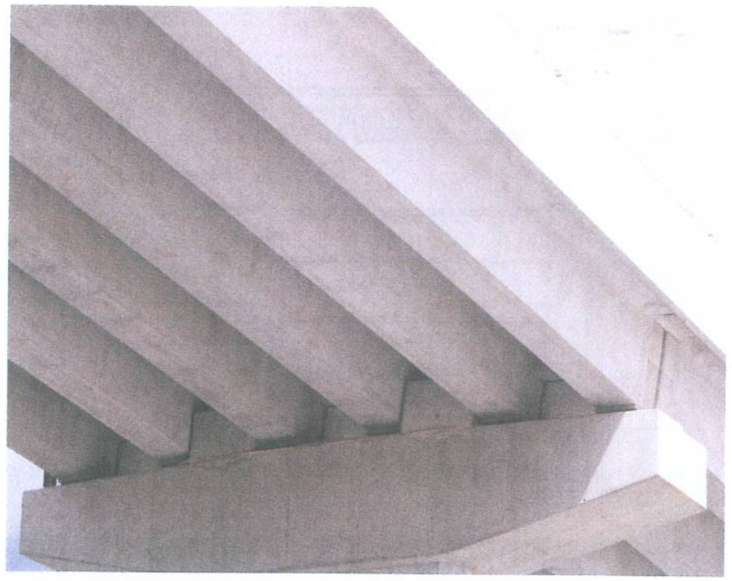


Fig. 4.17: Example of super Tee beam bridge

Another variant type of box-beams for bridge decks comprises a large bottom flange. The system has been conceived for bridges with closed under deck. The cast in-situ top plate is made in the same way as for classical box-beams bridges.

Fig. 4.18: Example of box-beams with bottom flanges for bridges with closed under deck

A third variant solution for box-beams consists of U-shaped precast units, covered with precast deck slabs and completed by a cast in-situ structural topping.

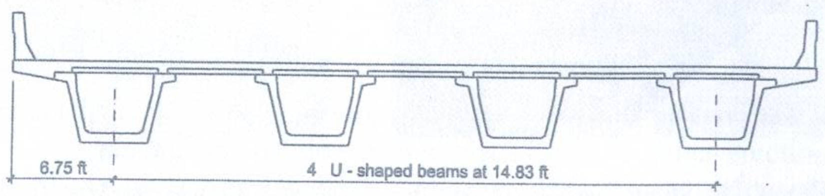


Fig. 4.19: Precast U-shaped bridge units with cast in-situ deck slab

Fig. 4.20: Bridge with U-shaped beams during erection

Fig. 4.21: Erection of box double lane bridge

Figure 4.21 shows a combination of longitudinal box beams and transversal segments for the cantilevering bridge deck. A steel frame supports the cantilevers.

4.5 Mono-box bridges

During the last decades, new systems for long spans and complex bridges were developed mainly in Spain. The bridge is composed of a large trapezoidal beam with cantilevering or braced cast in-situ deck slab. The bridges can be designed as continuous structures, with spans up to 90 m and more.

For reasons of handling and transport, the size of the single box beams is limited to about 45 m. When longer spans are needed the bridge is constructed with several beams, made continuous by post-tensioning. The beams are normally positioned on temporary supports and then connected to each other. It is an evolutive construction process in which every phase needs to be executed carefully. The construction is considered composite with parts of precast and in situ concrete. The design of the bridge for serviceability limit states is highly dependent on this process.

After erection, the precast prestressed beams may need additional prestressing by post-tensioning cables The post-tensioning can be placed within the cross section of the beam or externally. Post-tensioning bars are also used for the connections between beams.

This type of bridges is a more complex way of building precast bridges but the system enables to build longer spans than with normal beams (either simply supported or continuous). Up to now several bridges have been constructed with spans ranging from 50m to 90m.

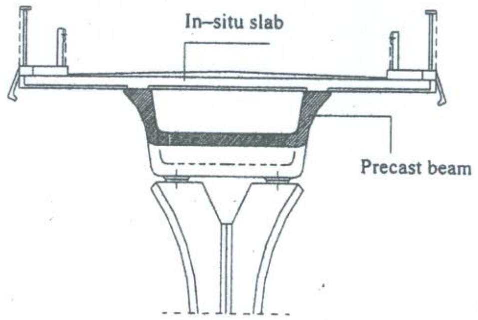
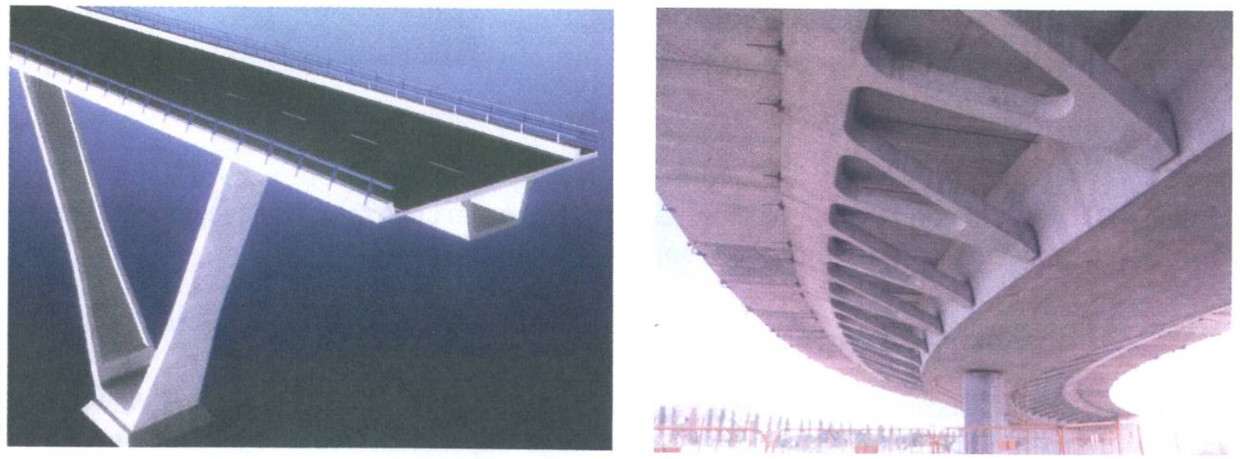


Fig. 4.22: Cross-section of mono-box bridge

The cantilevering deck of the bridges is either cast in-situ together with the deck slab, or made with precast slabs, supported by precast concrete bracing units or steel trusses. The following pictures show examples of mono-box bridges.



a. Cantilevering slab *b. Braced slab*

Fig. 4.23: Cross-section of mono-box and curved mono-box bridge

Fig. 4.24: Box beam bridge with precast cantilevering deck

Fig. 4.25: Mono-box-bridge with cantilevering slab deck

Precast mono-box bridges with curved soffit are similar to normal mono-box bridges, but the beams are cast in special moulds to achieve the curved shape. Pre-tensioning is normally not used and replaced by post-tensioning to cope with the curved moulds. Precast mono-box bridges with curved soffit are usually constructed with structural continuity and spans may reach more than 50 m.

Fig. 4.26: Precast mono-box viaduct with V-shaped piers and variable deck depth

Fig. 4.27: Precast mono-box bridge with variable depth and cantilevering slab

4.6 Curved box beam bridges

Since 1995 curved prestressed box beams have been developed by precasters to cope with the increasing demand for more aesthetic solutions. The torsional rigidity of box beams suits very well for bridges with a horizontal curvature. The solution is now currently being applied in Spain, the Netherlands and UK. The radius varies from 200 m to as low as 100m. During manufacture, the deviating force from the tensioned tendons is taken up by special equipment connected to the base of the mould.

Fig. 4.28: Curved box-beam girders and metro viaduct

Fig. 4.29: Examples of viaducts with curved box-beams

Fig. 4.30: Examples of curved precast bridges

4.7 Trough bridges

New types of bridge decks, characterised by a high cross-section modulus and a slender construction height, have been developed for the construction of the new high-speed train tracks in Belgium during the last decade.

The trough elements are mostly composite structures with a steel profile in the edges. The bottom plate of the units is prestressed with a large number of strands. The pre-curved steel profiles are pushed downwards before casting of the bottom plate. After hardening of the bottom plate concrete in which the flanges of the steel beams are located, the vertical forces acting on the steel beams are released and the prestressing force is gradually applied. In a second step, the webs and upper flanges of the steel beams are enveloped with reinforced concrete. The length of the units varies between 20 and 25 m, the height is 1.30 m and the width 4m. The total weight of the units can amount to 160 ton.

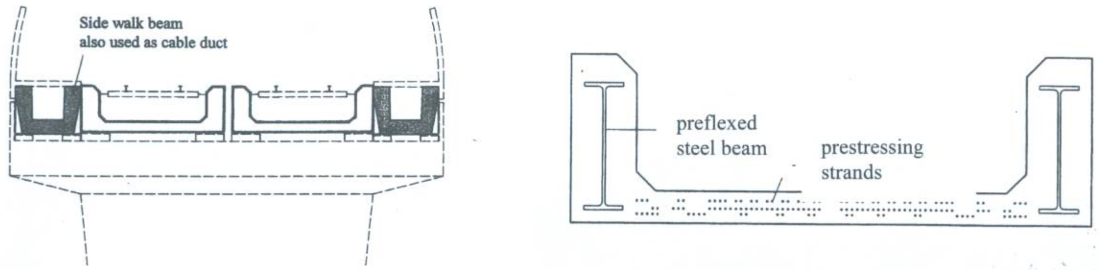


Fig. 4.31: Trough bridges for railway track

Another example of a precast through bridge is given on Figure 6.5. It concerns a railway viaduct. The track is situated at the bottom of the trough, thus enabling a very slender design of the project. There are also a few realisations of trough bridges with an arch shape.

4.8 Segmental bridges

Precast segmental decks are regularly used in traditional cantilever construction of large span bridges. The segments comprise the full width of the bridge and the length of the units is related to their weight and to the means of transportation and lifting. Large segments are usually precast on site, but there are also good examples of large bridges with factory precast segments (Figures 4.32 and 4.33). For smaller projects, for example viaducts in cities, segments are often manufactured in permanent precasting factories. One of the advantages lies in the large production series. The erection is mostly done on a temporary scaffolding, and after filling the transversal joints, the units are post-tensioned in the longitudinal direction.

Fig. 4.32: Segmental bridge for access to runway

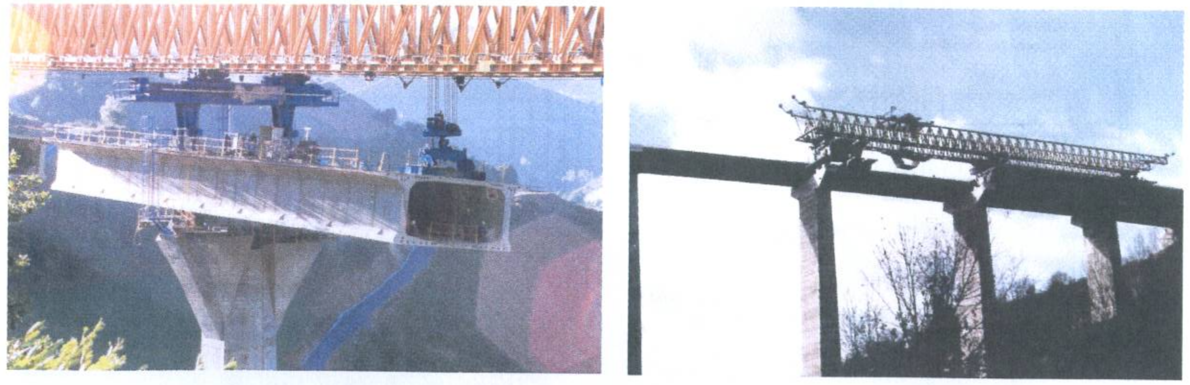


Fig. 4.33: Bridge with precast segments

In precast bridge construction, also longitudinal segments are sometimes used. It concerns beams or box girders for long span bridges, prefabricated in several units because of transport and lifting limitations. The units are assembled on site by post-tensioning before erection. Examples of such bridges are already given on Figures 4.26 and 4.27.

4.9 Cable stayed bridges

It is possible to use stays to reach longer spans in the construction of precast bridges. Spans up to 400 metres can be achieved with precast decks in cable stayed bridges.

Precast decks can be designed for two planes of stays with a box girder under each plane of stays. It is also possible to design a deck with a single plane of stays with one or two box girders joined by a transverse beam at each anchorage of the stays.

For shorter spans, up to 120 metres, other types of precast bridges can be used.

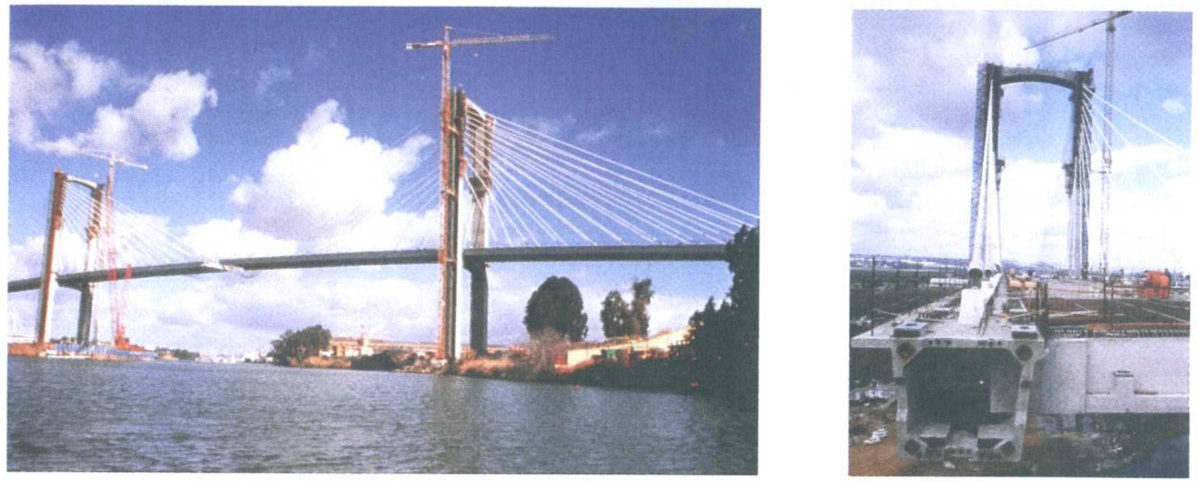


Figure 4.34: Precast cable stayed bridge

4.10 Special precast bridges

In addition to the classical more or less standard bridges, there is an evolution towards special concepts designed for specific bridge projects.

- **Arch bridges**

Bridges in dense populated areas are often designed with special attention to the aesthetical outlook and tradition. The following examples show how precast concrete has responded to the requirements. In Figure 4.35, the central arch is made with high strength concrete.

Fig. 4.35: Precast arch bridge

Fig. 4.36: Precast arch bridge

Fig. 4.37: Bridge beams with curved longitudinal profile

- **Bridges with variable depth**

Following figures show examples of one-off designed bridges made with precast concrete beams and a cast in-situ deck. The beams are cast in moulds made especially for the project.

Fig. 4.38: Precast bridge with variable construction depth

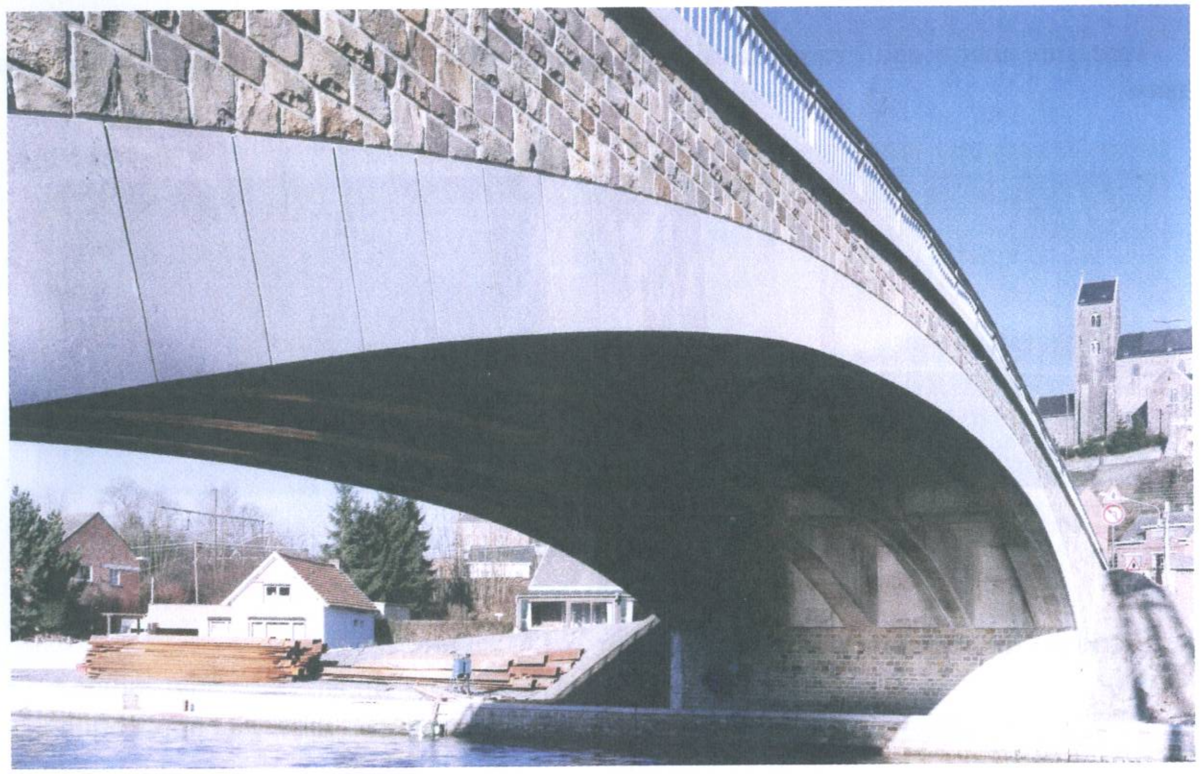


Fig. 4.39: Precast bridge with curved bridge beams. The edges are executed on site with masonry blocks, supported by the bottom flange of the precast beam.

- **Canal bridges**

Several examples of canal bridges have been built with precast concrete elements. Figure 4.40 shows an example.

Fig.4.40: Canal bridge

- **Pedestrian bridges**

There are many good examples of precast pedestrian bridges, from short to very long spans.

Fig. 4.41: Cable stayed pedestrian bridges

- **Bridges for special industrial purposes**

Precast bridge beams are used also for conveyor belts and other industrial applications.

Fig. 4.42: Bridge for conveyor belt

4.11 Culverts and vault systems

There are different types of precast culverts. The most classical ones are the box culverts, which are often used for small underpasses and tunnels.

Fig. 4.43: Example of box culvert underpass bridge

Another type concerns the arch culverts or vaults. The vaults are of curved or polygonal guideline structures of different types:

- Domed structures with more than two elements. These have an arch supported on two curved side walls that are fixed to a raft foundation or directly supported on the ground with precast strip footings incorporated to the precast piece.

- Domed structures with two elements that are composed of two curved lateral walls.

- Domed structures with one element, with the bottom slab built into the precast or in-situ element.

According to its functional scheme, they can be divided in several types:

I. - An arch simply supported on two side walls connected by a bottom slab.

II. - An arch simply supported on two side walls supported on two isolated footings.

III. - Domed structure with two elements, commonly known as tri-articulated. The connection to the foundations is a simple articulation; the foundations can be a bed-plate or a footing.

IV. - Domed structure of an element which can be fixed to the foundations or bi-articulated.

The different elements are usually of reinforced concrete, with rectangular section or ribbed section. The aspect from inside the passage is usually plain, although there may be solutions in which the lateral walls are ribbed inside (particularly in the second type of structure with large clearances). The arches generally have a rectangular section, although for large spans (L>10 metres) they are usually ribbed. In the case of vaults with two elements, the support points may be raised with some walls to give more clearance.

Multi-arch passages may be achieved by making two vaults sharing the same foot or wall.

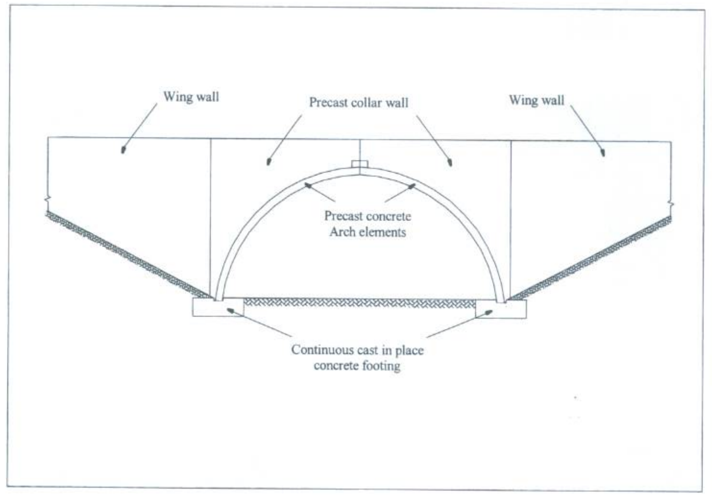


Fig. 4.44: Example of precast concrete arch structure

Fig. 4.45: Precast arch structure

4.12 Overview span ranges of the different types of precast bridges

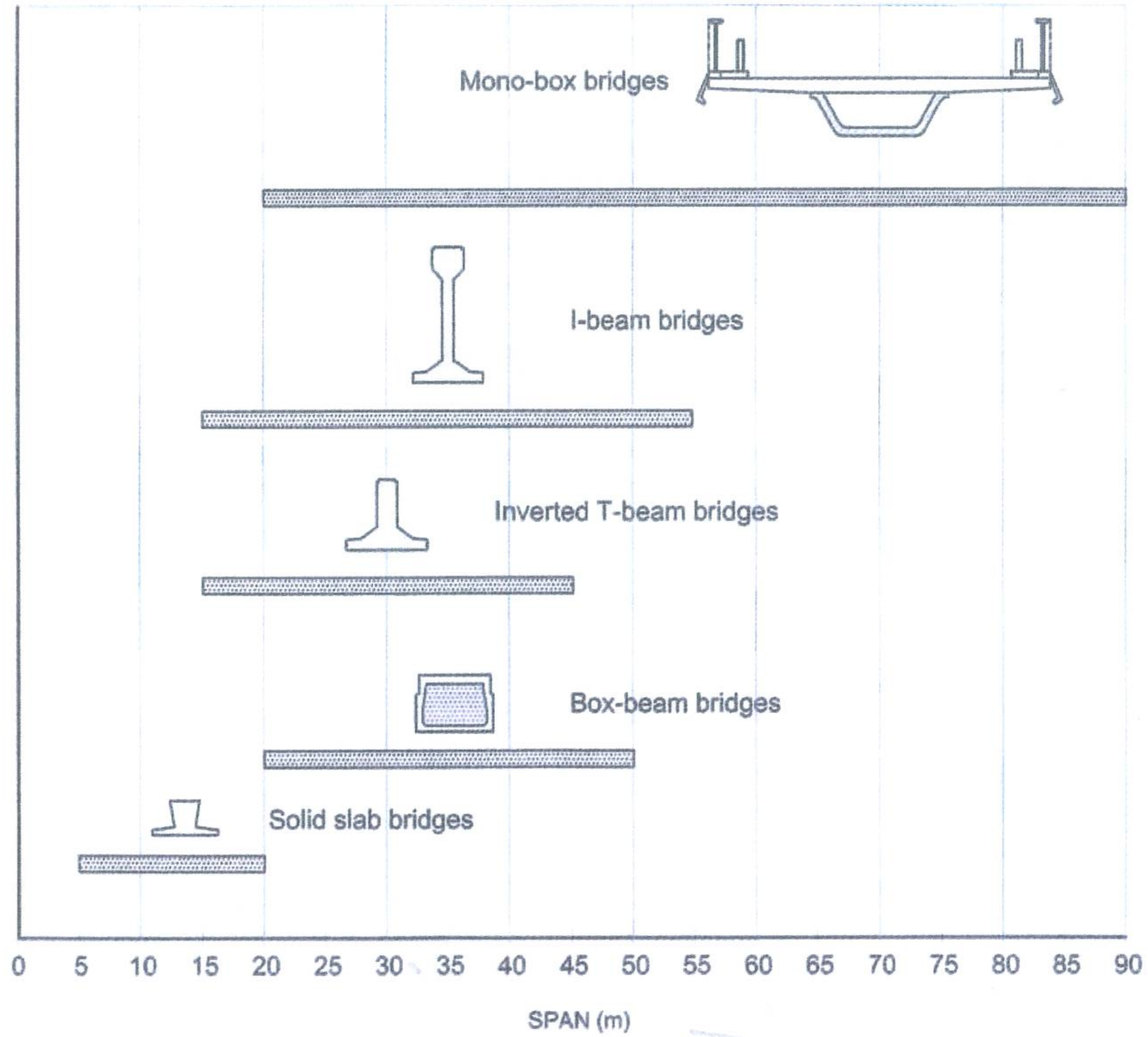


Fig. 4.46: Overview span ranges precast bridges

5 Structural systems

5.1 Simply supported bridges

In the first period of precast bridge construction, it was considered logical to design the bridge decks as simply supported structures with transversal joints at intermediate spans and between end spans and abutments. The beams were normally positioned on individual bearings – one at each beam end – and the joints were dimensioned to allow for thermal movement of the decks. Simply supported bridges also enable to take up deformations due to creep and shrinkage. In the same way, differential settlement of deck supports can easily be accommodated.

Many thousands of bridges have been built in this way and still behave very well. The main reasons for the high durability are:

- The high strength of the concrete, in the order of 45/50 MPa on cylinder, and the low water/cement ratio.
- The prestressing with pre-tensioned strands.
- The quality of execution, for example with respect to cover on the reinforcement.

Although the beams themselves have proved to be very successful, there are disadvantages inherent to simply supported deck systems. Bearings are required at each beam end. They are expensive and need sometimes to be replaced. However, the main problems with simply supported decks originate from the presence of expansion joints: long term durability in presence of de-icing salt and discomfort to traffic. Good detailing of pier supports and abutments could delay the corrosion of the concrete elements and bearings, for example:

- Possibility of inspection and replacement of bearings (Fig. 5.1).
- Installation of drainage channels for removal of the water (Fig. 5.2).

However, it is quite obvious that the best solution to prevent the above problems consists in eliminating the transversal joints within the bridge deck, either by continuous deck systems or by integral bridges.

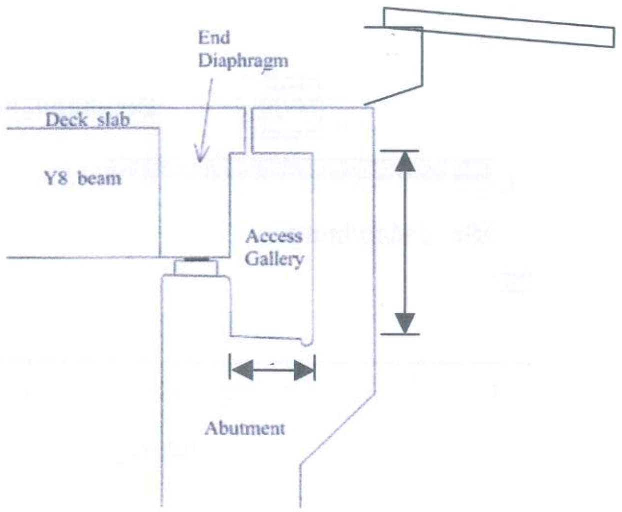


Fig. 5.1: Possibility of inspection with access gallery

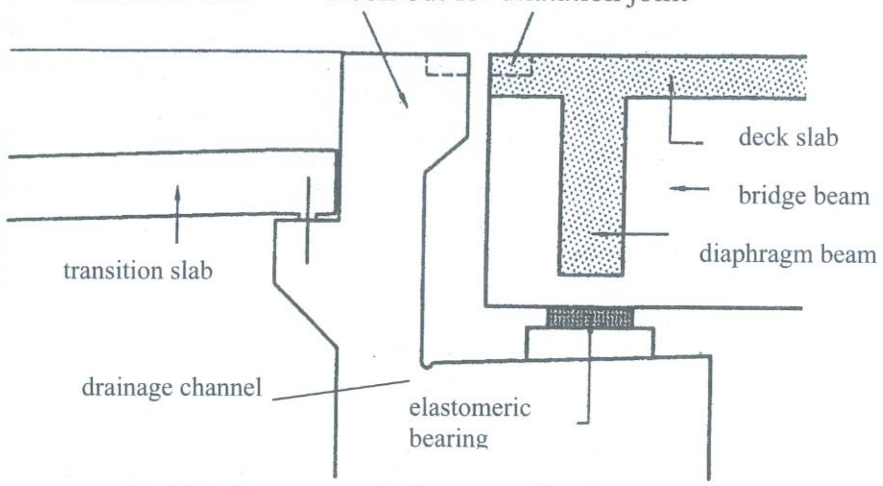


Fig 5.2: Support and abutment detail

5.2 Simply supported bridges with continuous slabs

Partial continuity is a method to provide only continuity of the deck slab, the beams being designed as simply supported. This means that no distribution of vertical load effects between the intermediate bridge decks can occur. This applies to all vertical loads, including self-weight and variable loading.

Two methods are used to provide partial continuity in beam and slab decks. In the first solution, the continuity is restricted to the slab only, which deflects to accommodate the rotations of the simply supported deck beams. The beams are erected in the conventional manner onto individual bearings. To permit flexure, the deck slab is separated from the support beams over a length of about 1.5m by a layer of deforming material, for example expanded polystyrene. Figures 5.3 and 5.4 are showing two alternative executions.

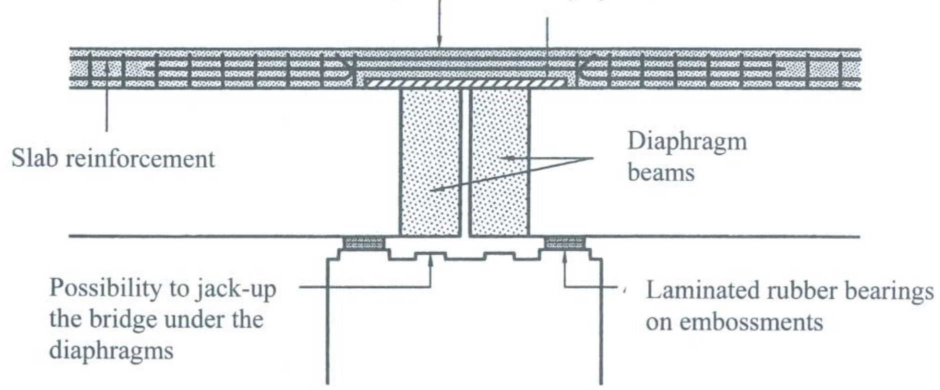


Fig. 5.3: Partial continuity - detail type 1: continuous separate slabs

Typical features:
1. Separate bearings and diaphragms are provided for each span
2. Deck slab is separated from support beams over a short length to provide rotational flexibility
3. There is no continuity reinforcement between ends of beams and there is moment continuity between spans for live load only.

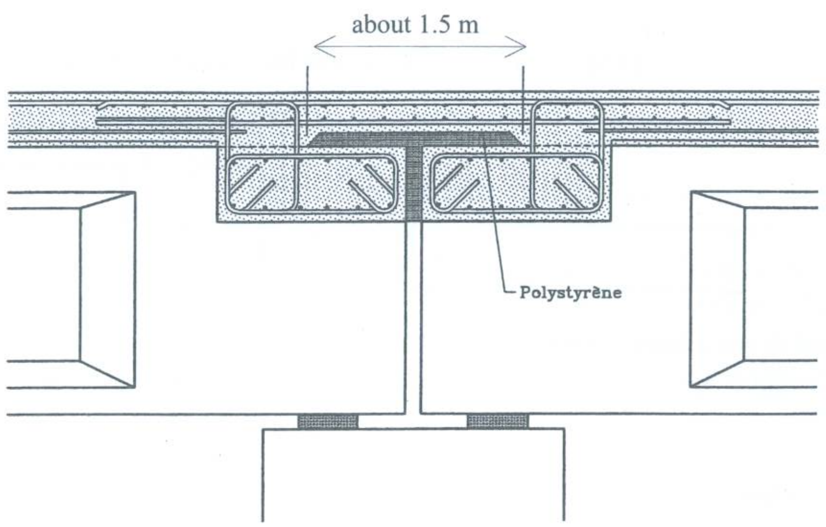


Fig. 5.4: Partial continuity - detail type 1: variant solution

In the second solution, the bridge decks are designed and constructed in the conventional manner for simply supported multi-span bridges, with slab trimmer diaphragms at the beam-ends. As with type 1, the beam-ends are supported on two parallel rows of bearings on the piers. Longitudinal reinforcement bars are incorporated at the slab mid-depth to tie the slabs together over the pier, eliminating expansion movement at deck level and permitting the use of an incorporated deck rotation joint. To accommodate this rotation, the dowels are debonded over a certain length at both sides of the joint. Also, the slab and trimmer beam have reduced thickness to give more flexibility and rotation capacity. A compressible joint filler is applied below and above the dowel connection.

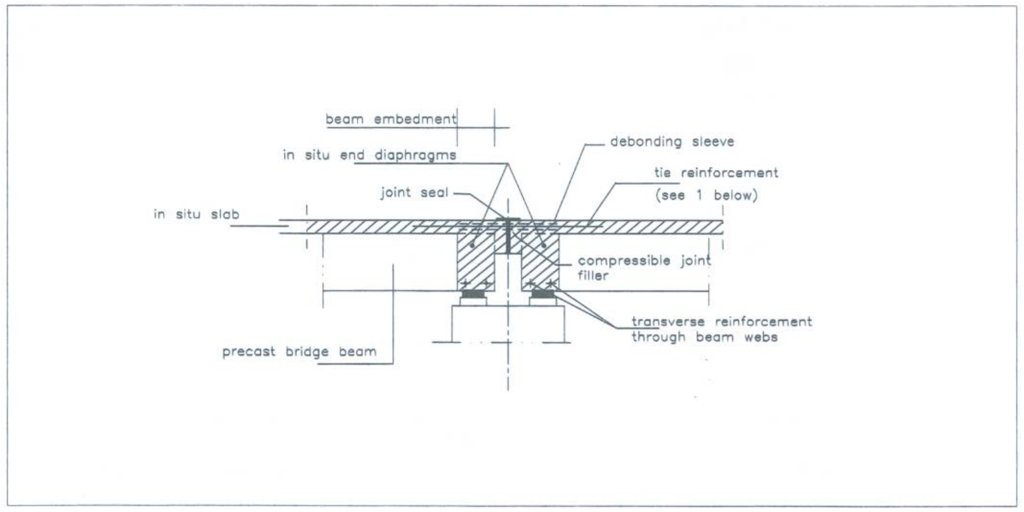


Fig. 5.5: Partial continuity - detail type 2: tied deck slab

Typical features:

1. The tie reinforcement at mid-depth of the slab is debonded over a short length at each side of the joint to permit deck rotation. There is no moment continuity between spans.
2. Slabs between spans are separated using compressible joint filling but deck water proofing and deck surfacing are continuous and special seals are provided over the joint for double protection.
3. Separate bearings and end diaphragms are provided for each span.

The solutions 1 and 2 are simple measures to provide simply supported continuous decks, with a minimum of extra design and construction effort.

5.3 Continuous bridges

Multi-span bridges with mechanical continuity between adjacent spans are realised by integration of the bridge beams into a reinforced concrete crosshead on top of the piers. The construction is done in two steps:

- In the first step the beams are simply supported and carry their own weight plus the load from the formwork and the wet cast concrete of the slab.
- In the second step, after hardening of the in-situ concrete, the structure becomes continuous, but only for the additional dead load and the variable loading.

Also here, different solutions exist to realise the continuity.

- In a first solution the beams are supported on temporary scaffolding, built off the pier foundations. The beam-ends with protruding strands and additional reinforcement are then incorporated over a certain distance in a rather wide in-situ integral crosshead, cast on top of the pier. The longitudinal top reinforcement is placed in the deck slab. The bridge deck is strengthened in the transverse direction, either with post-tensioning or with mild steel reinforcement. The crosshead is supported on a single row of bearings placed in the centre of the pier.

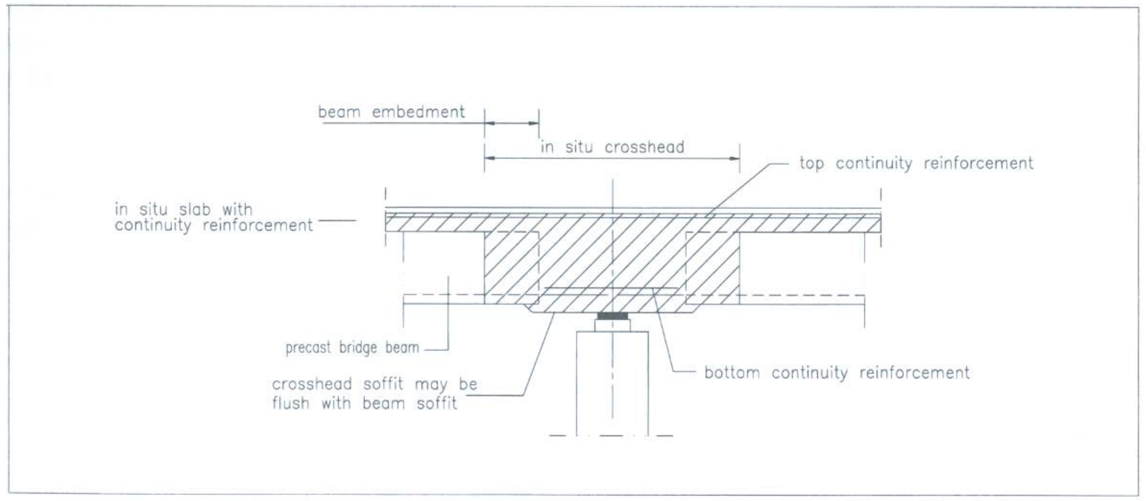


Fig. 5.6: Full continuity - detail type 3: wide in-situ integral crosshead

Typical features:

1. Beams are erected on temporary supports generally off pier foundations
2. Permanent bearings are in single line
3. Continuity reinforcement is provided in the slab and at the top and bottom of bridge beams. The lapping of reinforcement is normally not difficult.

Although more complex to design and more expensive to construct than any of the other methods, type 3 continuity offers more advantages.

- Horizontal curvature of the bridge can be easily accommodated by varying the width of the integral crosshead to form a trapezium. This permits the use of precast beams of the same length per span.
- Problems due to differential inclinations of the bridge spans can be reduced by curving of the top and bottom surfaces of the crosshead. In this way, the increased slab thickness at mid span required to take up the vertical curvature above the straight precast beams, can be reduced.
- Only a single central row of bearings is required. This immediately halves the number of bearings required for simply supported construction, although the individual bearing size will increase.
- The piers are more slender, not only because of the single line of bearings, but mainly because the dead and live load moments applied to the piers by the eccentric position of the bearings are removed.
- The piers need not to have a constant width. The integral crosshead can be designed to allow considerable deck cantilevering outside the pier. This also provides a further reduction in the number of bearings.

• In the second solution, the prestressed beams are provisionally supported on top of the piers. The in-situ integral crosshead over the pier is then cast between and around the beams over a width of about 1m on both sides. However, the crosshead is narrower than type 3 because of the small gap between the beams. This same narrow gap makes it more difficult to realise an adequate lapping of the bottom reinforcement between the beams. Longitudinal continuity is again easily realised with top reinforcement in the continuous composite deck slab. The longitudinal bottom reinforcement of the crosshead is partly installed through holes in the ends of the beams.

After hardening of the crosshead concrete, the two rows of temporary bearings are removed (see below) to transfer the support reaction on the central row of bearings. Some solutions use a wide single permanent rubber bearing, which acts as support for both beams.

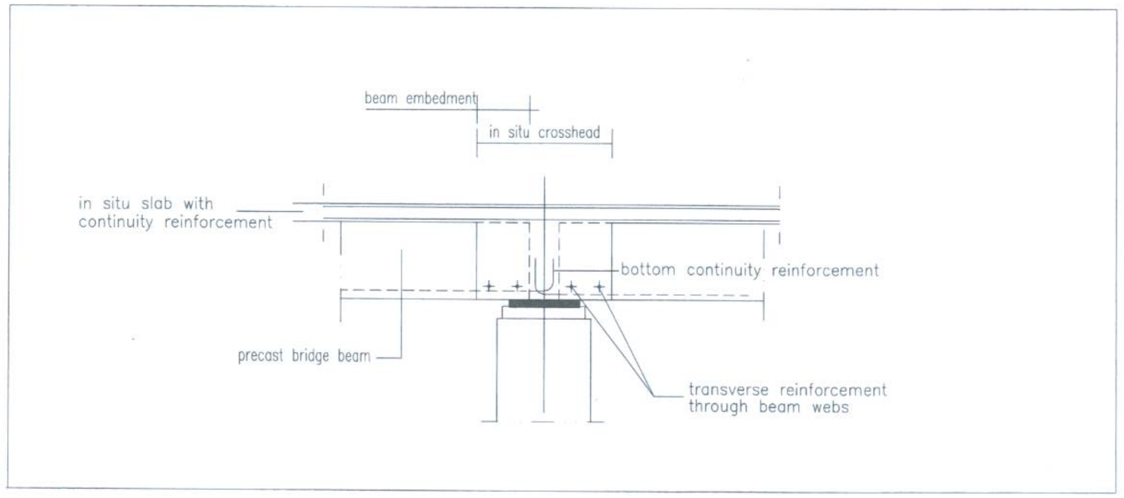


Fig. 5.7: Full continuity - detail type 4: narrow in situ integral crosshead

Typical features:
1. Temporary supports are not required.
   Permanent bearings may be in single or twin line.
2. Continuity reinforcement is provided in the slab and at the bottom of bridge beams.
   The lapping of reinforcement is difficult.

This type of continuity is relatively easier to construct than type 3. The greatest advantage lies in the easiness to erect the beams directly on the pier. Nevertheless, adequate connection between bottom flange reinforcement is difficult.

• The third solution is a variant of types 3 and 4, and the integral crosshead is cast in two stages. The crosshead has a greater depth than the main beams and the bottom section is cast first to support these beams, generally on thin mortar beds. In a second step, the complete crosshead is cast in the same way as described for type 3.

The advantage of this type of continuity is the complete elimination of temporary bearings. The disadvantage lies in the large size of the crosshead under the beams, both for aesthetic reasons as with respect to the free height. Type 5 continuity is also considered as a frame construction in case the piers are monolithic with the deck and consequently contribute in the moment distribution of the complete structure. However, it is also possible to provide a hinge between the crosshead and the pier.

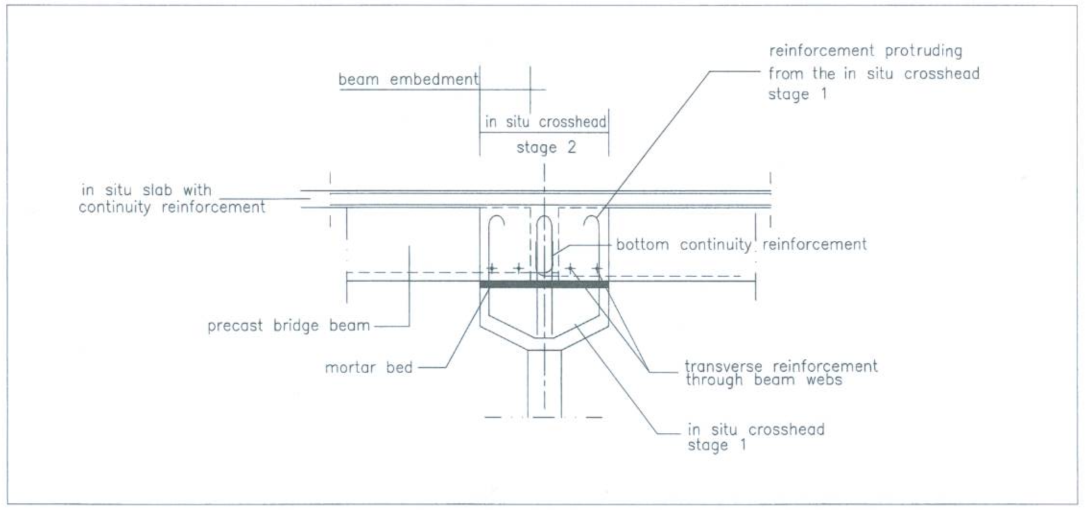


Fig. 5.8: Full continuity - detail type 5: integral crosshead cast in two stages

Typical features:
1. Beams are supported on stage 1 crosshead during erection.
2. Crosshead mostly to be monolithic with pier
3. Crosshead soffit is normally lower than beam soffit
4. Reinforcement is similar to types 3 and 4 depending on the cross-section of the stage 1 crosshead

Besides the above described solutions, full continuity of precast bridges can also been realised with post-tensioning systems.

- There are still other possible variants of solutions type 3 and 4 where the continuity is made by lapping of reinforcement in block-outs at the top of the beams and concrete filling between the end blocs.

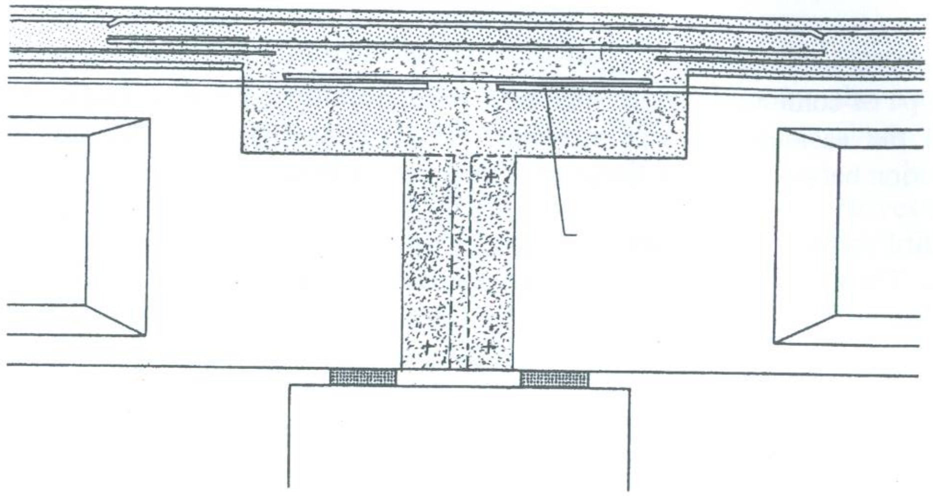


Fig. 5.9: Full continuity - variant solution with welded lapping of top reinforcement

Typical features:
1. Beams are supported on stage 1 crosshead during erection.
2. Permanent bearings under each beam
3. Continuity reinforcement is provided in the slab and top of the bridge beams.

Examples of continuous precast bridges

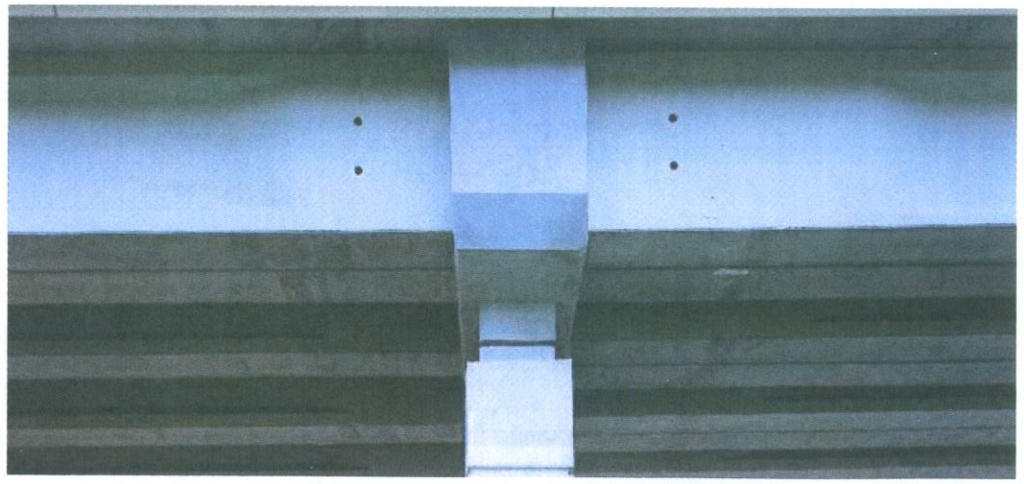


Fig. 5.10: Detail of full continuity with in-situ crosshead

Fig. 5.11: Continuous bridge with precast rectangular beams

Fig. 5.12: Continuous bridge with precast I beams

Fig. 5.13: Continuous bridge with precast I beams

Fig. 5.14: Continuous precast box beam bridge with precast piers

Fig. 5.15: Continuous precast box beam bridge

5.4 Integral bridges

Integral bridges are designed without expansion joints, neither between adjacent intermediate spans nor between end spans and abutments. This section describes the various types of integral abutments and their design procedure.

Just like continuous bridges at intermediate supports can be constructed with bearing pads, it is equally possible to provide such pads at abutments without expansion joints. This type of construction is referred to as semi-integral bridges. It is particularly suited for bridges with prestressed beams since the bearings eliminate the problems associated with moment continuity and rotation due to creep and thermal effects.

Abutments of integral bridges are attached to the bridge. They have to follow the horizontal temperature fluctuations of the bridge. The abutments must be designed to allow this movement to occur and at the same time be able to resist traffic loads. In the same way as for classical bridges with conventionally fixed abutments, the design of integral abutments for bridges with precast prestressed beams also requires special considerations, which are not needed in integral bridges using other forms of construction.

Several types of integral and semi-integral abutments can be used. Some countries recommend a limit to the overall length and skewness of bridges designed integrally (U.K. – maximum overall length = 60m, maximum skew = 30°). In the USA, integral bridges have been designed and constructed successfully with overall lengths in excess of 200m.

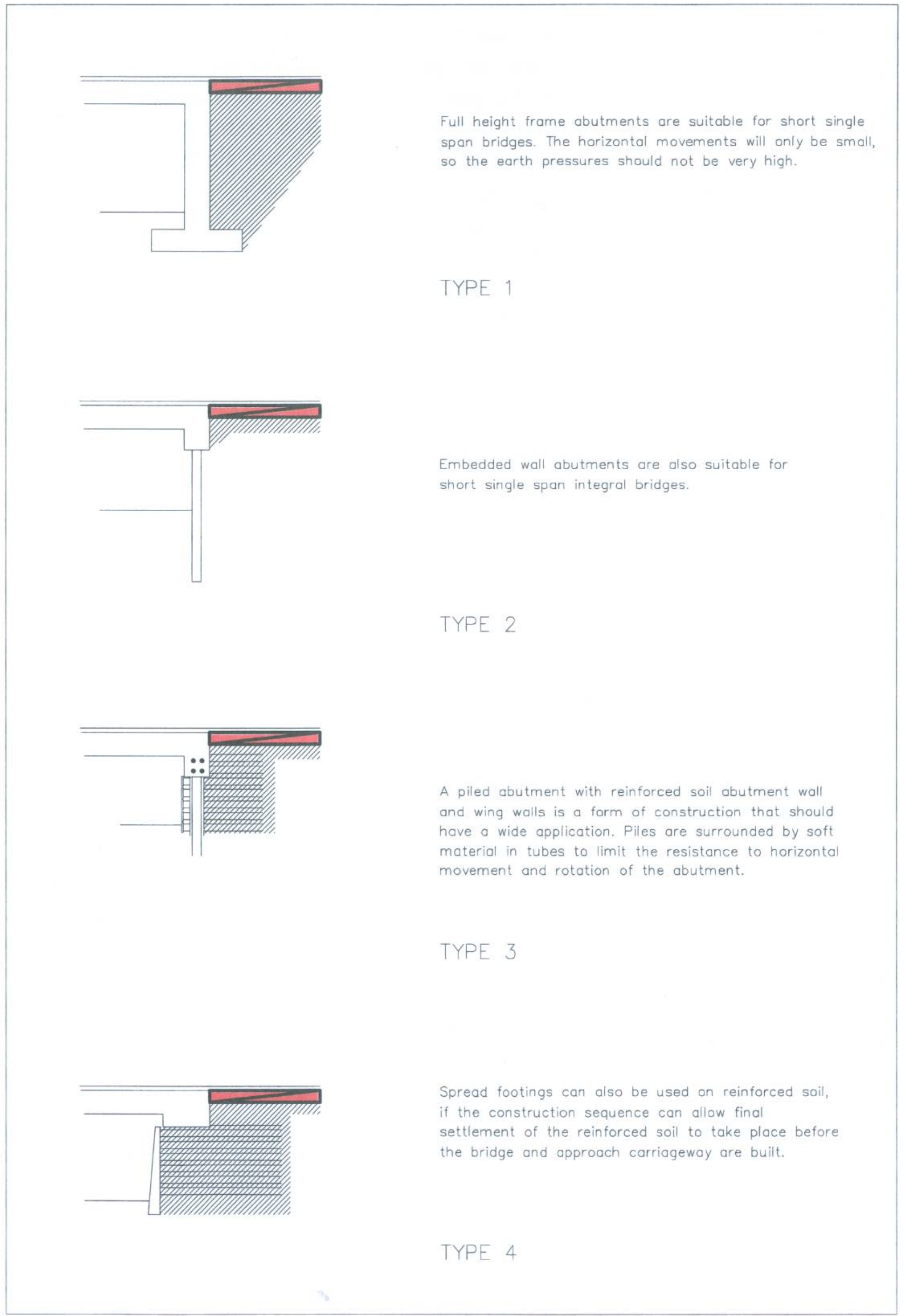


Fig. 5.16: Types of integral abutments

6 Aesthetics

The aesthetic appearance of a bridge is an essential factor, which has to be taken into account from the beginning of a project. As for construction works in general, the general silhouette of a bridge is conditioned by its overall aspect, in other words, by the first image perceived by an observer situated at a distance. The silhouette is particularly characterised by the regularity of the longitudinal profile, the proportioning and the general harmony of the disengaged lines, the integration of the project within the surroundings, etc. When the observer is getting closer, the perception becomes dominated by the outlook of details, such as the architecture of piers and abutments, the aspect of the surface, shape, colour and proportions of the edges, etc.

The normal slenderness ratio of bridges using precast prestressed beams leads sometimes but not always to deck thicknesses, which are thicker than in continuous slab bridges, especially in case of statically independent spans. In the beginning period of precast bridges, when the demand was large, the appearance of the bridges was not so important. However, in the eighties the situation changed and precast bridges were criticised for being less elegant than cast in-situ ones, especially when the headroom is limited. In addition, for an identical clearance, the additional thickness has an influence on the volume of the access embankment to the bridge. Today, there are different solutions to overcome this problem:

- The bridge can be designed with a larger number of more slender beams by decreasing the distance between them. This will of course influence the total cost of the project.
- Box beam bridges exhibit a slenderness ratio down to 30, which is comparable to classical slab bridges.
- The bridge can be executed with more slender edge beams, especially in case of box beam bridges.
- Structural continuity enables to reduce the deck thickness, comparable to cast in-situ bridges.
- The combination of prestressing at the plant and post-tensioning on site enables to reduce the height of the structure in an important way.
- High strength concrete, up to 100 MPa cylinder strength, enables also to decrease to a certain extend the cross-section for the same performances.

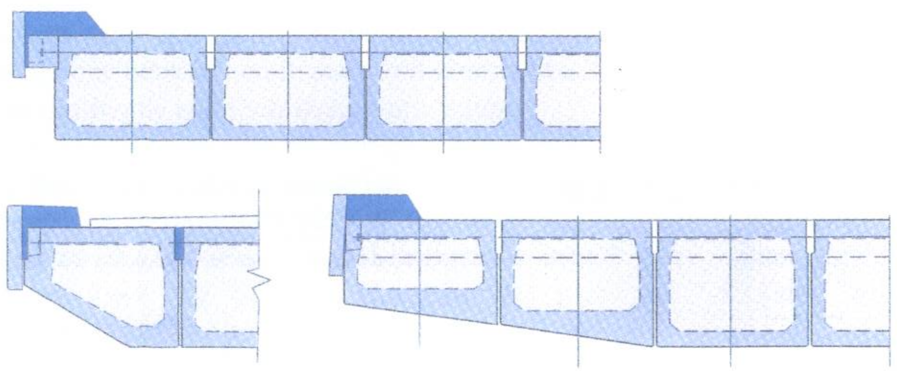


Fig. 6.1: Three alternative solutions for the edges with box beams

Another aesthetic inconvenience may arise from the camber effect of independent multi-span prestressed bridge units. Precast prestressed units are subjected to camber, varying according to the level of prestressing and the duration of storage on the stockyard at the plant. After erection, these deformations are partially compensated by the cast in-situ deck slab and other fixed loadings. Also here, the problem should not exist, since many appropriate remedies exist to overcome it.

Fig. 6.2: Imperfections of the longitudinal bridge profile due to camber of the independent prestressed bridge spans

The following measures can be used:

a) Edge profiles

The edge of a bridge determines the line of the structure, since it constitutes the most visible part of the bridge deck. There are different possibilities to realise the edge, either by the architecture of its shape, or by the surface finishing and colour. More details are given in chapter 8.3.

b) Variable depth of the longitudinal bridge profile

Although less currently applied, there are good examples of precast bridges with variable depth.

c) Architecture of the piers

The aspect of a bridge can also be considerably improved by an appropriate architecture of piers and abutments, especially in urban areas. Good examples of precast piers are given in chapter 8.4.

As far as horizontally curved bridges concerns, their realisation is more difficult in precast concrete than in cast in-situ. Placing the precast beams in a polygon following the curvature usually solves the problem. The solution is perfectly acceptable for large curvature radii, but less attractive for smaller ones. However, as already mentioned in section 4.6, today there are also curved precast pre-tensioned box beams, with a radius as low as 120 m.

The following figures show different realisations of precast bridges for which aesthetics were an important design issue.

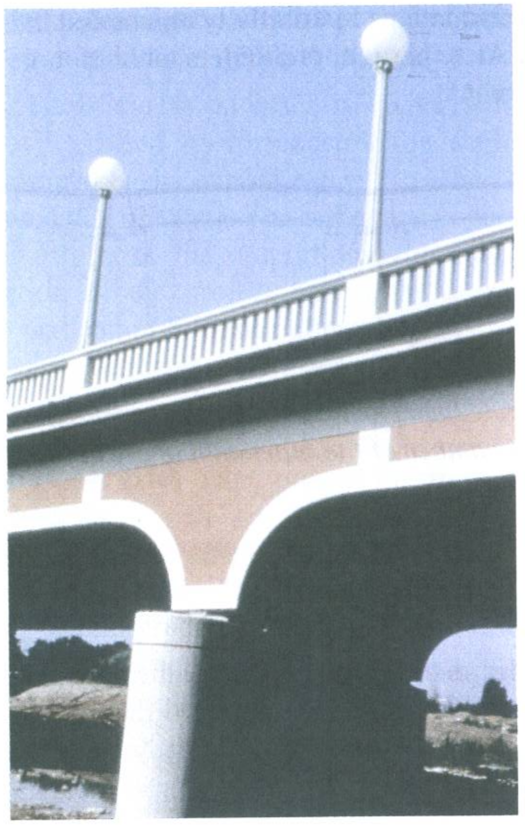


Fig 6.3: Precast bridge with coloured edge and marked parapet

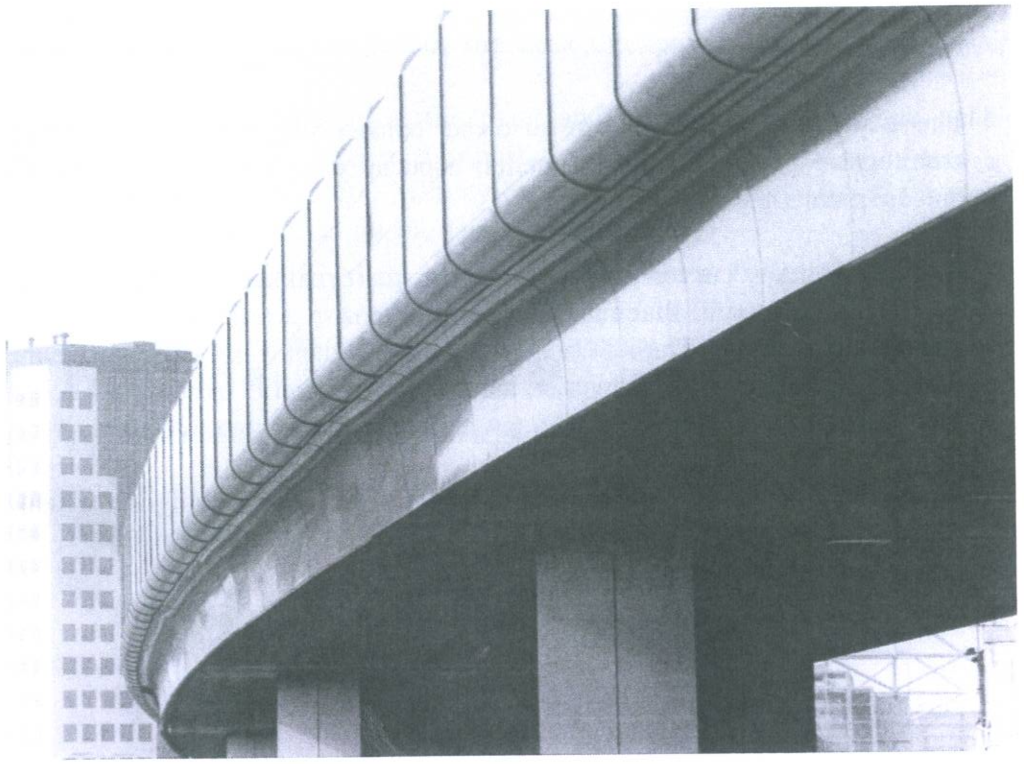


Fig 6.4: Precast bridge with curved beams and edge profile

Fig. 6.5: Railway viaduct, built with precast prestressed through elements. Also the piers and crossheads are in factory made precast concrete

Fig 6.6: Precast bridge with curved edge profile

Fig. 6.7: Viaduct in precast concrete

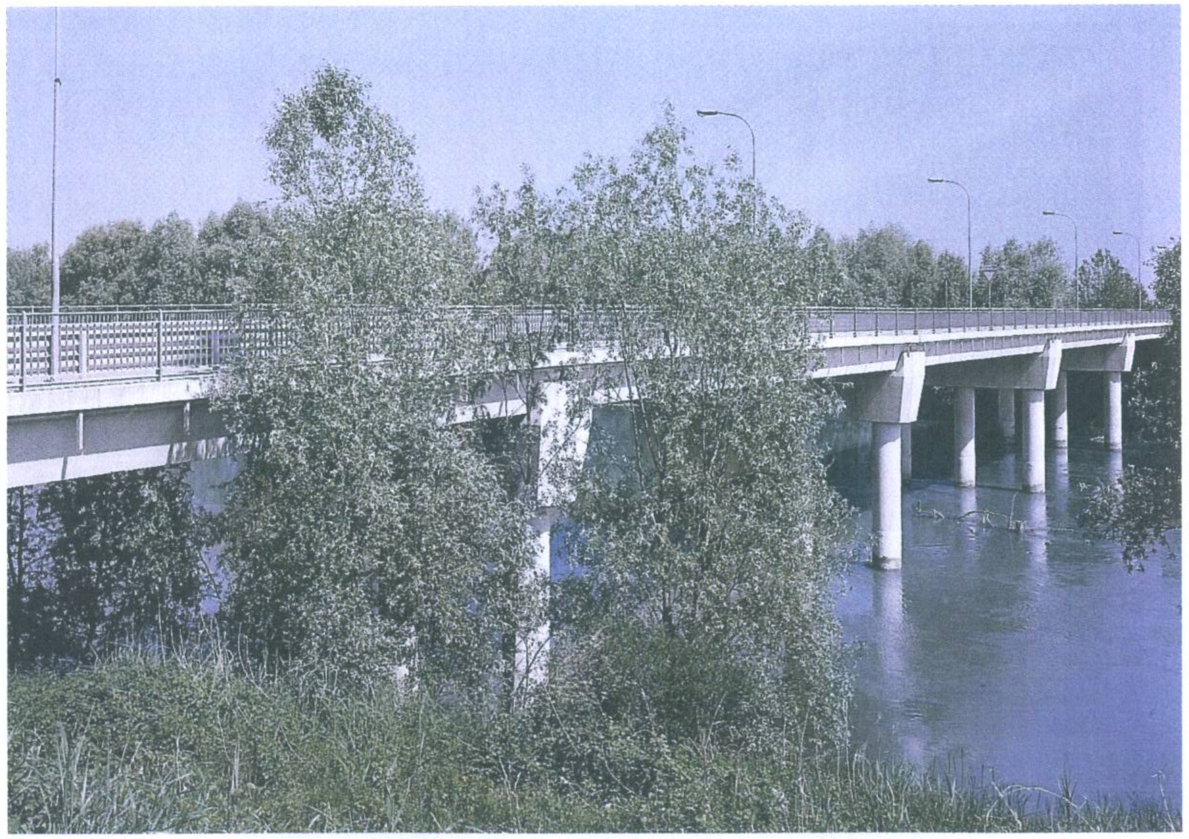


Fig. 6.8: Long precast bridge over river

Fig. 6.9: Curved precast box beam bridges for the intersection on motorways

7 Connections

This chapter describes some specific connections, which are used in precast bridge construction. It concerns mainly the connections between the precast beams and cast in-situ transversal diaphragm beams and deck slab.

- Precast beam to diaphragm beam

Because of the dense reinforcement in the end blocs of the precast beams, the connection with the diaphragm beam is made with protruding bars, threaded couplers, anchored in the precast beam or with sleeves through the beams. The contact surface at the precast beam is roughened.

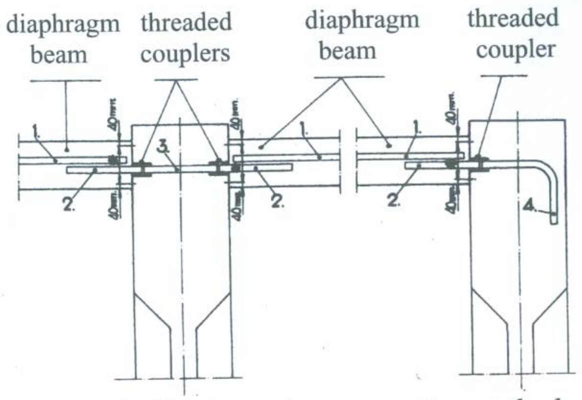


Fig. 7.1: Horizontal cross section at the beam end

For intermediate transversal diaphragm beams, the connection with the precast beams is generally realised through transversal openings in the precast units, enabling the passage of the main reinforcement of the diaphragm beam. For edge beams, threaded couplers are used.

- Support connections

The precast beams are normally supported on specially designed bearing pads. The positioning is given in Figure 7.3 for beams with rectangular ending and in Figure 7.4 for beams with cantilevering ending.

- Beam slab connections

The interface shear between precast beams and the cast in situ deck slab is taken up by protruding reinforcement from the precast beam. The shear transfer capacity is 25% to 33% higher when the protruding reinforcement is placed according to b) than to a). The transfer capacity of the interface shear can further be enhanced by the used of inclined stirrups

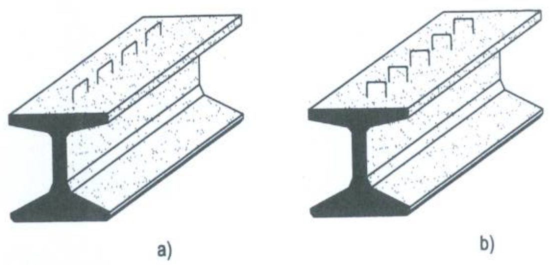


Fig. 7.2: Shear reinforcement between beams and deck slab

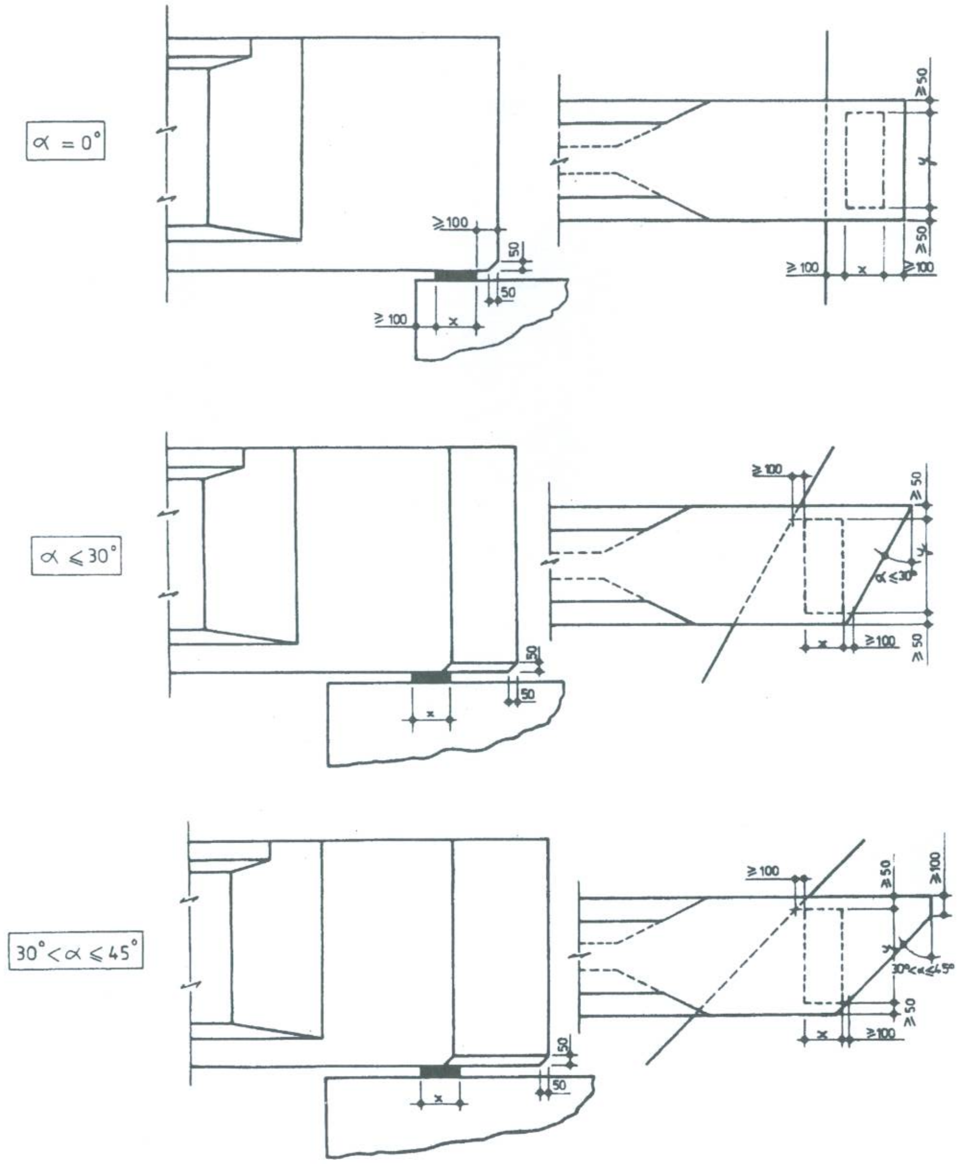


Fig. 7.3: Supporting details for beams with normal ending

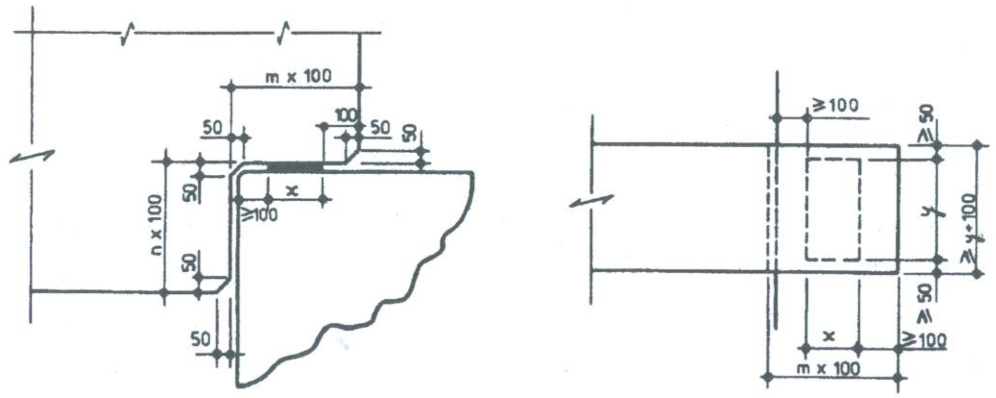


Fig. 7.4: Supporting details for beams with cantilever ending

- Connection between edge profiles and bridge deck

Edge profiles are normally connected to the cast in-situ deck slab by means of protruding bars. Figure 7.5 shows the connection of a special edge beam with a solid bridge deck composed of small I-beams and infill concrete.

Fig. 7.5: Connection reinforcement between precast and cast in-situ concrete

8 Detailing

8.1 Skew bridges

For moderate angles, for example between 70 and 100 degrees, the bridge concept both for the deck and for the beams is nearly the same as for straight bridges. The normal solution is to construct the bridge in the prolongation of the skew crossing road.

When the skew is higher than 70 degrees, the design is more complex. For a good functioning of the supporting devices, the axis of the pads should be parallel to the longitudinal axis of the beams. Figure 8.1 shows a solution with orthogonal beam-ends and an enlarged transversal diaphragm beam. However, it is also possible to produce the beams with skew endings.

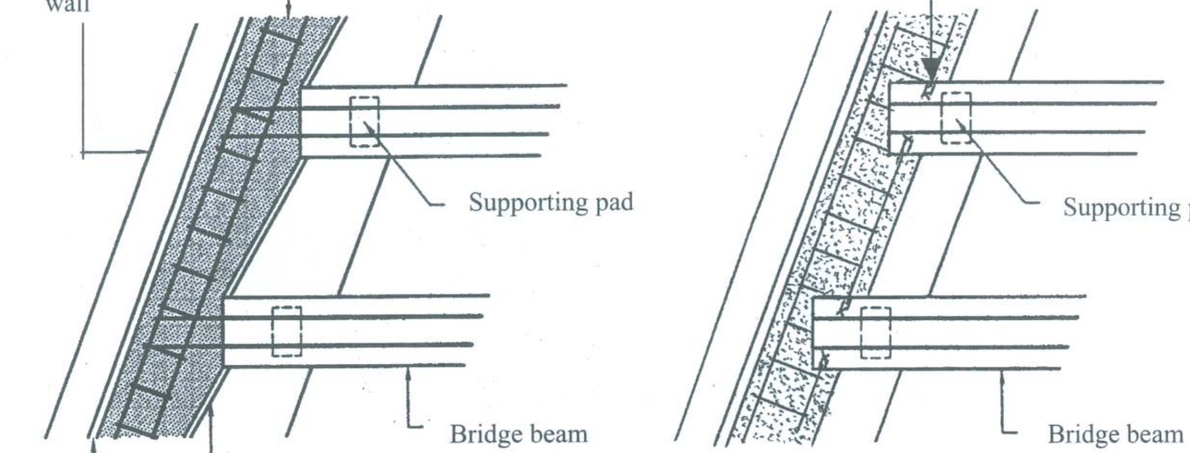


Fig. 8.1: Support arrangements for skew bridges

8.2 Banking

There are two solutions to realise the transversal inclination:

- The top surface of the crosshead is parallel to the inclination and the supports are identical.
- The crosshead is horizontal and the supporting embossments have a variable height.

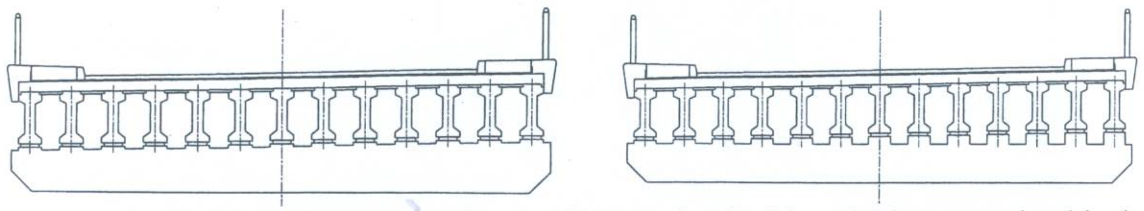


Fig. 8.2: Transverse inclination at crossheads

8.3 Edges

Edges are among the most visible parts of a bridge and thus contributing in an important way to the visual aspect thereof. Also here different solutions are available. Some consist in a simple finishing of the top of the deck; others are partially or completely hiding the precast beams behind an ornamental separate edge profile. In most cases, the edges are in precast concrete, but there are also realisations with cast in-situ concrete.

- Precast edges

Precast beams have a high quality smooth surface texture with a straight and regular shape, which can remain visible to show the structure of the bridge. The cast in-situ slab of the deck can be finished by a simple decorative profile, marking the line of the bridge.

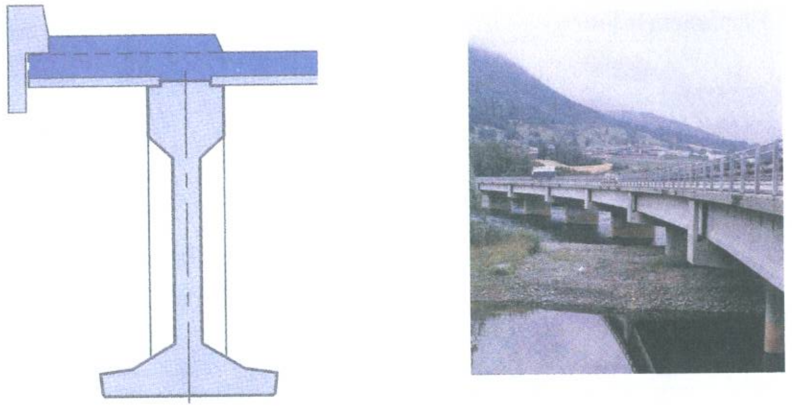


Fig. 8.3: Simple precast profile to finish the cantilevering deck slab in a beam bridge

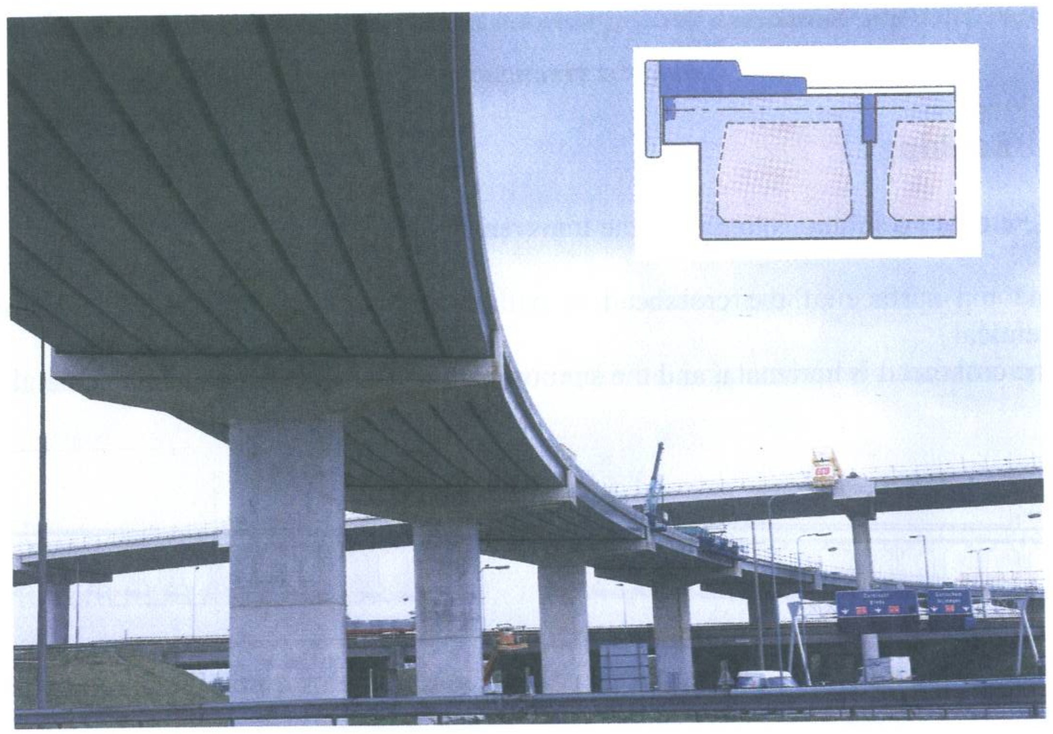


Fig. 8.4: Example of simple edge finishing in a curved box beam bridge

Precast edges are often much more pronounced, with a panoply of architectural shapes and surface finishes, in simulated natural stone, in coloured concrete, etc. They are either monolithic units, or executed as facing elements for a cast in-situ concrete backing. The following figures illustrate the many possibilities within this solution.

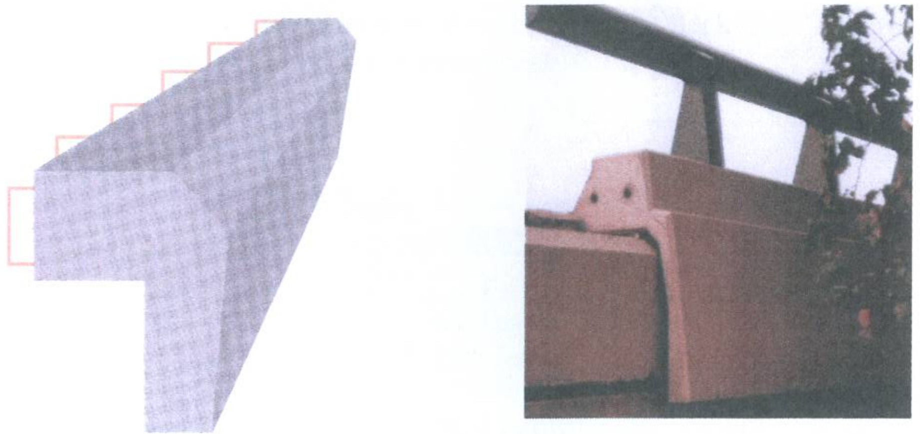


Fig. 8.5: Examples of precast architectural edge profiles

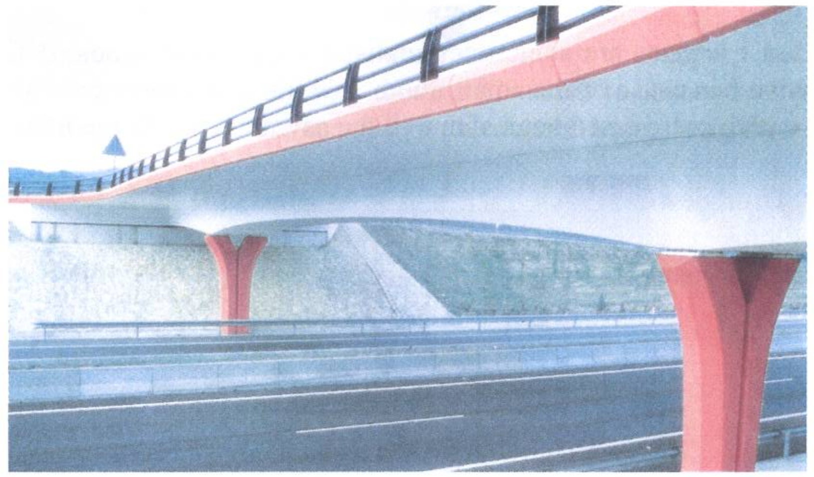


Fig. 8.6: Mono-box bridge with architectural edge

Fig. 8.7: Example of precast architectural bridge edge

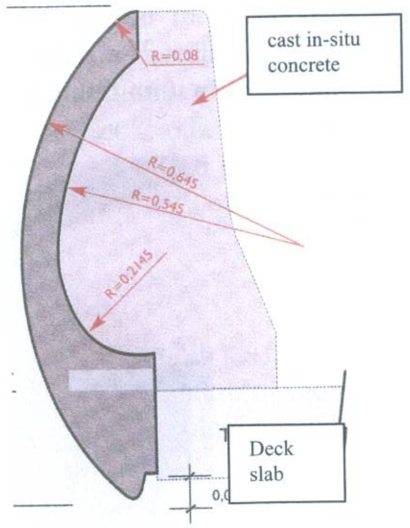


Fig. 8.8: Precast edge profiles with backing cast in-situ concrete

- Special precast edge beam

Edges of precast bridges are sometimes realised with a special beam. The solution is not only more expensive because of the small number of units, but there may also be problems of lateral curvature with prestressed beams, due to the asymmetry of the profile.

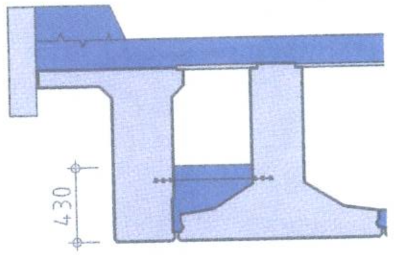


Fig. 8.9: Solution with a special edge beam

The infill concrete at the bottom part increases the resistance against lateral collision.

Fig. 8.10: Precast viaduct with special side beam

- Cast in-situ edges

Edges can be realised on site together with the casting of the deck slab. This way of execution is not very usual, especially for more complex cross-sections.

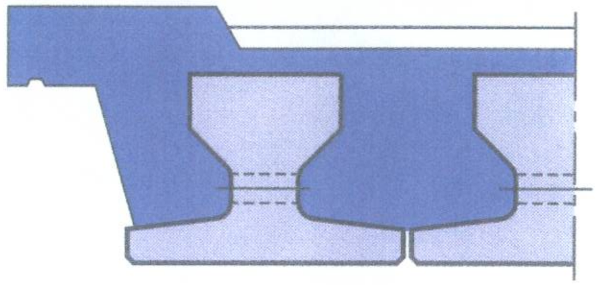


Fig. 8.11: Cast in-situ bridge edge

8.4 Piers and abutments

Piers are generally cast on site, because of their large size and weight. However, there are good examples of precast piers, as shown on the following pictures. Another example of a railway viaduct in Belgium with precast piers and cross-heads is given on Figure 6.7.

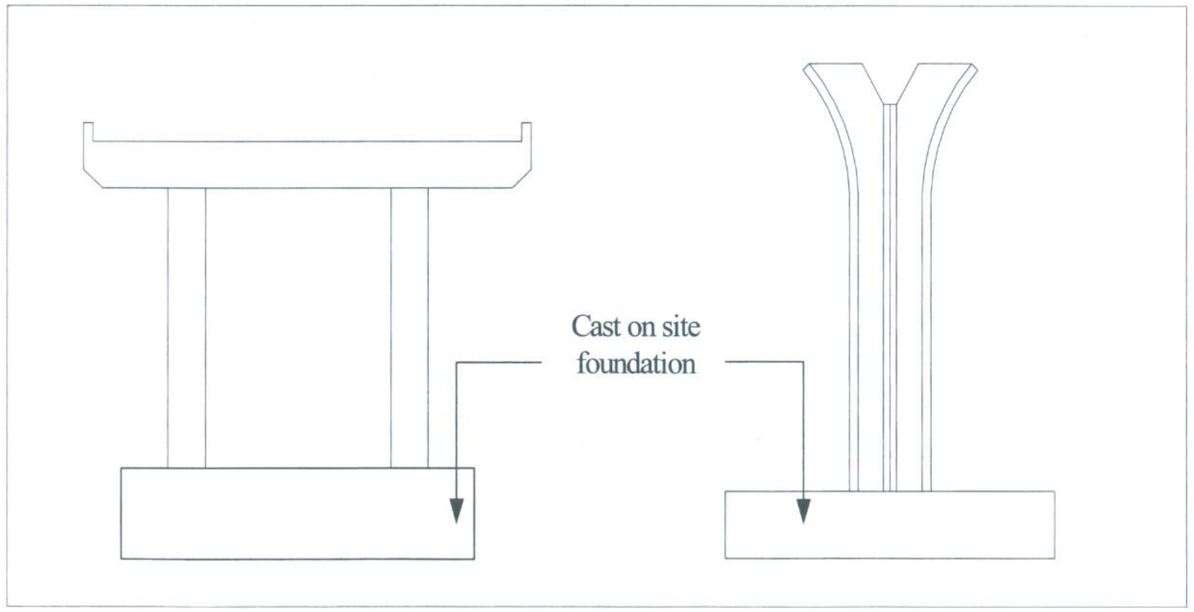


Fig. 8.12: Types of precast piers and crossheads

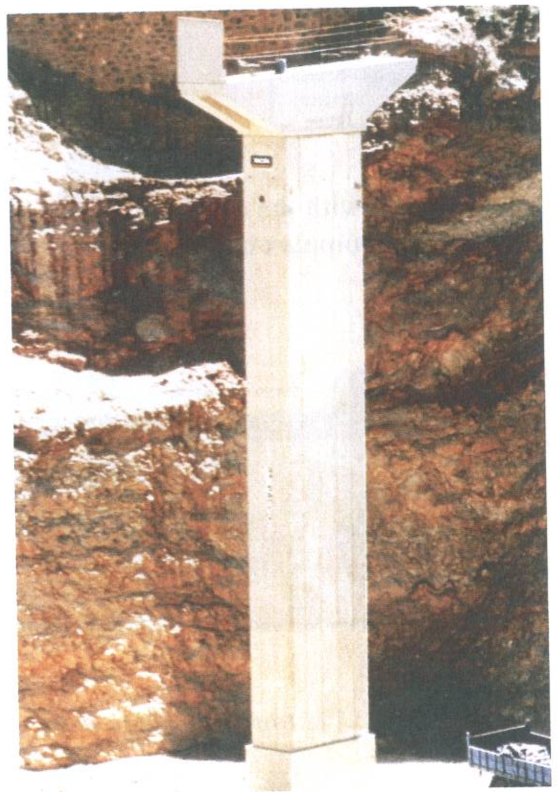


Fig. 8.13: Precast pier for viaduct along motorway

Fig. 8.14: Precast pier for cable stayed footbridge

Fig. 8.15: Box beam bridge with variable depth and precast piers

In some cases precast elements are used to form bridge abutments. The elements are full height, modular width, and usually have on the back side one or more webs from the top to the foundation. The resisting section is thus shaped as a T or π. For important heights a precast tie can be used to form a truss structure. The elements are placed on site side by side and are completed by the cast in-situ foundation and a top beam.

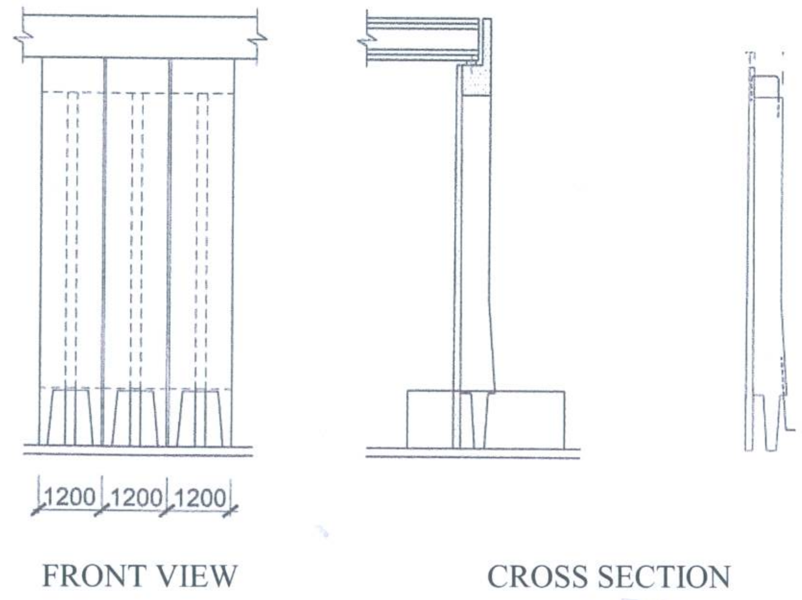


Fig. 8.16: Precast abutment

Fig. 8.17: Example of bridge abutment with ribbed precast wall

Fig. 8.18: Example of bridge abutment with ribbed precast wall

9 Design

9.1 Specific aspects

The design of precast bridges is based on the classical design procedures and code requirements set forth for bridges in general. In Europe, a specific standard for bridge design is now under elaboration: Eurocode 2 "Design of concrete structures - Part 2: Reinforced and prestressed concrete bridges". The *fib* Commission on Prefabrication intends to publish in the future design recommendations for precast bridges.

For precast concrete bridge elements, the following additional design aspects are to be considered:

a) Transient situations during the construction of the bridge: manufacture of the elements, storage, transport, erection on simple supports, composite action with the deck slab and when relevant, continuity through connections and post-tensioning.
b) Transfer of forces between precast elements and in situ concrete, for example shear reinforcement between beams and deck slab.
c) Standardised procedures for quality surveillance with supervision by an independent third party. In some countries, account is taken of the increased reliability of the high quality structure by the adoption of lower material safety margins for concrete (γ_c) and steel (γ_s) for the design of precast elements.
d) The use of high performance concrete up to 100 MPa, which is now currently being applied in precasting, also for bridge elements

The search for the most appropriate cross-section of precast bridge elements is of major importance in prefabrication, because of the impact on the weight of the units. In this context, designs have been focussing on the idealisation of the concrete dimensions for example with regard to web thickness, dimensions of the upper and lower flanges, necessity of end blocks, etc. The developments were often based on specific research programmes and national code stipulations.

The publication of the CEB-FIP Model Code 1990 has created a problem in some countries because of the more conservative requirements on the calculation of compression struts for members with shear reinforcement than in the previous edition. Due to the hereby increased minimum dimensions of the webs for bridge beams, existing expensive moulds could not be used any more. Tests carried out in Spain (see chapter 11) on the strut compression shear failure of bridge beams with thin webs showed however that the capacity is not depending on the concrete alone but also related to the quantity of stirrups.

9.2 Durability

The durability of concrete structures is mainly governed by the minimum cement quantity in the concrete mix, a low water/cement ratio and the compaction and the strength of the hardened concrete. Another important factor is the concrete cover, which must be large enough to prevent corrosion of the reinforcement.

Bridges are normally designed for a lifetime of minimum 100 years. In addition, the structures are often exposed to severe weather conditions and the influence of de-icing salts. Experiences with regard to the durability of precast bridges are generally positive, due to the high concrete strength, low water/cement ratio and quality of execution. The latter is positively influenced by the indoor manufacture, good workmanship, repetition of work and high control level.

In many countries, especially in Norway, Germany, Belgium and the Netherlands, where precast bridges have been applied for a long period and to a great extend, and where climatic conditions are worse than in southern countries, it has been stated repeatedly that the costs for maintenance and repair of precast bridges are much lower than for in situ ones. This is in particular the case for simply supported bridges with a continuous slab deck.

In a few countries, there are on the other hand also some objections against the use of precast bridges. One apparently minor drawback concerns the cost of inspection, which seems to be larger for precast bridges than for cast in-situ ones because of the larger exposed surfaces of the components in the former case.

Another less good experience has been has been reported in Germany, concerning spalling cracks at the ends of prestressed bridge beams. The problem may be due to the large prestressing forces needed to prevent decompression in the lower flange under full loading. The distribution of stresses under permanent loads is thus rather unbalanced, with limited stresses in the upper flange and large stresses in the lower one. This results in important spalling stresses, which should be taken up by sufficient reinforcement at the ends of the beams. However, similar problems did not occur in other countries. End tensile stresses can also be controlled by relieved strands or by debonding of a number of strands towards the ends of the beams.

9.3 Seismic aspects

The principles and design rules for bridges with respect to earthquake actions are not significantly different for precast bridges than for cast in-situ ones. The structural connections between the bridge beams, diaphragms and deck slabs are to be dimensioned for the acting forces. The same is valid for the connections with architectural edge elements and other equipment of the bridge structure. The following specific features related to the execution in precast concrete should be analysed.

- Support length

The overlap of the deck on its support must be long enough. The minimum support length must be sufficient for the support function to be maintained in the event of extreme seismic displacement. It can be calculated with the following formula:

$$b = b_0 + d + D$$

where:

b_0 is the minimum effective support length. For standard bridges a length of 300 mm can be adopted (unless special studies determine otherwise).

d is the differential displacement of the ground between the axis of the fixed support and the concerned support.

D is the displacement of the deck on the support as a result of seismic combinations.

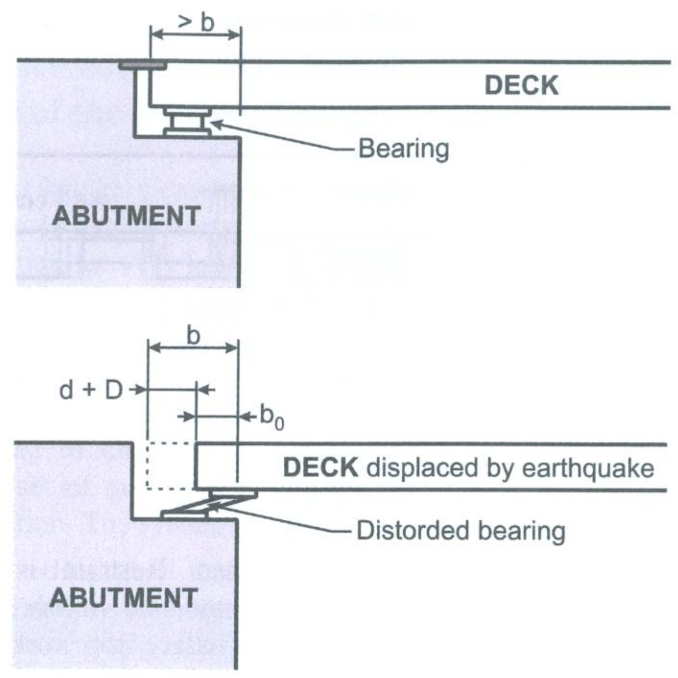


Fig. 9.1: Bearing behaviour under seismic action

- Stops

Stops can be made of steel or reinforced concrete. They are generally not very ductile.

There are two kinds of stops:

- Safety stops designed to prevent the deck leaving its supports while allowing free deformation of the bearings resulting from the seismic action.
- Limit stops (which also act as safety stops) designed to restrict relative displacements between the deck and its supports under seismic action.

The faces of the stops must be oriented appropriately to limit rotation of skew bridges around the vertical axis.

a) Longitudinal stops

In general it is not necessary to install longitudinal safety stops because of the safety margin contributed by the backfill behind the abutment. Longitudinal limit stops can be envisaged to complement laminated rubber bearings in some rare and special cases (e.g. long bridge on piers of the same characteristics for which a behaviour factor has to be applied). The gap around the stops must be adjusted in order to limit the effects of impact on the supports.

b) Transverse stops

Transverse safety or limit stops (for rail bridges) must be provided to limit the relative displacement between the bridge and its supports and to prevent the collapse of the deck. It is recommended that limit stops be installed on abutments, with a small gap (10 to 20 mm) which will allow the bridge to “work” in service and limit the effects of pounding in an earthquake.

In the case of a deck whose transverse movement is restricted at two supports, transverse stops are not generally required on the other supports.

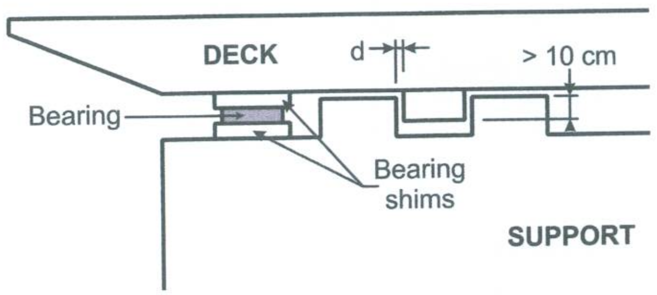


Fig. 9.2: Support with stops

The figure above shows one possible arrangement. Restraint is obtained by reinforced concrete embossings at the support or at the underside of the deck. The embossings overlap each other by about 100 mm. This type of safety stop works only in the transverse direction of the bridge.

10 Execution

10.1 Manufacture of the precast elements

Industrialised precast bridge elements are manufactured in permanent facilities under an officially agreed system of quality surveillance. The elements are generally cast on long line prestressing beds, although for very large and very heavy units such as mono-box girders and some special units, other prestressing techniques may be used.

The moulds are normally in steel. In some countries, like for example in Belgium, the standardisation of the geometrical characteristics of the main beams by the National Bridge Authorities, has enabled to elaborate a mould system composed of standardised mould segments. A complete set of mould segments enables the production of all types of beams given in the standardisation. The system has now been used for more than 45 years.

Fig. 10.1: Long line production of bridge beams

Fig. 10.2: Prestressing in a long line production of bridge beams

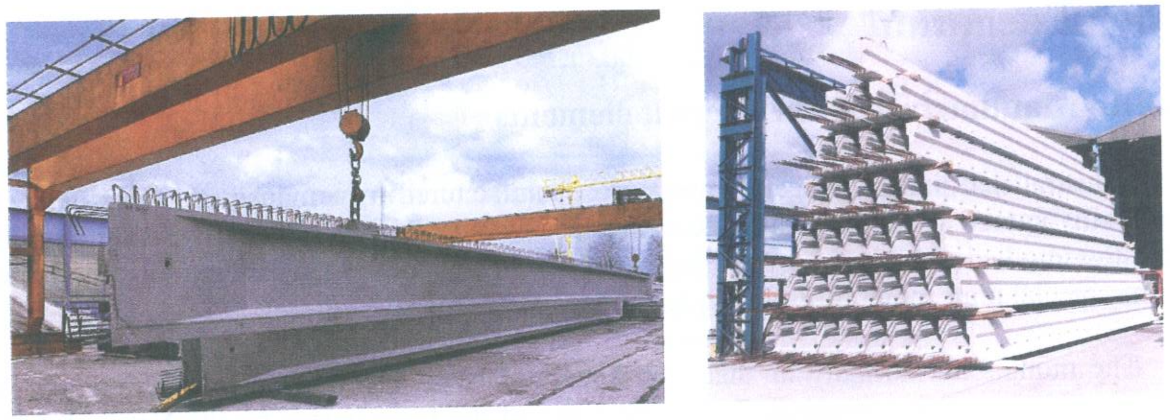


Fig. 10.3: Storage of bridge beams

10.2 Transport and erection

Transport of long and heavy bridge units may require special truck and selected itineraries. The transport is often done at night, in order to limit the disturbance of the normal traffic. In some countries, transport is also done by ship and by rail.

Fig. 10.4: Transport of a 210 ton heavy bridge beam by truck

Fig. 10.5: Transport of a mono-box beam by road

The necessity to transport heavy bridge units to the site is not necessarily a negative aspect of precast bridges. In fact, the transport of a limited number of large units has to be compared to bringing in scaffolding, material for the formwork, ready-mix concrete, etc. on separate transports. When the units are precast, all these materials do not have to be brought to the site at all. This represents a significant reduction in the number of truck movements, and hence less burden on the environment.

In most cases, the erection of bridge beams is done with mobile cranes. The crane capacity is now currently up to 400 ton. Very often two cranes are needed to hoist the long bridge elements up to their final position.

Fig. 10.6: Erection of curved box beams for the metro

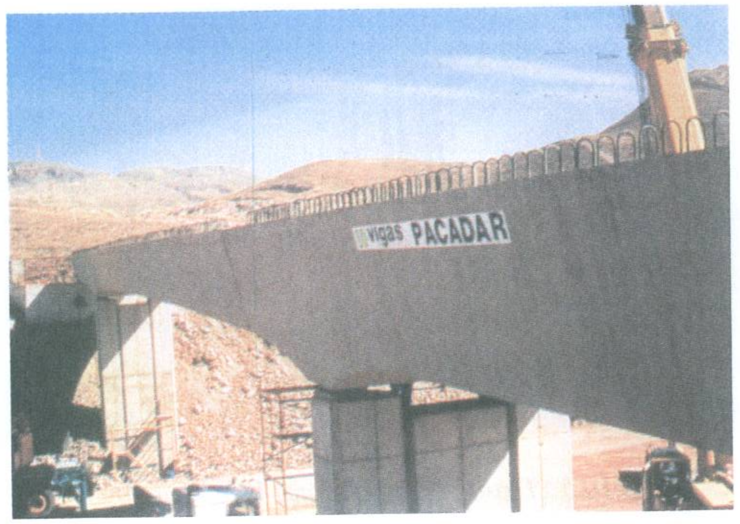


Fig. 10.7: Erection of mono-box beam

Fig. 10.8: Hoisting of precast pier for a bridge

Fig. 10.9: Erection of box beams using a gantry

10.3 Site work

Site work encompasses the preparation and casting of additional structural components like diaphragm beams, infill concrete and deck slabs, plus the finishing works of the bridge. The general contractor carries out the work. The following figures illustrate some of the works to be carried out on site.

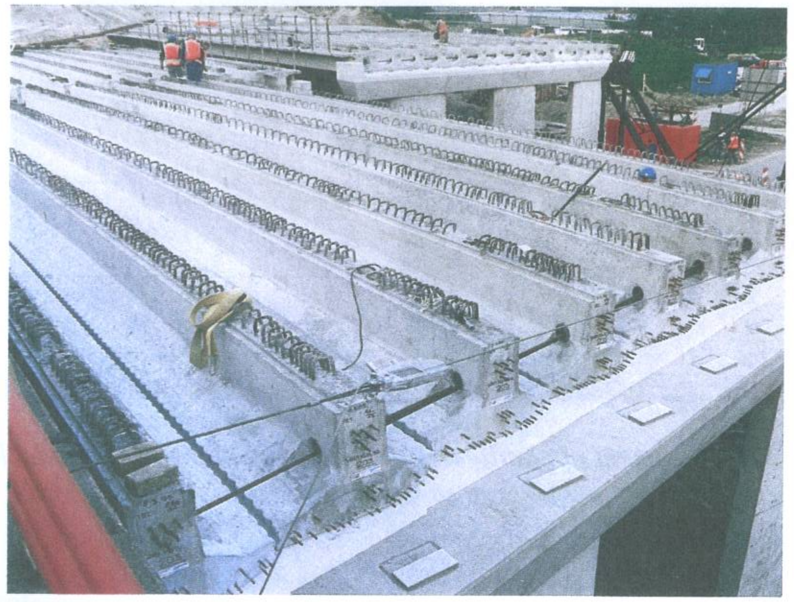


Fig. 10.10: Precast bridge after erection of the beams

Fig. 10.11: Placement of shuttering planks for the deck slab

Fig. 10.12: Placement of cantilevering shuttering planks for the deck slab

10.4 Quality assurance

- General

The quality assurance with regard to the production of bridge beams is generally based on the quality system described in EN ISO 9001 and EN ISO 9002. It consists in self-control supervised by an accredited third party, or State Highway Personel in the US.

- Factory production control

The factory production control system consists of procedures, instructions, regular inspections, tests and the utilisation of the results to control equipment, raw materials, other incoming materials, production processes and products. The daily control involves in particular checks on geometry, location of the reinforcement, initial prestressing force, and properties of the materials including concrete, reinforcement and prestressing steels. The results of inspections, which are expressed in numerical terms and test results, are recorded in a special register, available to the third party.

The frequency of checks and inspection controls are agreed between the manufacturer and the bridge authorities, generally based on national or international product standards. An example of an inspection scheme for process inspection is given in table10.1. It is based on the CEN draft product standard for precast products prEN 13369:2000.

SUBJECT	METHOD	PURPOSE	FREQUENCY
Mixture - composition (except water content)	- Visual on weighing equipment - Checking against production documents	Conformity with intended production	- Daily for each composition used - After each change
Water content of fresh concrete	Appropriate method	To provide data for the water/cement ratio	- Daily for each composition used - After each change - In case of doubt
Chloride content	Calculation	To ensure that the maximum chloride content is not exceeded	In case of increase of the chloride content of the constituents
Water/cement ratio of fresh concrete	Calculation according to specific standard	To assess specified water/cement ratio	Daily, if specified
Air content of fresh concrete	Test according to specific standard	To assess conformity with specified content of entrained air	First batch of each production day until values stabilise
Concrete mix	Visual check	Correct mixing	Daily for each mixer
Potential concrete strength	Testing according to specific standard	To assess conformity with intended value	Daily for each type of concrete
Density of hardened concrete	Testing according to specific standard	To assess specified density	As frequently as potential strength

Table 10.1: Example of inspection scheme for concrete control

- Production tolerances

An example of production tolerances specified by the CEN Product standard for bridge elements CEN/TC 229/WG1/TG14 is given in table 10.2

DIMENSIONS (Figure 10.9)	**PERMITTED DEVIATION (mm)**
Length (L)	- (20 + L/2000) + (20 + L/2000)
Height (h)	- h/100 or -10 (whichever is the greater) + (10 + h/100)
Width (a, b, e)	± (10 + b/200)
Flange depth (m)	± 10
Flange depth (s)	- 5 + 10
Vertical skewness (v_1, see fig 1b)	± 0.03 h
Horizontal skewness (v_2, see Fig 1c)	± 0.05 d
Verticality (g, see Fig 1d)	± 0.02 h
Lateral deviation (with reference to theoretical axis)	± L/500
Camber or sag (with reference to declared value evaluated taking into account the age and the load history of the element)	50% of the declared value or L/800 (whichever is the greater)
Position of holes or inserts (with reference to drawings)	± 30
Mutual position holes or inserts within a group	± 5
Concrete cover (The absolute minimum required by the durability should always be fulfilled)	- 5 + 10
Position of ordinary reinforcement (not related to cover), except the longitudinal position of stirrups.	± 10

Table 10.2: Example of product tolerances for bridge elements

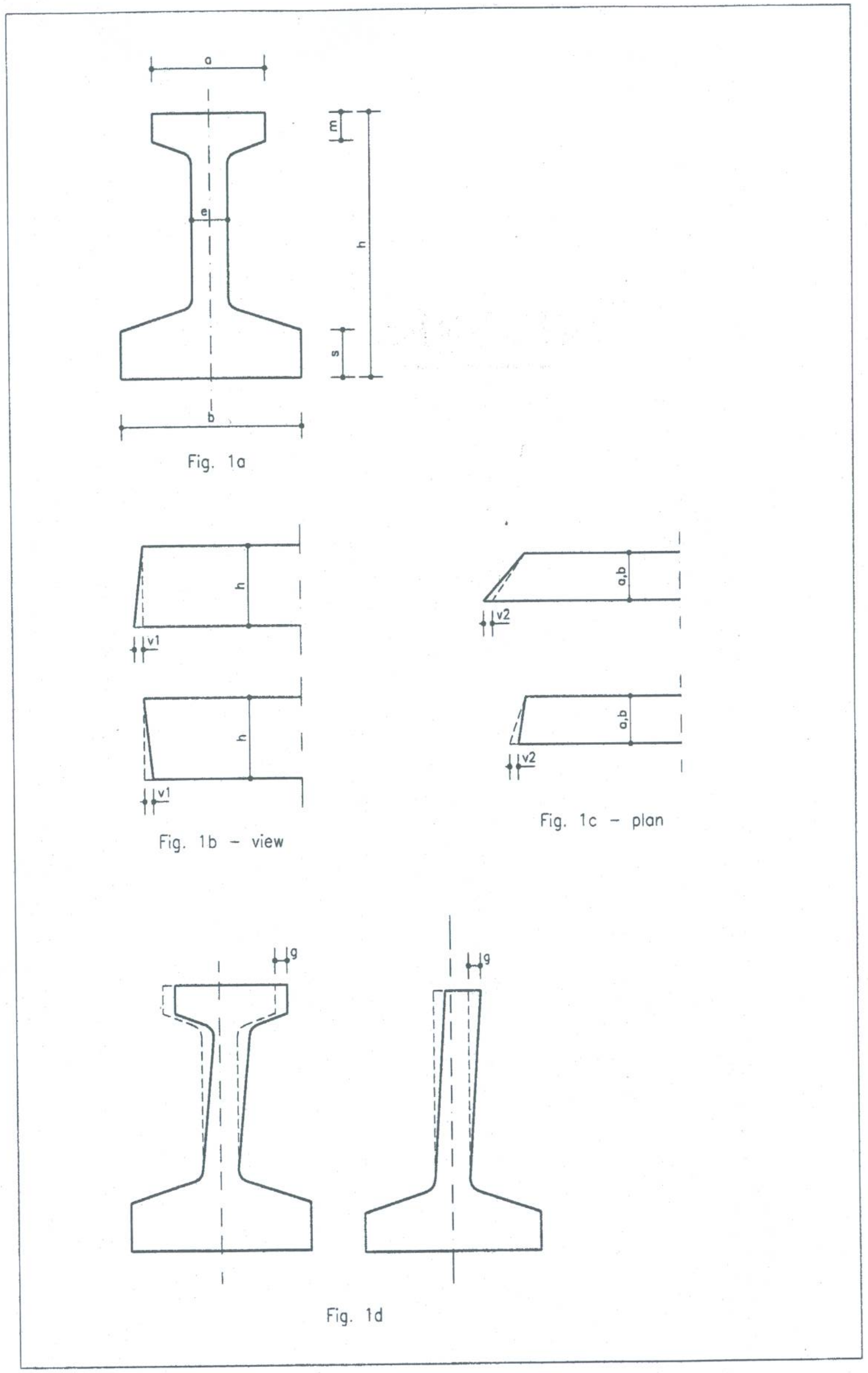


Fig. 10.13: Basic dimensions and deviations for bridge elements

11 Research

A lot of research programmes have been carried out especially for PCI in the US and different organisations in Europe. In the following, two outstanding examples of investigations on precast bridges are described.

11.1 Tests on strut compression shear failure of bridge beams – INTEMAC and Polytechnic University of Barcelona, Spain

Precast beams for bridges are manufactured in Spain from the early fifties on. Bridge construction techniques with precast members have constantly been developed since and are used today to build statically determinate, continuous bridges with spans of over 50 meters.

Different beam types have been developed such as I beams, trough and box girders. These beams have been designed in recent years to Spanish Codes EP-80 and EP-93, based on the CEB-FIP MODEL CODE 1978.

With the publication of former versions of Eurocode EC-2 Part 1 and Eurocode EC-2 Part 1-3, it was found that for the situations in which precast beams are usually employed, the solutions used with considerable success in recent years would not be valid any more. The problem arose on the compression allowed on the struts for the model to resist shear. In these beams the compression in the struts is high but there is always enough shear reinforcement to control tension stresses. After the result of the hereafter described investigation and tests, the formulation for shear compression in the struts in the final version of Eurocode EC-2 Part 1 has been changed and adapted to the values adopted in former Codes and consistent with these investigations.

The following work methodology has been followed in this investigation:

1. Study and analysis of available bibliography
2. Analysis of existing tests on shear failure
3. Analysis on shear failure made for FEDECE. Failure in compression of the struts
4. Establish a structural rational model for shear
5. Evaluation of the tests with the model
6. Final conclusions

A rational design and calculation model has been developed and evaluated with full-scale shear tests on elements.

Shear tests were originally made by F. Leonhardt in 1961 in Stuttgart together with R. Walter. Also M.P. Nielsen and M.W. Braestrup have performed tests at the Technical University of Denmark in 1980, and finally some test made by Teófilo Serrano in CEDEX (Spain) during 1982 have been analyzed.

Furthermore a number of data from the tests made for FEDECE by Intemac and the Technical School of Civil Engineers of Barcelona, under the direction of the Professors Aparicio, Calavera and Del Pozo, have been analyzed. In these tests the failure of the precast bridge beams, was produced directly in the shear struts, without previous plastification of shear reinforcement.

The developed rational model combines resistance to shear with the strut and tie model, originally developed by Ritter and Mörsch, and the inscribed arch and tension tie model, as proposed by the three professors that made Fedece Tests.

The proposed model takes into account redistribution between both mechanisms of strut and tie as well as the inscribed arch and tension tie, when one of the mechanisms reaches its maximum load capacity.

It has been possible to verify a correct correlation between previsions of the theoretical model and shear failure tests made by several authors, both in the case of direct compression in shear struts and with former plastification of shear ties and subsequent compression of shear struts or compression top chord.

In all studied cases the same failure mechanism has been obtained in the model as well as in the tests. This has occurred, both in the case of direct compression in the shear struts, as was the case of Barcelona Tests, and also in the case of failure in compression of shear struts after former plastification of shear ties, as in the case of Stuttgart shear test and CEDEX shear tests.

On the basis of the realized work, it can be demonstrated that the mechanism of shear resistance is very complex and that the proposed model can model it with enough approximation. This model has within two shear resisting mechanisms that interact depending on the different mechanic characteristics of its elements and the history of loads.

The application of the proposed model in the design allows adjusting the response of linear elements regarding combined bending and shear. Although it has not been explicitly looked for, the tension in the bending chord and the compression in the bending compression chord can be deduced from the model. Both depend strongly on the way the shear and bending reinforcement has been designed.

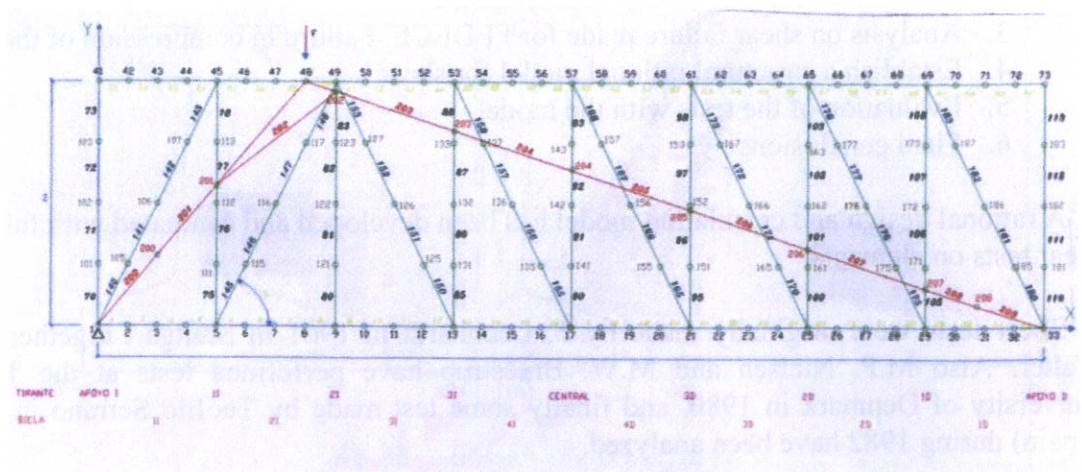


Fig. 11.1: Model developed in the investigation

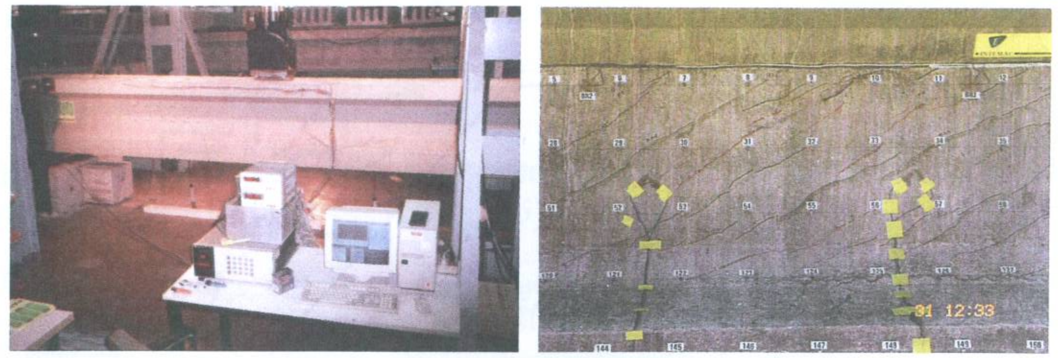


Fig. 11.2: Instrumentation of beams

Fig. 11.3: Ultimate load in the beams

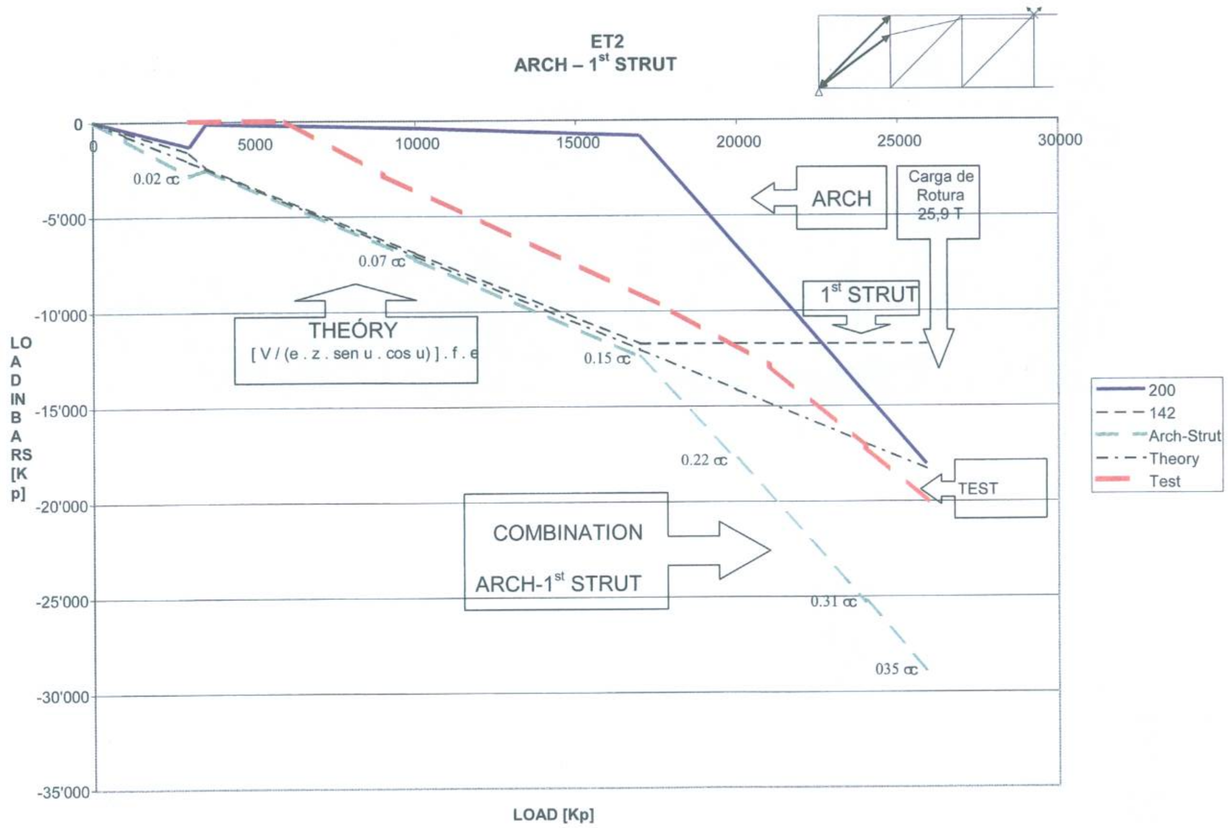


Fig. 11.4: Example of calibration between the model and the tests

11.2 Fatigue performance of precast prestressed beams in rail bridge decks - CERIB France

11.2.1 Test specimen and loading

The tests presented here have been undertaken to validate the technique of continuous precast bridge deck for high-speed trains (TGV) at the request of SNCF (French rail)

This type of bridge is built by placing separate precast pretensioned beams and joining them together with a reinforced-concrete slab. The mechanical continuity is provided by reinforced concrete crossbeams atop the piers. The aim of this study was to proof that the resulting composite assembly was capable of withstanding the specific loading effects of rail bridges for the lifetime of a TGV bridge, it was undertaken by the CERIB (Study and Research Centre of the French Precast Concrete Industry), in association with the SNCF and the FIB (French Federation of Precast Concrete Manufacturers).

This study took place in several steps:

- design and fabrication of a representative test specimen in accordance with SNCF design regulations;
- performance of a static loading test to failure on a first test specimen;
- performance of a 50-million-cycle fatigue test on a second specimen; this corresponds to a lifetime of about 100 years, followed by a static test to failure.

11.2.2 Test specimen

The test specimens consist of two 5.35 m long spans joined together by a crossbeam. The final T shaped cross section is obtained by pouring a 15 cm slab of C35 concrete on the pretensionned C50 beams. Continuity is achieved by ordinary longitudinal reinforcement in the slab and the crossbeam cast together.

The test specimens were designed in accordance with the SNCF's guidelines:

- design of the prestress by considering the requirements of Class II (tensile stresses up to 1.5 x fct allowed in concrete) in transient situations and the requirements of Class I (no tensile stresses allowed in concrete) in the service situation;
- design of ordinary reinforcement (continuity and shear reinforcement), particularly relative to fatigue.

The loading rig was designed to simulate the dead load caused by ballast and equipment as well as the live loads due to the passage of trains (see figure 11.5).

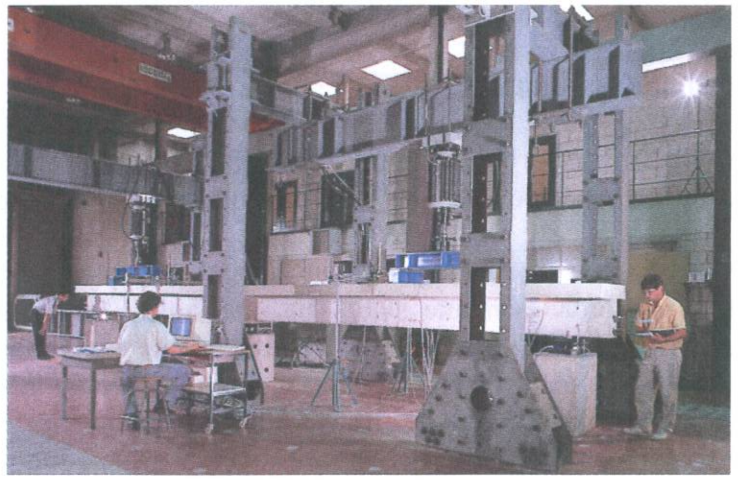


Fig. 11.5: General view

11.2.3 Results and main findings

11.2.3.1 Behaviour in service

The specimens behaved similarly, showing a slight cracking pattern under service loads in the reinforced concrete parts atop the continuity bearing.

Stiffness evolution, evaluated by rotation measurements, was in accordance with tension stiffening models of cracked sections in bending (Fig. 11.6 and 11.7).

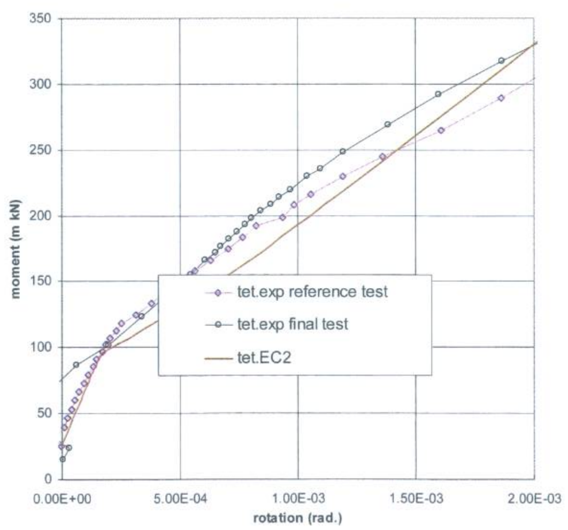


Fig. 11.6: Moment rotation behaviour

Fig. 11.7: Rotation of the crossbeam

The consequence of this behaviour was a mechanical continuity coefficient slightly below 1 (coefficient given by the ratio of continuity moment compared with a continuous beam with constant inertia): under service loads this coefficient was around 0.78 for all tests.

11.2.3.2 Fatigue test

The fatigue test was carried out at a frequency of 8 hertz, i.e. about 1/4 of the frequency corresponding to the first natural-vibration mode.

The coefficient of redistribution, k, defined above remained very close to 0.78 during the test. However, several things showed that the structure had undergone some change:
- cracks in the continuity zone became slightly wider, while remaining quite tight (from 0.13 mm at the start of the test to 0.17 mm at the end, under service loads) ;
- the modulus of elasticity of sections fitted with strain gauges decreased slightly, reflecting the fatigue of the materials at the local level;
- the overall stiffness of the spans, defined by the ratio of the force applied by the deflection measured mid-span, also decreased.

The above results appear to indicate that the test specimen has undergone some adaptation; in other words, the losses of stiffness mid-span and above the continuity bearing have been compensated so as to maintain a constant rate of redistribution throughout the duration of the test.

11.2.3.3 Post elastic behaviour and failure phase

The failure mechanism for both tests are identical. A plastic developed mid-span (plastification of the prestressing wires), then the beam/slab assembly separated between the point of maximum moment and a shear-bending crack near the crossbeam (Fig. 11.8 and 11.9). This separation was caused by shearing of all the connecting reinforcement and seems to be accompanied by buckling in the compressed and separated part of the slab. It should be mentioned that up to collapse no slippage of tendons was recorded at the simply supported end of the beams.

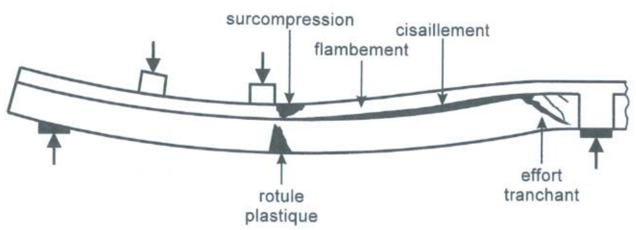


Figure 11.8: Failure mechanism

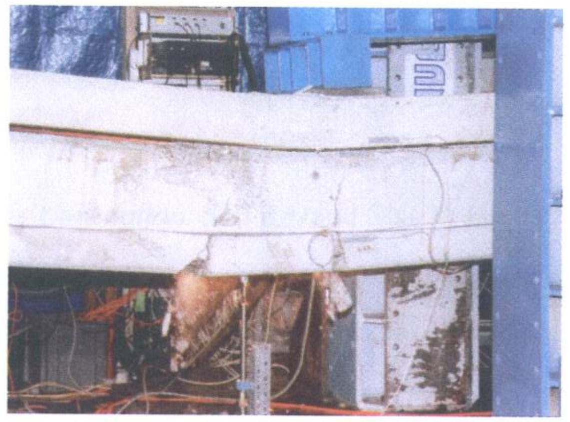


Figure 11.9: Failure of a plastic hinge

Considering a full redistribution between the spans and the intermediate support, the two failure modes (horizontal shear and bending) occur for close calculated load level, hence it is difficult to determine categorically how failure came about. The collapse of the 1st test was obtained for a lower load value than the 2nd one, this can be explained by a lower ductility in the 1st case, leading to less redistribution.

11.2.4 Conclusion

The test campaign presented here demonstrated the capacity of pretensioned components to withstand fatigue effects, particularly with respect to the strength of prestress anchor zones. Similarly, the composite beam/slab structure made continuous with reinforced concrete proved to behave very well : no change in overall performance, little evolution of cracking on the continuity bearing or of mid-span deformation throughout the duration of the test, i.e. 50 million cycles.

The safety margin at failure relative to the service load was more than 2.8 for both tests, this ratio is considered to be satisfactory.

At the end of both tests, the behaviour of the test specimen was modelled in detail: in terms of the overall mechanical situation, consideration of the loss of stiffness in cracked sections correctly represented the redistributions observed in the tests.

The results obtained mean this construction process can be validated for the construction of rail bridge decks. The findings can be used to improve design methods for this type of structure.

12 Bibliography

[1] ENV 1992-2:1996, *Eurocode 2: Design of concrete structures – Part 2: Concrete Bridges*.

[2] ENV 1998-2:1994, *Eurocode 8: Design provisions for earthquake resistance of structures – Part 2: Bridges*.

[3] CEN/TC 229/WG1/TG14 *Bridge Elements*.

[4] prEN 13369:1999, *Common Rules for Precast Concrete Products*.

[5] Rossner, *Brücken aus Spannbeton-Fertigteilen*. Ernst & Sohn, Berlin, 1988.

[6] *Vorläufige Richtlinien für Straßen- und Wegebrücken aus Spann- und Stahlbeton-Fertigteilen* (R FT-Brücken) 1979, Forschungsgesellschaft für das Straßenwesen.

[7] Pritchard, Brian P. *Bridge Design for Durability: a TRL Publication Incorporating Methods of Achieving Continuity in Composite Concrete Bridge Decks*.

[8] Hambly, Edmund C. and Nicholson, B. *Prestressed Beam Integral Bridges*. PCA, U.K.

[9] Taylor, H.P.J. *Continuity of Bridge Decks using Precast Beams*. PCA, U.K.

[10] Clarke, L.A. and Sugie, I. *Serviceability Limit State Aspects of Continuous Bridges using Precast Concrete Beams*. PCA, U.K.

[11] *fib* bulletin 9, *Guidance for good bridge design*, July 2000, chapter 1.4.2.

[12] RILEM Report 14, *Durability Design of Concrete Structures*. Edited by A. Sarja and E. Vesikari, 1996.

[13] *fib* bulletin 3, *Structural Concrete: Textbook on Behaviour, Design and Performance*, Volume 3. December 1999.

[14] EUROCODE 8-2 DAN

[15] *Association Française de Génie Parasismique (AFPS) Guide*, 1992.

[16] *Ponts Courants en Zone Sismique - Guide de Conception.* SETRA and SNCF, January 2000.

[17] PS92, Seismic engineering regulations.

[18] Association Française de Génie Parasismique (AFPS) recommendations, 1990

[19] Aparicio, A.; Calavera, J. and Del Pozo, F.J. *Plan de investigación sobre la compresión máxima en bielas, por esfuerzo cortante para vigas prefabricadas de hormigón pretensado con armaduras pretesas*. Madrid, November 1997.

[20] *ACI Manual Of Concrete Inspection,* Publication Sp-2. American Concrete Institute.

[21] *Concrete Manual – A Water Resources Technical Publication.* US Department of the Interior, Bureau of Reclamation.

[22] FIP report 578, *Composite floor structures*. SETO, 1998.

[23] *Recomendaciones para la realización de pruebas de carga. Recepción de puentes de carretera*. Dirección General de Carreteras. Ministerio de Fomento. Spain, 1999.

[24] SNCF, *Cahier des prescriptions communes applicables aux marchés de travaux d'ouvrages d'art et autres constructions*. Livret 2.01, 1995.

[25] ENV1992-1-3:1994, *Eurocode 2: Design of concrete structures – General rules – precast concrete elements and structures*.

[26] de Chefdebien, A. *Comportement à la fatigue de poutres industrielles précontraintes pour tabliers de ponts-rails*. Publication Technique n° 120. CERIB, 1998.

[27] Fernandez-Ordoñez, D. *Mecanismos de respuesta frente al esfuerzo cortante en vigas prefabricadas*. Madrid, 2001.

13 Acknowledgments

The authors of this bulletin gratefully acknowledge the following contributions.

Figure	**Source/Precaster**
[4.1]	CEN/TC 229/WG1/TG14 Bridge Elements
[4.2a]	CEN/TC 229/WG1/TG14 Bridge Elements
[4.2b,c]	Spanbeton BV, The Netherlands
[4.3]	Precompressi Centro Nord, Italy
[4.4]	Precompressi Centro Nord, Italy
[4.5]	Precompressi Centro Nord, Italy
[4.6]	Spanbeton BV, The Netherlands
[4.7]	Spanbeton BV, The Netherlands
[4.8]	Spanbeton BV, The Netherlands
[4.9]	Ianus srl, Italy
[4.10]	Ergon, Belgium
[4.11]	Spanbeton BV, The Netherlands
[4.12]	Spenncon, Norway
[4.13]	Structo, Belgium
[4.14]	CEN/TC 229/WG1/TG14 Bridge Elements
[4.15]	Spanbeton BV, The Netherlands
[4.16a]	Structural Concrete Industries, Australia
[4.16b]	Structural Concrete Industries, Australia
[4.17]	Structural Concrete Industries, Australia
[4.18]	RDB SpA, Italy
[4.19]	Precast/prestressed Concrete Institute (PCI), USA
[4.20]	Skanska UK, plc
[4.21]	Prefabricados Castelo SA, Spain
[4.22]	CEN/TC 229/WG1/TG14 Bridge Elements
[4.23]	Alvisa Prefabricados, Spain
[4.24]	Betonson, The Netherlands
[4.25]	Alvisa Prefabricados, Spain
[4.26]	Pavicentro Pré-fábricação, SA, Portugal
[4.27]	Alvisa Prefabricados, Spain
[4.28]	Spanbeton BV, The Netherlands
[4.29a]	Spanbeton BV, The Netherlands
[4.29b]	Spanbeton BV, The Netherlands
[4.30a]	Spanbeton BV, The Netherlands
[4.30b]]	Alvisa Prefabricados, Spain
[4.31]	Ergon, Belgium
[4.32]	Spanbeton BV, The Netherlands
[4.33]	FCC, Spain
[4.34]	Pacadar, Spain
[4.35]	Pacadar, Spain
[4.36]	Cav. Nico Velo & F.lli SpA, Italy
[4.37]	Ergon, Belgium
[4.38]	Spanbeton BV, The Netherlands
[4.39]	Belgium - Precaster Ronveaux
[4.40]	Ergon, Belgium

[4.42] Structo, Belgium
[4.43] Bonna Sabla, France
[4.44] CEN/TC 229/WG1/TG14 Bridge Elements
[4.45] Prefabricados Castelo SA, Spain

[5.2] SETRA, Ponts-routes à poutres préfabriquées précontraintes par adhérence (PRAD), Guide de conception. 1996
[5.3] SETRA, Ponts-routes à poutres préfabriquées précontraintes par adhérence (PRAD), Guide de conception. 1996
[5.4] SETRA, Ponts-routes à poutres préfabriquées précontraintes par adhérence (PRAD), Guide de conception. 1996
[5.5] CEN/TC 229/WG1/TG14 Bridge Elements
[5.6] CEN/TC 229/WG1/TG14 Bridge Elements
[5.7] CEN/TC 229/WG1/TG14 Bridge Elements
[5.8] CEN/TC 229/WG1/TG14 Bridge Elements
[5.10] Groupe KP1, France
[5.12] Groupe KP1, France
[5.14] Pacadar, Spain
[5.15] Prefabricados Castelo, Portugal
[5.16] CEN/TC 229/WG1/TG14 Bridge Elements

[6.1] Spanbeton BV, The Netherlands
[6.2] SETRA, Ponts-routes à poutres préfabriquées précontraintes par adhérence (PRAD), Guide de conception. 1996
[6.3] Pacadar, Spain
[6.4] Spanbeton BV, The Netherlands
[6.5] Ronveaux, Belgium
[6.6] Spanbeton BV, The Netherlands
[6.7] SCAC Precompressi, Italy
[6.8] Precaster Rivoli SpA, Italy
[6.9] Spanbeton BV, The Netherlands

[7.1] Federatie van de Betonindustrie – FeBe, Belgium
[7.3] Federatie van de Betonindustrie – FeBe, Belgium
[7.4] Federatie van de Betonindustrie – FeBe, Belgium
[7.5] Spanbeton BV, The Netherlands

[8.1] SETRA, Ponts-routes à poutres préfabriquées précontraintes par adhérence (PRAD), Guide de conception. 1996
[8.2] SETRA, Ponts-routes à poutres préfabriquées précontraintes par adhérence (PRAD), Guide de conception. 1996
[8.3] Spenncon, Norway
[8.4] Spanbeton BV, The Netherlands
[8.5b] Vanguard, Spain
[8.6] Alvisa Prefabricados, Spain
[8.7] Groupe KP1, France
[8.8] Vanguard, Spain
[8.9] Spanbeton BV, The Netherlands
[8.10] Pacadar, Spain
[8.11] Spanbeton BV, The Netherlands
[8.12] CEN/TC 229/WG1/TG14 Bridge Elements

[8.13] Pacadar, Spain
[8.15] Alvisa Prefabricados, Spain
[8.16] CEN/TC 229/WG1/TG14 Bridge Elements
[8.17] Prefabricados Castelo SA, Spain
[8.18] Prefabricados Castelo SA, Spain

[9.1] CEN/TC 229/WG1/TG14 Bridge Elements
[9.2] CEN/TC 229/WG1/TG14 Bridge Elements

[10.1] Spanbeton BV, The Netherlands
[10.2] CPC, France
[10.3a] Spanbeton BV, The Netherlands
[10.3b] CPC, France
[10.4] Ergon, Belgium
[10.6] Spanbeton BV, The Netherlands
[10.7] Pacadar, Spain
[10.8] Alvisa Prefabricados, Spain
[10.9] Generale Prefabbricati SpA, Italy
[10.10] Spanbeton BV, The Netherlands
[10.11] Ergon, Belgium
[10.12] Prefabricados Castelo SA, Spain
[10.13] Federatie van de Betonindustrie – FeBe, Belgium

[11.1] INTEMAC, Spain
[11.2] INTEMAC, Spain
[11.3] INTEMAC, Spain
[11.4] INTEMAC, Spain
[11.5] Centre d'Etudes et de Recherche de l'Industrie du Béton (CERIB), France
[11.6] Centre d'Etudes et de Recherche de l'Industrie du Béton (CERIB), France
[11.7] Centre d'Etudes et de Recherche de l'Industrie du Béton (CERIB), France
[11.8] Centre d'Etudes et de Recherche de l'Industrie du Béton (CERIB), France
[11.9] Centre d'Etudes et de Recherche de l'Industrie du Béton (CERIB), France

fib Bulletins published since 1998

N°	Title	Price (CHF)
1	Structural Concrete Textbook on Behaviour, Design and Performance Vol. 1: Introduction - Design Process – Materials Manual - textbook (244 pages, ISBN 2-88394-041-X, July 1999)	100
2	Structural Concrete Textbook on Behaviour, Design and Performance Vol. 2: Basis of Design Manual - textbook (324 pages, ISBN 2-88394-042-8, July 1999)	100
3	Structural Concrete Textbook on Behaviour, Design and Performance Vol. 3: Durability - Design for Fire Resistance - Member Design - Maintenance, Assessment and Repair - Practical aspects Manual - textbook (292 pages, ISBN 2-88394-043-6, December 1999)	100
4	Lightweight aggregate concrete: Extracts from codes and standards State-of-the-art report (46 pages, ISBN 2-88394-044-4, August 1999) Original edition out-of-print; available as photocopy only	60
5	Protective systems against hazards: Nature and extent of the problem Technical report (64 pages, ISBN 2-88394-045-2, October 1999)	60
6	Special design considerations for precast prestressed hollow core floors Guide to good practice (180 pages, ISBN 2-88394-046-0, January 2000)	90
7	Corrugated plastic ducts for internal bonded post-tensioning Technical report (50 pages, ISBN 2-88394-047-9, January 2000)	60
8	Lightweight aggregate concrete Part 1 – Recommended extensions to Model Code 90 Part 2 – Identification of research needs Part 3 – Application of lightweight aggregate concrete Guide (part 1), technical report (part 2) and state-of-the-art report (part 3) (118 pages, ISBN 2-88394-048-7, May 2000)	80
9	Guidance for good bridge design Part 1 – Introduction Part 2 – Design and construction aspects Guide to good practice (190 pages, ISBN 2-88394-049-5, July 2000)	100
10	Bond of reinforcement in concrete State-of-art report (434 pages, ISBN 2-88394-050-9, August 2000)	130
11	Factory applied corrosion protection of prestressing steel State-of-art report (20 pages, ISBN 2-88394-051-7, January 2001)	50
12	Punching of structural concrete slabs Technical report (314 pages, ISBN 2-88394-052-5, August 2001)	110
13	Nuclear containments State-of-art report (130 pages, 1 CD, ISBN 2-88394-053-3, September 2001)	100
14	Externally bonded FRP reinforcement for RC structures Technical report (138 pages, ISBN 2-88394-054-1, October 2001)	90
15	Durability of post-tensioning tendons Technical report (284 pages, ISBN 2-88394-055-X, November 2001)	100

N°	Title	Price (CHF)
16	Design Examples for the 1996 FIP recommendations *Practical design of structural concrete* Technical report (198 pages, ISBN 2-88394-056-8, January 2002)	90
17	Management, maintenance and strengthening of concrete structures Technical report (180 pages, ISBN 2-88394-057-6, April 2002)	90
18	Recycling of offshore concrete structures State-of-art report (33 pages, ISBN 2-88394-058-4, April 2002)	50
19	Precast concrete in mixed construction State-of-art report (68 pages, ISBN 2-88394-059-2, April 2002)	80
20	Grouting of tendons in prestressed concrete Guide to good practice (52 pages, ISBN 2-88394-060-6, July 2002)	60
21	Environmental issues in prefabrication State-of-art report (56 pages, ISBN 2-88394-061-4, March 2003)	60
	Directory 2003 (108 pages, March 2003)	80
22	Monitoring and safety evaluation of existing concrete structures State-of-art report (304 pages, ISBN 2-88394-062-2, May 2003)	110
23	Environmental effects of concrete State-of-art report (68 pages, ISBN 2-88394-063-0, June 2003)	70
24	Seismic assessment and retrofit of reinforced concrete buildings State-of-art report (312 pages, ISBN 2-88394-064-9, August 2003)	110
25	Displacement-based seismic design of reinforced concrete buildings State-of-art report (196 pages, ISBN 2-88394-065-7, August 2003)	100
26	Influence of material and processing on stress corrosion cracking of prestressing steel - case studies Technical report (44 pages, ISBN 2-88394-066-5, October 2003)	50
27	Seismic design of precast concrete building structures State-of-art report (262 pages, ISBN 2-88394-067-3, January 2004)	110
28	Environmental design State-of-art report (86 pages, ISBN 2-88394-068-1, February 2004)	70
	Directory 2004 (132 pages, July 2004)	80
29	Precast concrete bridges State-of-art report (83 pages, ISBN 2-88394-069-X, November 2004)	100

Prices are given in Swiss Francs (CHF), valid for non-members of *fib*. Packing and postage by surface mail are included; airmail at extra charge. The above prices were valid and all bulletins were available at the time of publication of Bulletin 28.

Abstracts for each bulletin are available on *fib*'s website at http://fib.epfl.ch/publications/fib/. To order, please use the order form at http://fib.epfl.ch/publications/order/.

ISSN 1562-3610
ISBN 2-88394-069-X

Precast concrete bridges

Contents

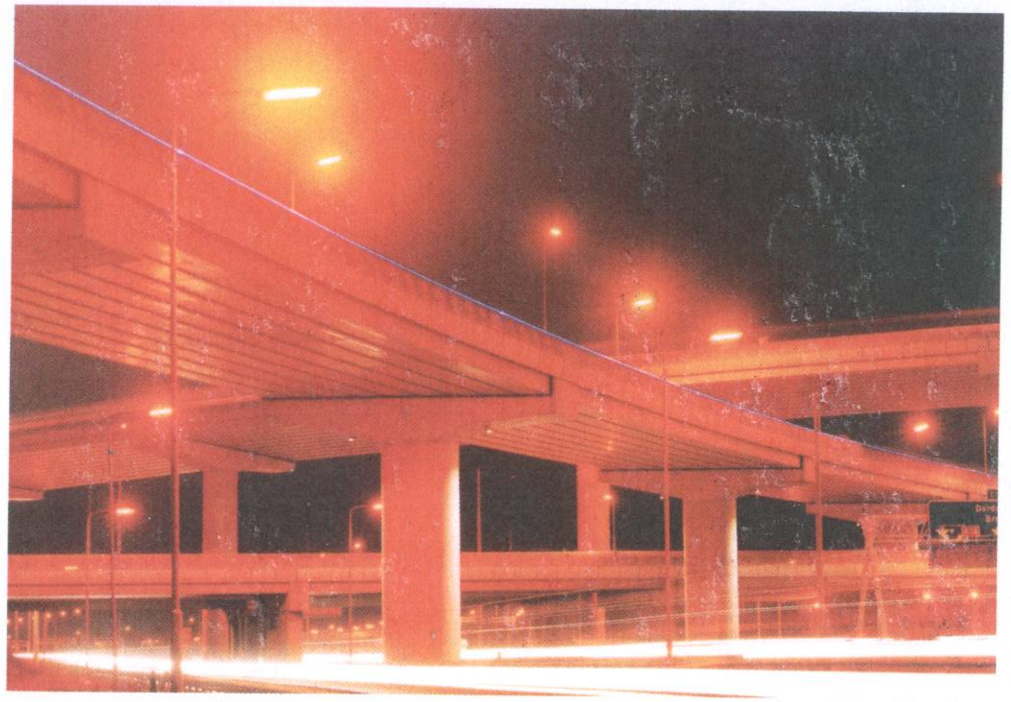
fib CEB-FIP

fédération internationale du béton
the international federation for structural concrete
created from the merger of CEB and FIP

bulletin 29

state-of-art report

fib CEB-FIP



Precast concrete bridges