Use of Precast Concrete Elements in Bridges in Europe (Spain)

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1 Introduction

The use of precast concrete elements in bridge construction has unquestionable advantages:

– As the elements are not made where the bridge is located, they can be built at the same time as other bridge parts are being constructed such as foundations, piers and abutments, thereby reducing the overall construction time.
– It is possible to use a larger area for precasting the elements or even various plants, which is a special advantage if there is only a small area available at the bridge site (fig. 1).
– The concretes used are stronger and have better characteristics.
– The fabrication tolerances, quality of the finish and quality control are better.
– Less struts, scaffoldings and forms are less required at the jobsite.

But there are also some disadvantages:

– Large equipment is required to transport and install the precast elements and there must be adequate access to the site and work platforms for these machines. Waterways like the sea, lakes and large rivers make transporting and installation operations easier (fig. 2).
– The joints between elements or between elements and parts of the bridge built in situ can be very complicated especially in hyperstatic structures.

The concrete used for precast bridge elements is usually stronger than that used for the parts of a bridge cast in situ with the same resisting function. There are several reasons for this:

– The element can have a smaller section if the strength of the concrete is greater, thereby reducing the weight of the element and the size of the means for transporting and installing it at the jobsite.
– In order to remove the forms sooner and, therefore, be able to reuse them quicker and, as a result, reduce the precasting time cycle, the element must have sufficient strength at this early age, particularly in the case of prestressed elements. This results concrete with a higher final strength.

In general, in order to produce a stronger concrete, a larger dosage of cement and a lower water-cement ratio are required and results in a more compact and durable concrete with the corresponding advantage.

Today, there are precast solutions for practically all types of concrete bridges although usually only the deck slab is precast. The parts of a bridge can be classified by the frequency with which precast elements are used to build them. Below is a list of these elements starting with those employed most frequently:

- Decks built with beams:
  - Decks of I-beams
  - Decks of U-beams
  - Decks of mono-beam (single U-beams)
  - Decks of U-beams with longitudinal joint to form a unicellular or multicelular box
  - Decks built of inverted T-beams
- Deck slabs on beams:
  - Slabs as non-recoverable forms between beams to built the deck slab
  - Partially precast slabs between beams or with outer projecting zones
  - Slabs of full thickness
  - Deck slabs built on steel beams
- Decks of segments:
  - Segments of full or incomplete transversal section
  - Segments of full transversal section joined by the deck slab
  - Segments joined by upper and lower slabs forming a unicellular or multicelular box
- Special decks
- Complete decks

- Abutments:
  - Reinforced earth abutments
  - Abutments of cantilever counterfort elements
  - Gravity abutments
  - Abutments of floating beam on backfill
- Piers:
  - Independent columns with or without capitals
  - Portal frame piers formed of vertical columns and upper joining crosshead
  - Piers built of horizontal segments
- Foundations:
  - Piles under site built pile cap-slab
  - Piles forming columns of portal frame piers
  - Footings
- Auxiliary elements:
  - Overhangs and curbs
  - Sidewalks
  - Safety barriers

All of these elements are described below.

2 A brief history of precasting for bridges in Spain

In Spain, the first precast bridge elements were built in the early 1950's, that is, more than fifty years ago. They were prestressed precast deck beams.

In 1963 the first bridge using tight fitting precast segments was built over the Guadalquivir River in Almodóvar del Río, near Córdoba. The elements were precast in the site near the bridge and then installed using a cableway crane placed on the abutments. The bridge has a 70 meter span. In 1969, a similar method was used to build a bridge over the Ebro River in Castejón de Navarra, between Logroño and Zaragoza. This bridge has a 100 meter span.

At the beginning of the 1960's, DRAGADOS was given a license to build Raymond precast prestressed spun piles in Spain formed of hollow cylindrical segments with outer diameters of 0.91 m, 1.37 m and 1.98 m. They were built in lengths of 5 m or 2.5 m using an energetic combined spinning and vibrating system, resulting in high compaction. Their strength of approximately 50 to 60 MPa (in test cylinder) was high for the time. The segments were joined with prestressing strands running through longitudinal holes. They were post-tensioned against temporary anchorages supported on the end surfaces. After injecting the holes, the temporary anchorages were removed and the prestressing strands were fixed in place by adherence. Epoxy resin mortar joined one segment to the next until the length of pile required was reached.

A plant was built in Huelva (fig. 1), southern Spain, where a great number of these piles were needed for the wharves of the port located at the mouths of the Tinto (fig. 2) and Odiel Rivers in a marsh area requiring very deep foundations. The Raymond piles were also used as columns for the portal frame piers, with crossheads cast in situ, for the port's two access bridges, one crossing each river. The decks were made of precast beams. At the end of the 1960's, a similar solution was used to build the toll bridge over Cádiz Bay (fig. 3) except for the moving section, obviously. During the 1970's several tanker berthing facilities were constructed in Algeciras, La Coruña and Bilbao, Spain, employing a similar solution. However, this time the pile crossheads were also precast.

Precasting of large quantities of concrete bridge elements began at the end of the 1960's when DRAGADOS started to build the toll motorway between Seville and Cádiz, concession that extended from the Cádiz Bay Bridge. This 100 km long toll motorway required a large number of bridges, both for overpasses for roads and highways crossing it and for it to cross over riverbeds. In order to begin to fully exploit the toll motorway as soon as possible, construction had to be carried out at a very fast pace. Furthermore, large construction equipment had to be able to use the motorway at the earliest possible date due to the large amount of marshlands in many areas that made it difficult to access the works.

Since the soil bearing capacity for the foundations was very low, the bridges were designed with isostatic beam decks, portal frame piers deep founded by Raymond piles used as columns, joined at the top by precast crossheads with a rectangular section and accompanying spans supported by floating foundation slab abutments on backfill. The beams were pi or TT-beams, with two webs of inverted trapezoi-

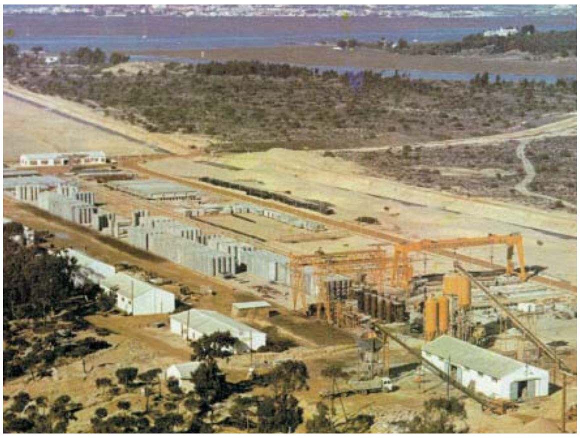

Fig. 1: Huelva plant of precast elements

Fig. 2: Bridge over Tinto River

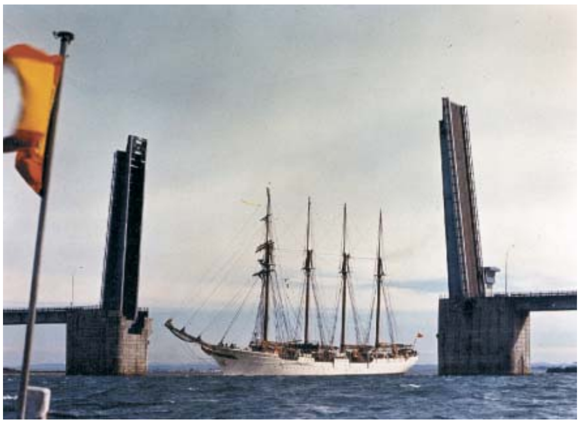

Fig. 3: Bridge over Cádiz Bay

Fig. 4: Ebro bridge – Tarragona motorway

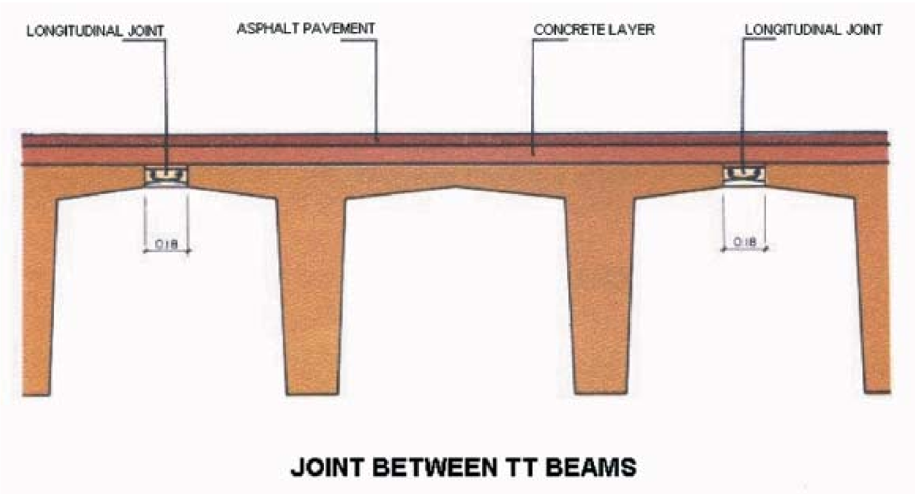

Fig. 5: TT beams deck of Sevilla motorway

dal section joined by an upper slab. The deck slab was formed by joining flanges of adjacent beams by means of a 18 cm wide, site cast longitudinal joint (fig. 5). It was then covered with asphalt pavement. The bridges were almost totally precast, the only parts built in situ being the abutments that were embedded into the backfill with very small side retaining walls and the joints of piles to crossheads and of adjacent beams. The beams were pre-tensioned with strands with a polygonal layout by means of diverters. The concrete strength for these beams was 45 MPa (test cylinder).

Neither the T-beams nor the TT-beams (two T-beams joined together) have a very good resisting function as they have a very high neutral axis and require a larger amount of concrete and, therefore, weigh more. Nevertheless, the mould is fixed (does not have to be opened in order to remove the beams) and also allows the polygonal layout of strands. Furthermore, the same mould can be used for various beam heights (between 0.50 m and 1.00 m in the Seville-Cadiz toll motorway) by simply adding a concrete false bottom of the height not to be used. The proximity of the plant in Huelva decreased the disadvantages of the extra weight for transport.

DRAGADOS used a similar solution in the early 1970's to build approximately 200 overpasses crossing railroad lines in an extensive project to eliminate grade crossings. The typical layout involved three spans, the central one located over the tracks and the other two accompanying it, one on each side to be able to place floating beam abutments on the backfill giving access to the bridge. The length of the spans was 11 m when the overpass was perpendicular to the tracks. It increased as the angle crossing over the tracks decreased, the most common angles being 90º, 75º, 60º and 45º. The height of the beams varied between 0.50 m and 0.70 m, depending on the length. The amount of precasting for these bridges was increased to the point where almost all of the bridge was precast, only concreting in situ the longitudinal joints between beams and, in the unusual case of deep foundations, the joint between pile crossheads and Raymond piles.

The floating beams on the abutments were reinforced and had an inverted T section, similar to half a TT-beam, that was turned over after being removed from the mould. The portal frame piers generally had two Raymond pile columns, but their number increased in wider bridges. In most cases, the foundations were not deep but shallow. The 7 meter long columns were built of two Raymond segments, the length of one being the standard 5 meters and the other making up the rest of column. They were joined temporarily with three reinforcing bars placed in the pile at 120º with respect to each other in three of the existing 12 holes. Epoxy resin mortar was used to fix the bars in the holes and join the two segments together. Each footing, with an inverted trapezoid cross section, was reinforced and also precast. It was fit with three embedded sheaths at 60º under each pile support and one strand (in some cases two) was inserted into each sheath. Thus, six strand ends extended out of it at a 60º angle.

In the erection of the pier, the foundation slab was placed on a 30 cm thick gravel bed, the six strand ends of each column were inserted into the corresponding holes in the Raymond pile and into another six holes left in the crosshead in each area where it meets the column, after which these strands were anchored by means of permanent plates and wedges located on the upper face of the crosshead. Next, the sheaths and holes were injected to protect the strands from corrosion. The gravel under the foundation slab was then injected with cement mortar so that the pier would settle better and the load would be more evenly distributed on the ground (fig. 6). The support for the abutment was built in a similar way with a 20 cm thick gravel bed that was also injected later. All the bridge elements, including the steel handrails, were shipped by rail from the factory in Huelva to where they were stored near the corresponding jobsite. In one work day, the two piers and the beams of the central section were installed. Afterwards, the two backfills were built covering the piers footings. In another work day, the two abutments and the beams of the two access spans were added. And finally, the longitudinal joints between beams were concreted, the ex-

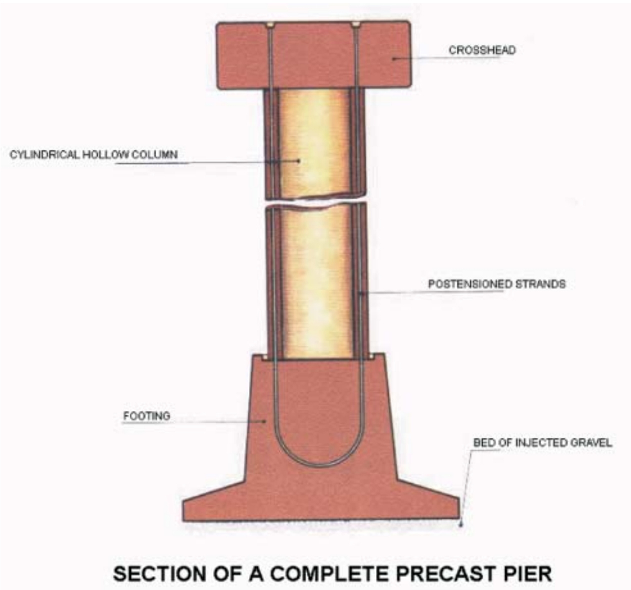

Fig. 6: Section of a complete precast pier

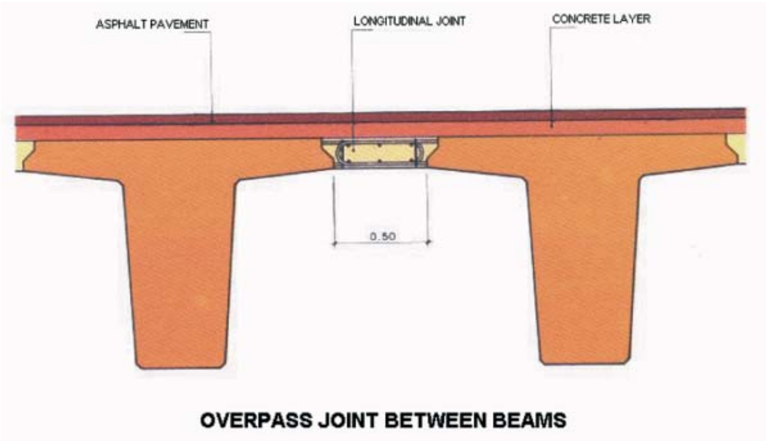

Fig. 7: Overpass joint between beams

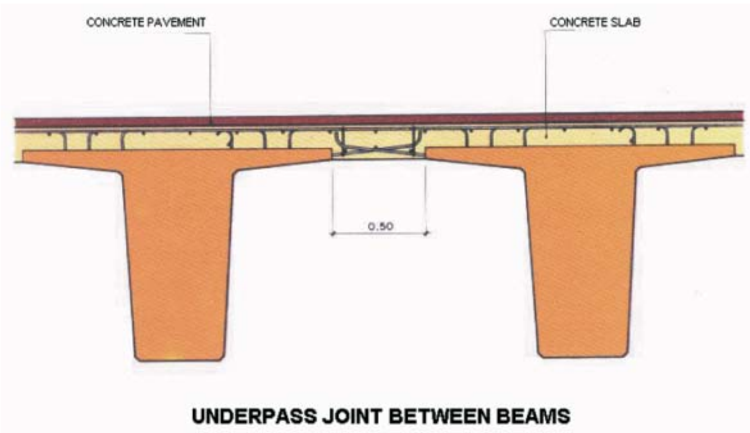

Fig. 8: Underpass joint between beams

pansion joints in the deck slabs and the guide rails were installed and the carriageway paved.

During the 1970's DRAGADOS used a similar solution to build three other toll motorways, between Tarragona and Valencia (fig. 4) and between Valencia and Alicante on the Mediterranean coast of eastern Spain and the Navarra toll motorway that crosses the region north of the Ebro River from North to South. When the new Spanish regulations on highway loads were published in 1972 which considered 60 ton heavy vehicles on these roads, the height of the beams in the main spans had to be increased from 1 m to 1.65 m. The corresponding increase in weight made it necessary to use T-beams instead of TT-beams. Furthermore, a rigid concrete pavement was used for the motorway instead of flexible asphalt. To build the precast elements for this motorway a new plant was constructed in Sagunto, 30 km north of Valencia. The elements precast there were hauled by road for the first two toll motorways. For the Navarra toll motorway, they were shipped by rail to a storage facility located near Pamplona and from there by road.

The beams for the overpasses were joined together in a way similar to that described above, although the width of the joint was increased to 50 cm. The flanges of the beams and the joints formed the deck slab (fig. 7). In the case of underpasses, the beams were precast practically without flanges as they were cast in situ forming the deck slab and the concrete pavement at the same time, with an additional thickness to take wear and repairs into account (fig. 8). Most of the piers had good ground support making it possible to use surface type foundations such as footings with a rectangular section. These had round holes in them with an upper lip into which the Raymond pile columns were inserted and then joined together. These footings as well as the abutments were built in situ.

In Castejón de Navarra, where the Navarra motorway crosses the Ebro River, a singular bridge was built with a cable stayed span 140 m long, a pylon leaning in the opposite direction and two big concrete blocks as counterweight to anchor the cables (fig. 9). The deck slab has an overall width of 29 m and is formed of a three celled central box and two lateral projecting flanges stiffened with ribs every 3.20 meters. The central cell, much narrower than the side ones, is where the 35 pairs of cables supporting the deck slab are anchored. It was built of precast segments with the 3.20 meter length of the deck slab, and in two longitudinal halves, each forming one carriageway, joining the upper and lower slabs with site cast joints running down the centre of the deck slab. Epoxy resin was applied in the joint between the segments. Like the rest of the precast elements for the motorway, they were made at the plant in Sagunto. Each new segment was concreted against the one that was to precede it in the bridge so that they would fit tightly together when installed.

The slow-down in road construction after the oil crisis in the mid-1970's, made it necessary to start using the I-beams (fig. 10) that were structurally better, weighed less and used less material. However, they did require more complicated moulds in which it was necessary to turn the sides down to remove the element being made and either a different mould was required for each beam height or supplements had to be added to increase the height. The prestressing used was straight, within the lower flanges. To reduce the prestressing force in the parts of the beam near the supports and prevent too much tensile stress in the upper flanges where the bending moments are less, strands were sheathed with rubber tubing.

Towards the middle of the 1980's, the construction of motorways with a large number of bridges increased and precasting was used massively. Contractors that built bridges in situ, realizing that their market share was declining, convinced the people at the Ministry of Public Works that bridges built of I-beams were ugly to look at when driving down these motorways and that the U-beam bridges built in situ on other toll motorways for which the construction times were longer, were much more attractive and less disturbing for drivers. This obliged the precasting companies to offer U-beam solutions. Even though the resulting precast elements were heavier and more expensive, they were acceptable as they reproduced the form of site built U-beam bridges (fig. 11). This is when the

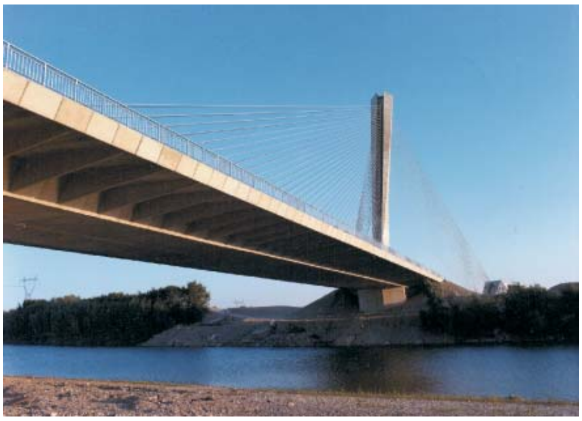

Fig. 9: Ebro bridge – Navarra motorway

Fig. 10: Precast bridge with I beams deck

Fig. 11: Precast bridge with U beams deck

Fig. 12: Precast bridges with mono-beams

Fig. 13: High Speed railway bridge with hyperstatic continuity

Fig. 14: Transport of variable height U beam

Fig. 15: Bridge with curved layout

Fig. 16: Diagonals of complex shape

Fig. 17: Piece in cantilever over the pier

mono-beam arrived on the scene, one beam that covered the entire 10 meter width of a normal bridge (fig. 12). The more economical I-beams were still used for underpasses where they were not visible to the motorway users and had no aesthetic importance. Furthermore, piers with independent columns started to be used, with or without capital or with double capital (palm piles) depending on the type of deck slab support (fig. 12).

All these solutions were also applied to railroad works, along existing routes as well as for the high speed line between Madrid and Seville built at the end of the 1980's and early 1990's. For the high speed train between Madrid and Barcelona and the rest of the network currently under construction, the railroad authority considered that in bridges formed of various spans, solutions with hyperstatic continuity between them were better than solutions with isostatic discontinuity to reduce the relative rotation between adjacent spans and vibrations that would disturb the comfort of the passengers. As a reaction to this, the precasting companies finished developing solutions for joining spans that would guarantee this continuity, whether by secondary prestressing, by reinforcement or by a combination of both (fig. 13).

In response to functional, structural and aesthetic demands of the road, railroad, city and regional authorities and private clients, the precasting companies have designed precast solutions for bridges that currently cover an extremely wide range of products. These include beams of various heights (figs. 14 & 30) with a straight or curved layout (fig. 15), flat and curving lateral and bottom sides, cantilever slabs supported by stiffening ribs or diagonal braces

Fig. 18 & 19: Bridge with spans supported on diagonals, during construction & complete

Fig. 20 & 21: Cable stayed bridge with precast concrete deck, complete & during construction

Fig. 22: Precast bridge with special shape

with a variety of complex forms (fig. 16), spans whose lengths are divided into two pieces, one in cantilever over the pier, generally of variable height (fig. 17), and the other covering the central part, generally of a constant height, although this too can be variable, spans supported on diagonals to reduce the effective span length (figs. 18 & 19), complete precast decks for cable stayed bridges (figs. 20 & 21), bridges of special shape (fig. 22), arches (fig. 23), and many more.

Fig. 23: Precast concrete arch bridge

Fig. 24: Bridge with decks of I-beams

Fig. 25: Transport of a large I-beam by road

Fig. 26: Bridge with decks of U-beams

Fig. 27: Bridge with decks of mono-beams of curved layout and variable height

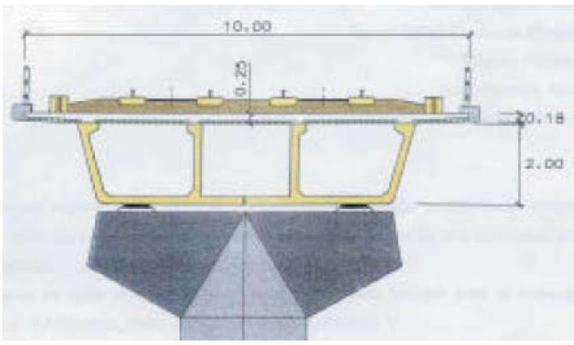

Fig. 28 & 29: U-beam for railway bridge with longitudinal joint to form a tricelular box

3 Types of precast bridge elements used in Spain

3.1 Decks built with beams

3.1.1 Decks of I-beams

The I-beam is the most widely used precast element although it is aesthetically questionable if the underside is visible from the road or in the case of urban bridges. These beams are made in heights between 0.60 and 2.50 meters, using isostatic solutions to cover spans up to 50 meters long in roads and up to 40 meters in railroads (figs. 24 & 25).

3.1.2 Decks of U-beams

These are widely used for aesthetic reasons if the underside is visible from the roadway or in urban bridges. They are made in constant heights between 0.70 m and 2.50 m, and use isostatic solutions to cover spans up to 50 m in roadways and 40 m in railroads (fig. 26). However, sometimes the height of the beam is not constant. The U-beams are also built for solutions with spans the length of which is divided into two pieces, with a cantilever over the pier, generally of variable height and another covering the central part, generally of constant height. The lateral edges and underside are generally flat but they can also be curved for aesthetic reasons.

3.1.3 Decks of monobeams (single U-beams)

This solution is an offspring of the U-beam of which it is simply a wider version. It can be used for road decks up to 10 meters wide. They can also be made with a curved layout (fig. 27).

3.1.4 Decks of U-beams with longitudinal joint to form a unicellular or multicelular box

In the case of decks that are wider or that require greater strength, multicelular U-beams can be used. They are divided longitudinally into two halves that are installed sideways and joined in situ along the upper and lower slabs (figs. 28 & 29).

3.1.5 Deck slabs of inverted T-beams

These beams are used for decks with a very short span, placed so that the lower flanges touch each other and then site concreting the space between the beams plus a specified thickness on top of the beams to form the deck slab with a constant thickness.

3.2 Deck slabs on beams

3.2.1 Slabs as non-recoverable forms between beams to built the deck slab

This is the most widely used method for concreting gaps between I-beams or U-beams and gaps between both U-beams webs. It does not allow cantilever zones extending beyond the exterior beams. The slabs are between 4 and 6 cm thick and can be reinforced or prestressed depending on the width of the gap to be covered. The deck slab is concreted in situ over these slabs in the full width after installing upper and lower reinforcing bar meshes (fig. 30).

3.2.2 Pre-slabs or semi-slabs between beams or with outer projecting zones

These slabs are thinner or equal to half the total thickness of the deck slab. They are generally reinforced, containing an embedded bottom reinforcing bar mesh. The upper reinforcement is installed in situ before concreting the rest of the slab thickness (fig. 31). If necessary there are reinforcing connectors between the two layers of concrete. They can also contain part or all of the deck's upper cross reinforcement with a truss type layout of triangular section with one upper rebar and two lower rebars. This reinforcement layout makes it possible for part of the concrete slab to extend beyond the outer edge of the outer beams. Although it is not a common solution, this arrangement has been used to reinforce transversally prestressed deck

Fig. 30: Stock of non recoverable slabs

Fig. 31: Upper reinforcement mesh placed on partially precast slabs of bridge decks

slabs with large outer cantilevers and a large separation between beams.

3.2.3 Slabs of full thickness

This solution is less common than those mentioned above. Generally, these slabs cover the total width of the deck and are used in decks supported by two I-beams or one mono-beam. The slabs are joined together by cross joints built in situ and to the beams below by means of voids left in the slabs that are concreted in situ whereby the beam connectors are situated in specific points and not distributed along the entire beam length without discontinuity (fig. 32). If they do not cover the complete width

Fig. 32 & 33: Precast deck slabs of full thickness

Fig. 34: Precast deck slabs of full thickness on steel structure (box girder & diagonals)

Fig. 35: Segment of full transversal section at the precast plant

Fig. 36: Segment of partial transversal section

Fig. 37: Segments of deck half width

of the deck, they require longitudinal joints that are more difficult to do as they affect the deck's transversal reinforcement which is much more important and dense than the longitudinal one (fig. 33).

3.2.4 Deck slabs built on steel beams

The three slab solutions indicated above can also be applied in a similar way to bridge decks with steel beams, whether I-beams or one or multiple cell box beams (fig. 34).

3.3 Decks of segments

3.3.1 Segments of full or incomplete transversal section

Depending on the width of the deck and the weight that is adequate for the means of transportation and installation to be used, the segments can be built to cover the complete deck section (fig. 35) or only that of the central box (fig. 36). In the latter case, the projecting slabs on both sides are added in situ with or without diagonals or stiffeners, both of these being elements that can also be precast.

3.3.2 Segments of full transversal section joined by the deck slab

In the case of motorways and dual highways, that is, divided roads with independent carriageways for each direction of traffic, two separate decks can be used built of segments each covering the full width of one carriageway or joined by the deck slab by a longitudinal joint concreted in situ.

3.3.3 Segments joined by the upper and lower slabs forming a unicellular or multicelular box

If the deck is very wide, a multicellular box can be used extending out on both sides. If the full section segments are too large and heavy, they can be divided into two or more parts that are later joined by longitudinal joints concreted in situ in the upper and lower slabs. A solution of this type was used for the cable stayed Castejón Bridge described above (fig. 37).

3.4. Special decks

There are precast solutions for special decks like the decks for cable stayed bridges (fig. 38).

3.5. Complete decks

This is a very special solution because of its great weight requiring exceptional means of transportation and installation. It was used in Portugal on several spans of the Vasco de Gama bridge on the toll motorway that crosses the Tagus Estuary in Lisbon. In that case, the complete spans were transported by sea and installed with large marine equipment.

In Spain, at the end of the 1990's DRAGADOS built the spans of the two approach bridges to the cable stayed bridge crossing the Oresund Straight between Copenhagen, Denmark, and Malmo, Sweden (fig. 39). This project involved 42 spans 140 meters long and 7 spans 120 meters long, with a total length of 6,754 meters. The expansion joints were located in the abutments, at the connections with the cable stayed bridge and every 6 spans. The structural section is a steel-concrete composite one. The traffic runs on two levels. The upper part, formed of a 24.8 m wide transversally prestressed concrete slab, has four normal vehicle traffic lanes

Fig. 38: Precast cable stayed bridge deck

plus two for emergency. The lower part, formed of a U-shaped steel structure with a 12 meter horizontal clearance, has two railroad lines with a service footpath at each end (fig. 43).

These complete decks, weighing up to 5,500 tons, were built in Cadiz (fig. 40) in southern Spain and shipped by sea two at a time to the installations in Malmo Harbor (fig. 41). There they were fitted with precast, reinforced concrete U-beams supported by the lower beams of the steel structure to hold the rail tracks on a ballast bed. Then they were transported to the bridge site and installed on piers by means of an enormous floating crane with a load capacity of 9000 tons (fig. 42). A 1,500 ton counterweight

Fig. 39 & 40: Oresund bridge: General view and prefabrication plan

Fig. 41 & 42: Oresund bridge: Transport by sea and installation on piers by a very big crane

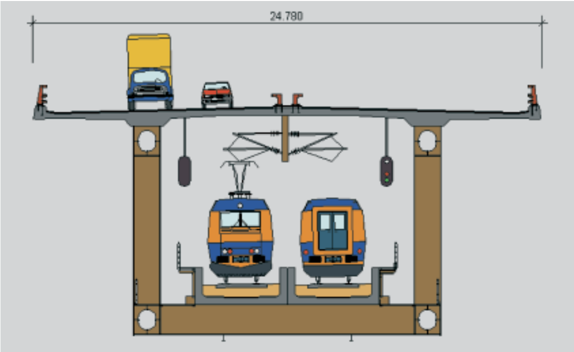

Fig. 43: Oresund bridge transversal section

Fig. 44: Abutments of cantilever counterfort elements

was built to lift them into place. This crane was used to lift the spans hanging from the 60 m central zone supported on the counterweight.

3.6. Abutments

3.6.1 Reinforced backfill abutments

These are formed of thin reinforced concrete plate elements, usually hexagonal in shape, forming the outer face of the abutment with its accompanying walls. These plates are held in place by strips, usually of steel, that are anchored within the backfill by friction forming reinforcement for it. The decks are supported by floating beams concreted in situ penetrating sufficiently into the backfill.

3.6.2 Abutments of cantilever counterfort elements

These are reinforced concrete elements. They consist of a thin vertical plate that forms the exterior wall of the abutment with its accompanying walls and that has one or two stiffening ribs on the backfill side. Reinforcing bars come out of the lower end of the stiffening ribs to anchor the elements to a footing of rectangular transversal section that is concreted in situ. The deck slabs rest on site poured rectangular beams supported by the stiffening ribs (fig. 44).

3.6.3 Gravity abutments

The gravity abutments are formed of small interconnected elements that are installed on a slope so that the backfill lateral surface will stay in place. They can be used to support vegetation on the slope. They are only used in accompanying walls.

3.6.4 Abutments of floating beam on backfill

These are described above with the almost totally precast solution used for railroad overpasses built to eliminate grade crossings. This solution is not used frequently.

3.7. Piers

3.7.1 Independent columns with or without capitals

These are generally used for overpasses or bridges that are usually no more than 10 meters high. If only one support is placed on the column and the column section is sufficient, it is not necessary to use a capital in the upper part. If two supports are needed, either in the longitudinal direction of the bridge or in the transversal direction, the capital's shape can open out like a palm tree. These columns can be of a wide variety of sections, e.g., circular, square, polygonal, etc., depending on the look the architect wants to give the bridge (figs. 45 to 47). The connection to the foundations can be done by inserting the column into a hole left in the footing and then filling the remaining gap with a non-shrinkage type cement mortar, or, more commonly, by anchoring reinforcing bars projecting from the lower face of the column by inserting them into sheathes or holes left in the footings and later filling these holes with a high adherence, high strength mortar. Another solution also used is precast crossheads installed on the upper part of a site cast one shaft pier with rectangular hollow section (fig. 48).

3.7.2 Portal frame piers formed of vertical columns and upper joining crosshead

Different solutions using Raymond piles were described above (fig.49). These portal frame piers can also be built with similar solutions involving solid section columns but varying the methods used to join the column and the pier crosshead. Sixty-five meter tall piers have been built with two columns, each divided into three

Fig. 45 to 47: Piers of independent columns with simple and double capital

Fig 48: Precast crossheads on site cast piers

Fig. 49: Frame piers with Raymond piles

21 meter long elements and with two joints and two intermediate cross elements (fig. 50). Other types of portal frame piers of reduced height and therefore of limited weight can be prefabricated in only one piece avoiding site joints between columns and crossheads (fig. 51).

<u>3.7.3 Piers built of horizontal segments</u>

Although the author knows that this solution has been used in the U.S.A., he has not heard of it being applied in any bridge in Spain.

3.8. Foundations

<u>3.8.1 Piles under site built pile cap-slab</u>

In this case any of the precast piles existing on the market can be used providing they have the required strength and the soil conditions allow them to be driven.

<u>3.8.2 Piles forming columns of portal frame piers</u>

These were discussed above with the description of Raymond pile column solutions used in various motorways.

<u>3.8.3. Footings</u>

Footings were described above when considering almost fully precast railroad overpasses built to eliminate grade crossings. This solution is not used frequently.

Fig 50: Precast bridge with piers 65 m tall

Fig. 51: Portal frame piers of reduced height prefabricated in only one piece