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Cast-in-situ box girder for Paira river extra-dosed cable stayed bridge

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Paira Bridge (Lebukhali Bridge) Construction Project, Barishal, Bangladesh

PROJECT BACKGROUND: The Government of Bangladesh (GOB) has embarked for significant development of the southern region of Bangladesh including Barishal, Patuakhali and the coastal Kuakata tourist area. Together with new under construction Paira seaport at Patuakhali, the region is expected to have significant industrial development and improvement of standards in the coming years. The Paira (Lebukhali) bridge project forms an integral infrastructure link to this development, and by replacing the existing ferry, service with a fixed bridge river crossing the traffic flow will enhance at this focal point of the region. Kuakata, one of the major Tourist spots of Bangladesh is located about 287km away from capital city Dhaka and is connected with the capital through the National Highway (N8) i.e. Dhaka-Mawa-Bhanga-Barishal-Patuakhali. Currently massive development work is taking place in this region under different ministry of Bangladesh focusing the national development plan. At Lebukhali ferry Gat 189th Km of this National Highway (N8) i.e.26th km of Barishal-Patuakhali Road, a ferry service is being maintained by Roads and Highways Department (RHD) on the river Paira. The construction of Paira Bridge over the river Paira at Lebukhali location will ensure a smooth transportation link to other parts of Southern region of Bangladesh and to Paira Sea Port as well as Kuakata. This will aid and promote the connectivity for entire southern region of Bangladesh. The Paira (Lebukhali) Bridge project is situated in the South-Central Region (SCR, WARPO August 2000) on N8 Highway lying between Barishal and Patuakhali Districts located at 26Km of Barisal-Patuakhali Road. The exact location of the Bridge is at the cross point of 22° 28’ 89.11” N Latitude and 90° 19 49.34” E Longitude as shown in the map below. The N8 Highway approaches in north-south direction to Kuakata beach site. The landscape is level with low gradient towards south that is at places intersected by tidal rivers and channels. Temporary / Semi permanent houses over low man-made platforms in clusters are prevalent over the entire area.

1 INTRODUCTION

The continuing expansion of highway network throughout the world is largely the result of great increase in traffic, population and extensive growth of metropolitan urban areas. This expansion has led to many changes in the use and development of various kinds of bridges. The bridge type is related to providing maximum efficiency of use of material and construction technique, for particular span, and applications. As Span increases, dead load is an important increasing factor. To reduce the dead load, unnecessary material, which is not utilized to its full capacity, is removed out of section, this Results in the shape of box girder or cellular structures, depending upon whether the shear deformations can be neglected or not. Span range is more for box bridge girder as compare to T-beam Girder Bridge resulting in comparatively lesser number of piers for the same valley width and hence results in economy. A box girder is formed when two web plates are joined by a common flange at both the top and the bottom. The closed cell which is formed has a much greater torsional stiffness and strength than an open section and it is this feature which is the usual reason for choosing a box girder configuration. Box girders are rarely used in buildings (box columns are sometimes used but these are axially loaded rather than in loaded in bending). They may be used in special circumstances, such as when loads are carried eccentrically to the beam axis “When tension flanges of longitudinal girders are connected together, the resulting structure is called a box girder bridge”. Box girders can be universally applied from the point of view of load carrying, to their indifference as to whether the bending moments are positive or negative and to their torsional stiffness; from the point of view of economy.

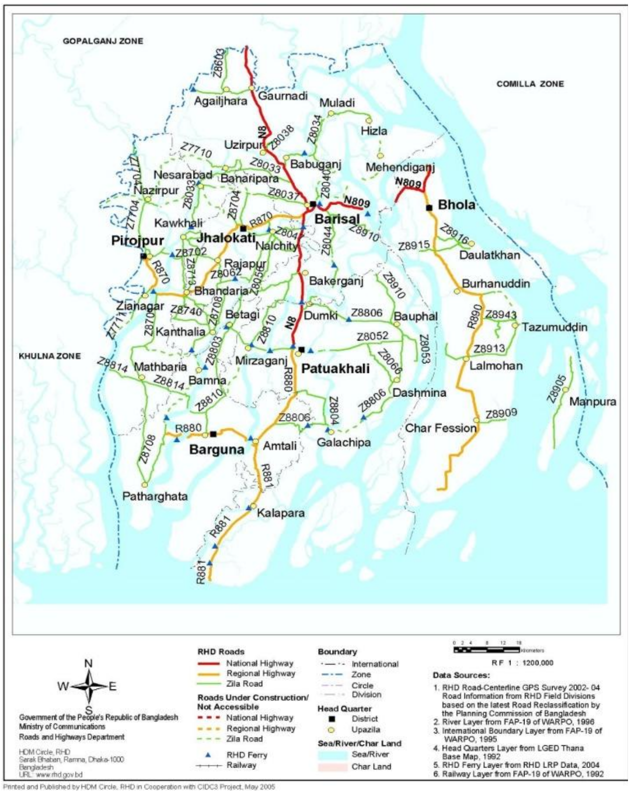


Figure 1. Bridge location.

Figure 2. Project location map.

Historical development and description: The first box girder cross section possessed deck slabs that cantilevered out only slightly from the box portion. With the prestressed concrete the length of cantilever could be increased. The high form work costs caused a reduction in the number of cells. In order to reduce the construction loads to minimum possible extent or to require only one longitudinal girder in working states even with multiple traffic lanes. It was only with the development of high strength prestressing steel that it became possible to span longer distances. The first prestressed concrete bridges, most of I-cross sections were built towards the end of the 1920's.The great breakthrough was achieved only after 1945. "THE SCLAYN" bridge over the river Maas, which was built by Magnel in 1948, was the first continuous prestressed concrete box-girder bridge with 2 spans of 62.70m. In following years the ratio of wages to material costs climbed sharply. This thereby shifted the emphasis of development of construction method. The box girder cross-section evolved structurally from the hollow cell-deck bridge or T-beam Bridge. The widening of the compression zone that began as a structural requirement at the central piers was in the extended throughout the entire length of bridge because of advantages transverse load-carrying characteristics.

Evolution: The spanning of bridges started with simple slabs. As the spans increased, the design depth of slab is also increased. It is known that material near centre of gravity contributes very little for flexure and hence can be removed. This leads to beam and slab systems. The reinforcement in bottom bulb of beam provided capacity for tensile forces and top slab concrete, the capacity to resist the compression. They formed a couple to resist flexure. As the width of slab is increased more number of longitudinal girders are required resulting in reduction of stiffness of beams in transverse direction and relatively high transverse curvature. The webs of beams get opened out spreading radially from top slab. Under high transverse bending these will no longer be in their original position. To keep it in their original position the bulbs at bottom should be tied together which in-turn leads to evolution of box girder. Long spans with wider decks and eccentric loading on cross-section will suffer in curvature in longitudinal and transverse direction causing heavy distortion of cross-section. Hence the bridges should have high torsional rigidity in order to resist the distortion of cross-section deck to a minimum. Accordingly box girders are more suitable for larger spans and wider decks, box girders are to be suitable cross-section. They are elegant and slender. Economy and aesthetics further lead to evolution of cantilevers in top flanges and inclined webs in external cells of box girder. The dimension of cell could be controlled by prestressing. As the span and width increases the beams and bottom slabs are to be tied to keep the geometry which in turn leads to evolution box girder. Any eccentric load will cause high torsional stresses which will be counter acted by the box section. The analysis of such sections are more complicated due combination of flexure, shear, torsion, distortion. But it is more efficient cross-section. It is used for larger spans with wide cross section. It can be used for spans up to 150m depending upon the construction methods. Cantilever method of construction is preferred most.

Advantages Associated with Box Girders:

- In recent years, single or multi-cell reinforced concrete box Girder Bridge have been proposed and widely used as economic aesthetic solution for the over crossings, under crossings, grade separation structures and viaducts found in modern highway system.
- The very large Torsional rigidity of the box girder‘s closed cellular section provides structures beneath is more aesthetically pleasing than open-web type system.
- In case of long span bridges, large width of deck is available to accommodate prestressing cables at bottom flange level.
- Interiors of box girder bridges can be used to accommodate service such as gas pipes, water mains etc.
- For large spans, bottom flange could be used as another deck accommodates traffic also.
- The maintenance of box girder is easier in interior space is directly accessible without use of scaffolding.
- Alternatively space is hermetically sealed and enclosed air may be dried to provide a non-corrosive atmosphere.
- It has high structural efficiency which minimizes the prestessing force required to resist a given bending moment, and its great Torsional strength with the capacity this gives to re-centre eccentric live loads, minimizing the prestress required to carry them.

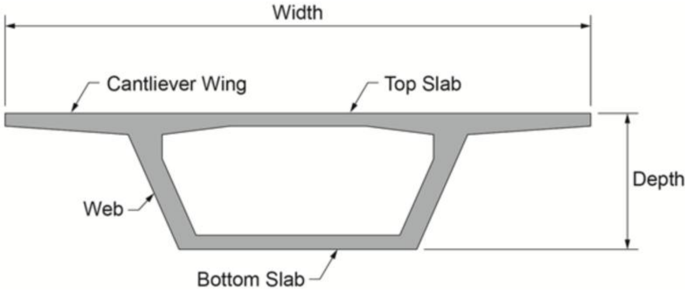


Figure 3. Single cell box girder.

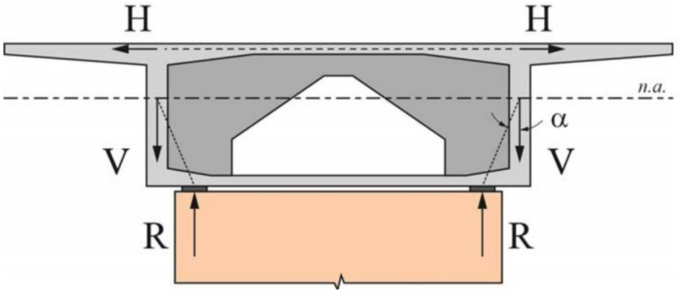


Figure 4. Eccentric web/bearing orientation.

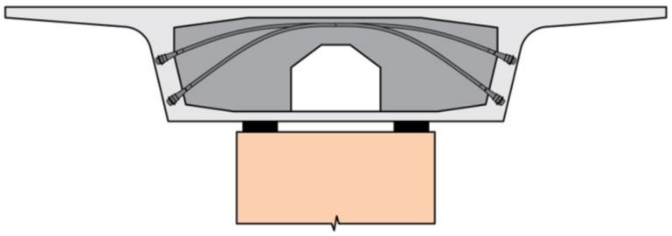


Figure 5. Transverse post-tensioning in diaphragms.

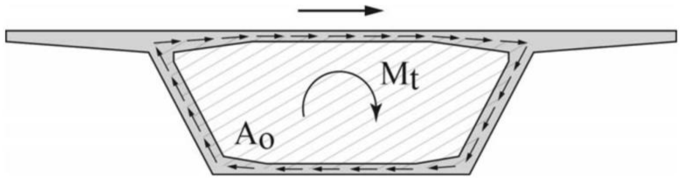


Figure 6. Shear flow resulting from torsional moments.

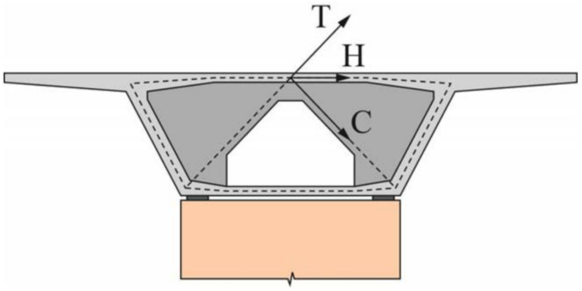


Figure 7. A shaped torsion diaphragm.

Disadvantages: One of the main disadvantages of box decks is that they are difficult to cast in-situ due to the inaccessibility of the bottom slab and the need to extract the internal shutter. Either the box has to be designed so that the entire cross section may be cast in one continuous pour, or the cross section has to be cast in stages.

The Paira bridge is having a length of 1470 mts with 840 mts of viaduct portion and extra dosed cable stay main bridge of length of 630 mts. Span Length 630 mts is further divided in 400 mts continuous span and 2x115 mts transition span. The viaduct is simply supported span with I- Girders and Main bridge consists of

Single Cell Box Girder Bridge construction methodology includes Cast-in-Situ method with Balanced Cantilever Form Traveler Movement.

Single cell box-girder cast-in-situ are used for spans form 40m to 270m.The box arrangement is done in order to give aesthetic appearance where the web of box will act as a slender appearance when combined with a slim parapet profile. Single box arrangements are efficient for both the longitudinal and transverse designs, and they produce an economic solution for mot medium and long span structures. This type of deck is constructed span-by-span, using full-height scaffolding or trusses, or as balanced cantilever using form travelers.

There are about 3-Sets of Form Travelers used to construct the balanced cantilever cast-in-situ box girder at 3 – Pylon locations of approximate height of 25 mts below and above deck level. Below the Deck Pylon consists of 4 Nos. Circular Battered piers supporting a Pier head which provides a plat form for the Spherical Bearings and further supporting Pier table which forms a part of the deck as well. The concept is Single Cell Box Girder Transfer of vertical shear to Bearings. Using the diaphragm to transfer vertical forces, the bearing spacing may be reduced and the width of the pier cap greatly reduced. This narrowing of the pier cap provides significant cost reduction and can greatly enhance aesthetics. By the use of strut and tie modeling, the horizontal forces developed by the eccentricity of the web to the bearing is computed. Though occurring over some depth of the box girder, the transverse reinforcing or post tensioning used to resist the horizontal forces is typically placed near the top of the diaphragm, detailed to fully develop the width of the webs.

2 BEHAVIOUR OF BOX GIRDER BRIDGES

A general loading on a box girder, for single cell box, has components which bend, twist, and deform the cross section. Thin walled closed section girders are so stiff and strong in torsion that the designer might assume, after computations based on the elemental torsional theory, that the torsional component of loading has negligible influence on box girder response. If the torsional component of the loading is applied as shears on the plate elements that are in proportion to torsion shear flows, the section is twisted without deformation of the cross section. The resulting longitudinal warping stresses are small, and no transverse flexural distortion stresses are induced. However, if the torsional loading is applied there are also forces acting on the plate elements which tend to deform the cross section.

Torsional moments along a span are transferred to the substructure at the bearings. The shear flow in the top slab caused by the torsional moment reaction produces horizontal force in the top slab as shown above.

Diaphragms located at the piers are to be detailed to resist the horizontal force in the top slab and maintain the integrity of the transverse cross section of the superstructure such as A-Shaped Diaphragm which resists torsion, shown below.

Torsion: The main reason for box section being more efficient is that for eccentrically placed live loads on the deck slabs, the distribution of longitudinal flexural stresses across the section remains more or less identical to that produced by symmetrical transverse loading. In other words, the high torsional strength of the box section makes it very suitable for long span bridges. Investigations have shown that the box girders subjected to torsion undergo deformation or distortion of the section, giving rise to transverse as well as longitudinal stresses.

3 CONSTRUCTIONS AND GENERAL ARANGEMENT OF BOX GIRDER

General arrangement: The deck arrangement is similar to a voided slab, but with the voids occupying a larger proportion of deck area and usually being rectangular in section. The outer webs are often sloped and side cantilevers made longer to improve the appearance. The web thickness is governed by the shear requirements, but they must be wide enough to provide space for reinforcement and concrete to be placed around prestressing ducts. This usually requires a minimum web thickness of 300mm, but may be wider if larger tendons are used. The deck slab size is governed by web spacing and live load carried and is typically between 150mm and 200mm being sufficient. Transverse diaphragms are provided across the full width of the box at each of the support locations. The diaphragms provide rigidity to the box assist in transferring the loads in the webs to the supports. Intermediate diaphragms are often placed at ¼ or 1/3 points along the span to stiffen up the box and to help distribute the loading between the webs. Access into box cells is achieved through soffit access holes of a minimum of 600mm diameter, and is located near the abutments. Similar sized holes are provided through each of diaphragms and webs, as required to give access into each section of deck. Small drainage holes, typically 50mm diameter, are provided through bottom slab at the low point in each section of deck to ensure that water cannot collect inside box cells. Concreting and construction restraints dictate a minimum deck depth of 1200mm; although for reasonable inspection and maintenance access a depth of at least

1800mm is needed. With an optimum span –to-depth ratio of between 18:1 and 25:1 the preferred span lengths are usually greater than 30m. Multi-strand tendons are used following a draped profile, and are located in the bottom of the webs in the mid span and at the top of webs over the supports. For decks with a overall length less than 80m and fully cast before applying prestress, the tendons would usually extend over the full deck length and be anchored on the end diaphragms. Longer decks are cast in stages on span-by-span basis, with the prestress tendons anchored on the webs at the construction joint. The tendons are then continued into next stage of deck by using couplers.

The Deck is constructed sequentially with the movement of the form traveler as balanced cantilever and post tensioned in stages after every casting length of the deck.

Post tensioning tendon forces are established in design to provide pre-compression to compensate for the undesirable tensile stresses in the box girder. The designer provides the required tendon force. The difference between jacking forces and the effective forces are termed as prestressing force losses. These losses are of two types as mentioned below.

Loss Related to material Properties:
- Elastic shortening of concrete.
- Shrinkage of concrete.
- Creep of concrete.
- Relaxation of Prestressing steel.

Loss related to Physical Properties:
- Duct friction due to curvature.
- Wobble friction.

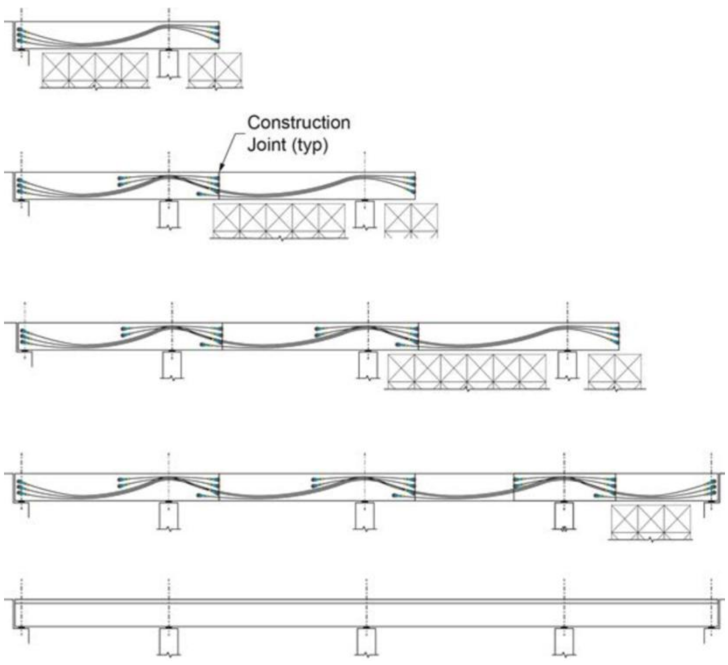
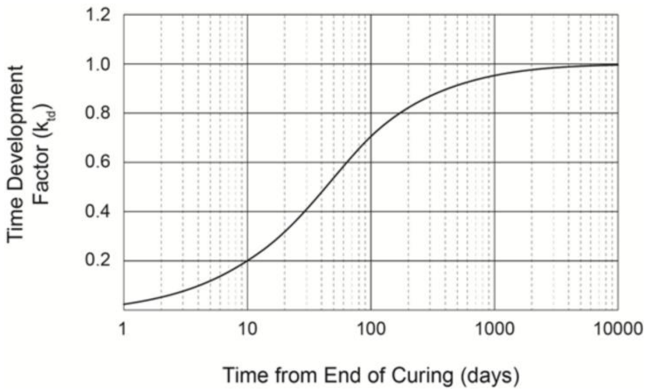


Figure 8. Tendon layout for sequentially cast spans.



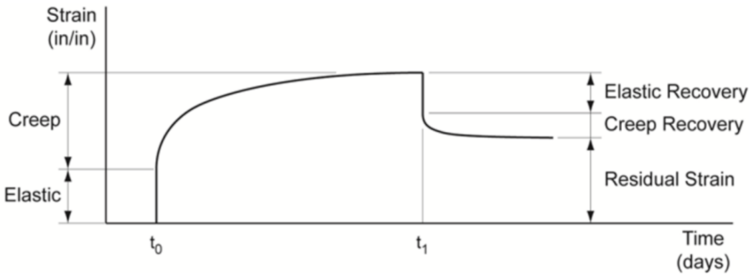


Figure 9. Rate of shrinkage over time.

Figure 10. Creep of concrete.

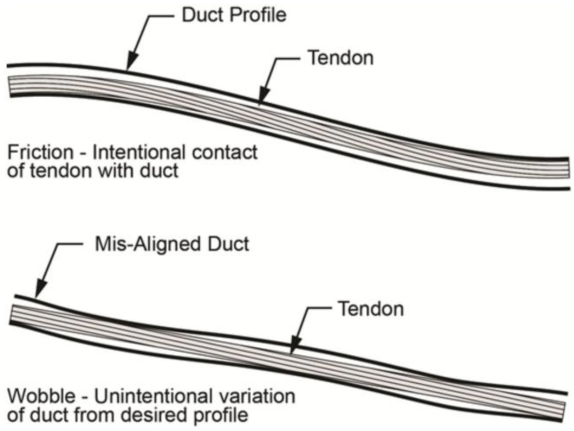


Figure 11. Friction and wobble.

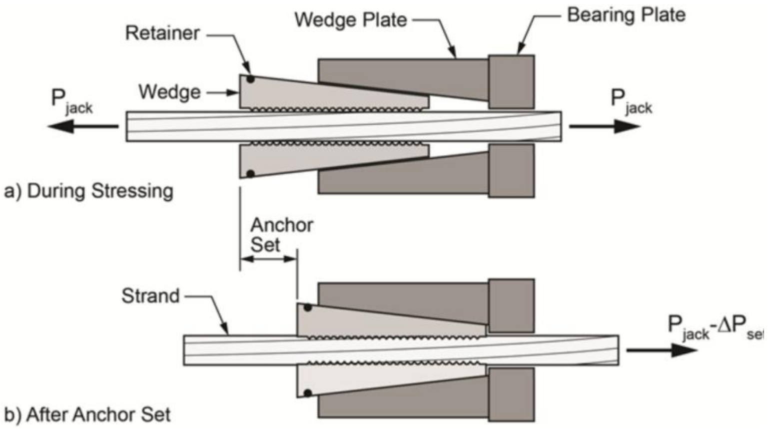


Figure 12. Wedge set.

4 CONSTRUCTION OF CAST- IN SITU SINGLE CELL BOX GIRDER

Casting the cross section in one pour with wide bottom slab cast through trunking, Narrow bottom slab with concrete cast down webs. There are two approaches to cast a box section in one pour. The bottom slab may be cast first with the help of trunking passing through temporary holes left in the soffit form of top slab. This requires laborers to spread and vibrate the concrete, generally possible for decks that are at least two meters deep. The casting of webs must follow closely, so that cold joints are avoided. The fluidity of the concrete needs to be designed such that the concrete will not slump out of the webs. This is assisted if there is a strip of top shutter to bottom slab about 500mm wide along web. This method of construction is most suitable for boxes with relatively narrow bottom flanges. The compaction of bottom slab concrete needs to be effected by external vibrates, which impels the use of steel shutters. The concrete may be cast down both webs, with inspection holes in the shutter that allow air to be expelled and the complete filling bottom slab to be confirmed. Alternatively, concrete may be cast down first with the second web being cast only when concrete appears at its base, demonstrating that the bottom slab is full. The concrete mix design is critical and full-scale trials representing both the geometry of the cross section and density of reinforcement and prestress cables are essential. However, the section is cast, the core shutter must be dismantled and removed through a hole in the top slab, or made collapsible so it may be withdrawn longitudinally through the pier diaphragm. Despite these difficulties, casting the section in one pour is under-used. The recent development of self-compacting concrete could revolutionize the construction of decks in this manner.

During concreting of deck slab the level and finishing of the top surface has to be carefully controlled. The deck is suspended with 2-PLANE each 6 Nos extra dosed cables of 91 strands of 15.2mm dia having a five layer protection namely Epoxy coating, Grease Filling, HDPE and finally encased with Two-Layered outer casing.

5 LONGITUDINAL PRESTRESS

Each cable consists of 15.2 mm dia. 7-ply class 2 Low relaxation strands as per ASTM A416 and has an area of 140 mm2. The properties as given by the manufacturer are as follows.

1. Ultimate tensile strength = 18960 kg/cm^2
2. Breaking strength of cable = 2245.62 kN
3. Anchorage slip at stressing = 6mm
4. All cables are used with hdpe of 75mm ID= 0.25 K = 0.0046/m
5. Allowable force in 27T15 cables at stressing end before anchorage = 1718 kN

6 DESIGN DATA

Effective Span (c/c of bearings) = 19.500 m
Length of girder = 20.400 m
Length of deck slab at top = 20.960 m
Carriage way width = 7.500 m

Width of footpath = 1.500 m
Width of Kerb = 0.325 m
Depth of kerb = 0.275 m
Height of parapet wall = 1.800 m
Thickness of parapet wall = 0.275 m
avg. Thickness of wearing coat = 0.075 m
Thickness of Vertical ribs at mid span = 0.300 m
Thickness of vertical ribs at support = 0.450 m
Thickness of intermediate diaphragm = 0.300 m
Thickness of end diaphragm = 0.450 m
Width of box girder at mid span = 6.600 m
Width of box girder at support = 6.750 m
Width of deck slab = 11.050 m
Depth of box girder = 2.000 m
Thickness of deck slab = 0.220 m
Thickness of cantilever slab at support = 0.350 m
Thickness of cantilever slab at tip = 0.220 m
Thickness of soffit slab at mid span = 0.300 m
Thickness of soffit slab at support = 0.450 m
Haunches at top at mid span = 0.30 m = 0.150 m
Bottom haunches at mid span = 0.30 m = 0.150 m
Top haunches at support = 0.15 m = 0.075 m
Unit weight of concrete = 25.00 KN/ m^3

The concrete grade used in the casting of Box Girder at Paira Bridge is C-60, with an Target Mean strength of 83 MPa. The coarse aggregates used are 19mm and down size. The concrete ingredients consist of Flyash, Microsilica in addition to the regular materials.

7 PRESTRESSING COMPONENTS

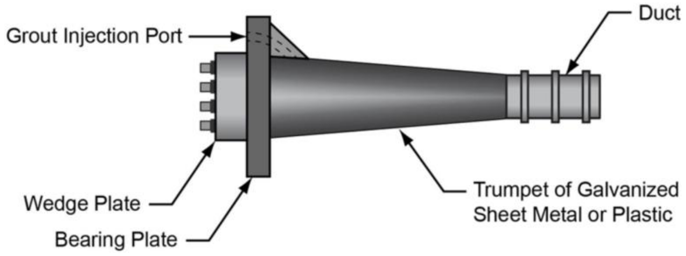


Figure 13. Basic bearing plate anchorage system.

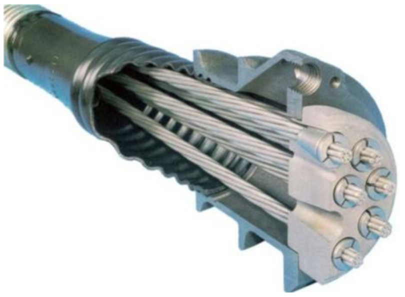


Figure 14. Multiplane anchorage system.

Figure 15. Flat anchorage system for deck prestressing.

Figure 16. Corrugated plastic ducts.

8 BEARINGS

Spherical bearing capacity: 36500 kN
Seismic transmission unit: 140 mm STROKE

The box girder can also have variable depth to better withstand the bending moments in long spans and increase navigation clearance beneath the bridge. For wider bridges an increased number of boxes and webs may be used in the bridge superstructure.

New methods of superstructure erection were invented. In the meantime, advancement had also taken place in bridge construction. The twentieth century finally saw two major innovations in bridge design and construction. Reinforced concrete gave the bridge engineers a most versatile construction material at hand that could be cast into literally any shape, only limited by laws of nature and the imagination of the designer. Incorporating prestressing steel into the concrete superstructures and making use of precast or cast-in-place segmental construction contributed much to the overall economy of concrete bridge spans in comparison with steel structures. With growing span lengths, the weight of concrete superstructures increases very much and steel girders become more economical. Secondly, the new type of cable-stayed bridges appeared in the second half of the twentieth century and quickly established itself as a very economical and aesthetically satisfying member of the bridge family. It is certain that technological advancement will continue to influence the ways in which bridges are designed and constructed. New structural concepts in connection with improved or newly engineered materials offer a wide range of possibilities for future bridges. The further design process will comprise many drafts and revisions until a feasible design has been produced. Constructability issues need to be included from a very early stage on to ensure that the bridge can be built in a safe and economical manner. In the beginning the dimensions of structural members will be chosen mostly based on the designer’s experience, in later stages engineering software is then employed to compare alternatives and optimize member dimensions. Finally, complete analytical calculations for all important construction stages and detailed shop drawings will be produced. As mentioned above, aesthetics is considered one of the four main functions of bridges. Several so-called aesthetic values of bridge structures are identified. These are character and function, proportions and harmony, complexity and order, color and texture, and environmental scale. It is the composition of all of these values together that makes a bridge become accepted by the general public as an appealing structure. With respect to the bridge site itself, several influencing factors are identified. Soil conditions, topography, the river crossing, protection of the environment, and the local climate are the main environmental influences. Furthermore, technical factors such as bridge type and erection method, labor-related factors, and the particular needs of the owner need to be considered by the designer. All aforementioned factors should have been considered in designing the bridge before structural analysis is begun. Analysis of the structural system generally makes use of a variety of simplifying assumptions. The four main elements of a structure – its geometry and boundary conditions, structural details such as bearings and expansion joints, material properties, and actions affecting the structure, i.e. loads or restraints on deformations are modeled mathematically. An adequate factor of safety will have to be incorporated to account for any uncertainties on the load and resistance sides of structural equations. Designing with redundancy against structural failure increases the overall safety of the bridge. Both Ultimate Limit States and Serviceability Limit States need to be examined during structural analysis. Any numerical results produced by engineering software need to be checked for consistency and accuracy of results. Finally, the results need to be interpreted by the structural engineer to apply them to the real structure. Issues pertaining to cast-in-place segmental cantilever construction are dealt. Cantilevering the bridge superstructure subsequently with cast-in-place segments requires consideration of different segment ages and time-dependent material properties. Major points in time for structural analysis are the end of construction and the state of ‘infinity’. Furthermore, the stepwise changes in the overall structural system until continuity is achieved need to be considered. Interaction between these issues makes cast-in-place cantilevering a challenging task. Usually newly added segments are stressed to their predecessors when they have reached only a specific portion of the 28-day compressive strength of the concrete. Young concrete that is loaded is susceptible to increased time-dependent effects that depend on ambient conditions, i.e. concrete shrinkage and creep that can cause losses of prestressing forces in the post-tensioning tendons. Further losses are incurred immediately at the time of stressing e.g. through elastic shortening of the segment and in the long run through relaxation of the steel tendons themselves. After continuity is achieved in the structural system redistribution of bending moments takes place, effectively shifting moments from the supports more towards midspan. Thus internal forces change and influence the further development of time-dependent effects. Furthermore, movements or rotations of the bridge substructure can impose additional forces, which would not have been the case in the statically determinate cantilever system before continuity was achieved. Structural analysis needs to thoroughly incorporate the outlined effects and their interactions in modeling of the structural system and its construction stages. Cambering the superstructure by the anticipated overall deflections will ensure proper long-term alignment of the bridge. Cast-in-place cantilever construction is technically feasible for span length up to more than 250 m. Form travelers are employed at the tip of the cantilever to place the concrete. These travelers remain in place until the concrete has cured sufficiently to achieve minimum strength for posttensioning. Another factor determining the minimum casting cycle time is the speed with which the form travelers can be adjusted to possibly changing segment geometry, reinforcement can be installed, and concrete can be placed. The aforementioned time-dependent effects in the concrete segments occur to an increased extent in cast-in-place segments in comparison with prefabricated segments. A very common type of concrete bridge superstructures is the box girder. Box girders consist of a top slab, usually with cantilevering flanges, webs, and a bottom slab. They have several distinct advantages when used in medium-span to long-span bridges. They are extremely versatile and can be adjusted to a great number of different superstructure alignments as required by the topography of the bridge site. Width can easily be adjusted by varying the width of the cantilevering flanges of the top slab without affecting the main box girder itself. Their simple beam-type structural system incorporates all structural load-carrying elements below the bridge deck and is aesthetically pleasing through its clear, smooth lines. The box girder can also have variable depth to better withstand the bending moments in long spans and increase navigation clearance beneath the bridge. For wider bridges an increased number of boxes and webs may be used in the bridge superstructure. In any case, box girders with their closed cross-section have a high torsional stiffness that allows relatively long prestressed spans. Box girders facilitate prestressing operations and maintenance works because elements such as tendon anchorages are accessible from within the bridge superstructure.

Modern concrete segmental bridges are prestressed structures in which the posttensioning tendons provide enough built-in moment resistance to withstand dead loads and live loads on the long and slender spans. In most cases post-tensioning is employed, i.e. the prestressing tendons are stressed with hydraulic jacks after the concrete has been placed and cured. Usually the tendons are located in steel/plastic ducts within the concrete and are anchored in special anchorages. Cantilevering can be carried out in two different fashions. In case the cantilever system consists of two arms on both sides of a pier support it is called Balanced Cantilever Construction as the cantilever arms balance each other with their respective weight in a scales-like fashion. The second type of cantilevering is the Progressive Placement Method, in which only one cantilever arm is growing from its pier or abutment. Usually the superstructure is then supported by overhead stay cables that are attached to a temporary tower or by temporary towers under the superstructure. Cantilevering has the important advantage of being an erection method with which the valley that is crossed is widely left unobstructed by the construction process. The repetitive nature of segmental construction, either with cast-in-place or as precast segments can be used very advantageously in cantilevering. Once cantilevering is finished the closure segments are placed between the cantilever arms to form a continuous superstructure. Special construction equipment is employed in cast-in-place cantilevering. So-called form travelers made of steel framework are attached to the cantilever tip where they carry the formwork in which new segments are cast. After a newly cast segment has gained strength it is stressed to the already existing part of the superstructure and the form traveler is advanced and adjusted for the next segment. Maximum segment length achieved with form travelers is about 5.00 m.