Foundations of Zarate-Brazo Largo Bridges

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Foundations of Zarate-Brazo Largo Bridges

Les fondations des ponts Zarate-Brazo Largo

Die Gründung der Zarate-Brazo Largo Brücken

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1 - Introduction

The Zárate-Brazo Largo Highway-Railway Complex, now under construction, will permit the crossing of the Paraná River at about 80 km North of Buenos Aires City. At present this crossing is made using rafts and ferry-boats, and these bridges will permit a great saving in time and cost, not only for the Argentine interprovincial traffic but also for the international traffic with Uruguay and Brasil.

At this point, the Paraná River is divided in two branches, each navigated by ocean going ships. The Complex is, then, formed by two identical bridges with a free span and clearance of 300 m x 45 m respectively. The bridges' decks support one railroad and one four lanes highway.

Each bridge is 550 m long, with a central span of 330 m and two lateral spans of 110 m each. Both are cable-stayed bridges with cables fanning out from the top of the 120 m high towers. These towers, as well as the two anchorage pier, are of reinforced concrete hollow rectangular section. The deck is of high resistance steel, and is formed by two lateral box girders and plate deck, suitably stiffened and covered with a reinforced concrete pavement.

2 - Description of Foundations

Both bridges' main piers (towers) and the two anchorage piers of one of them are on the river bed. The other two anchorage piers, and almost every access viaduct pier, are on the flood bed of the Paraná River.

The soil over the entire width of the river flood bed is formed by alluvial deposits of great depth. The upper layers show lime and soft clay. At different depths there are some half consolidated clay layers, sand layers, and finally very thick dense sand layers. These dense sand layers can take the loads transmitted by the piers. The upper part of these sand layers is at depths ranging between 20 and 50 m.

Consequently, all piers were founded on big diameter piles. Two-meter diameter cast in place piles were used, with steel casing when built in water, and without steel casing when built on land.

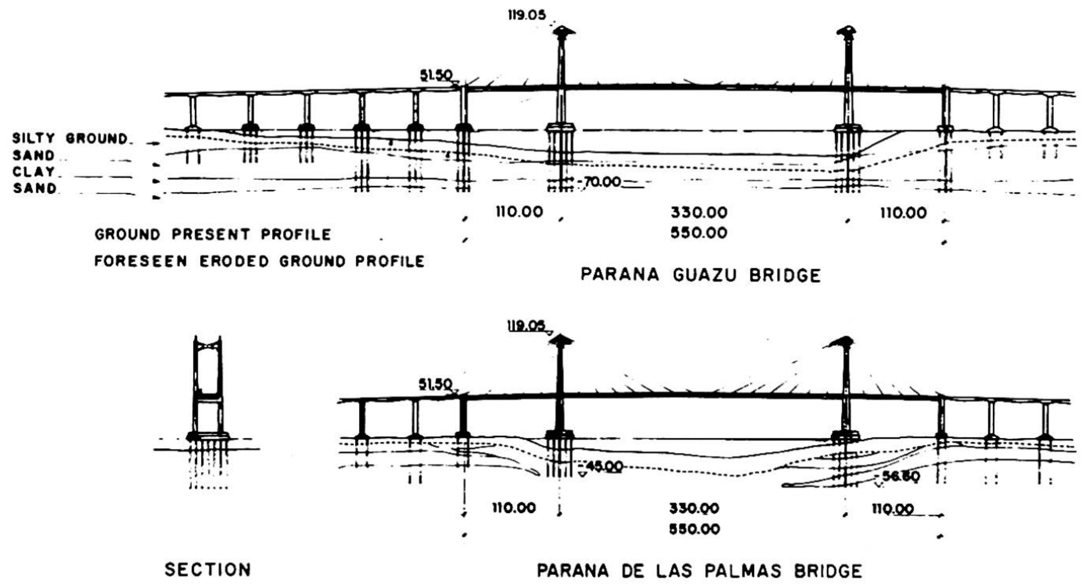

Fig. 1 - Bridges lateral views and geological profiles

The piles' length was determined by the need of entering a minimum of 5 m in dense sands. Also the eventual future modifications of the river beds due to erosion phenomena both general and around the piles, have to be taken into account in said determination. Thus, pile length varied between 25 and 73 m.

Parallelepiped pile caps, lightened by hollows, join the piles. These pile caps are built over the water level. Preformed slabs hang from their lower edge and sink some centimeters into the water for aesthetic reasons.

Based on the soil characteristics and taking into account load transmission by the tip and lateral friction, the maximum allowable vertical load for piles in water was established at 1200 tons plus the pile weight.

A simple arrangement was adopted for the plant distribution of piles. They were lined up in both directions, separated by a distance practically the same as the minimum advised (three times the pile diameter). Because of the different water depth in both rivers, now and even more in the eventual future situation of an eroded bed, a greater number of piles was needed for the Paraná Guazú than for the Paraná de las Palmas. Because of its greater slenderness and greater bending moments due to horizontal loads, the maximum allowable vertical load on the pile head had to be reduced in the Paraná Guazú piles to 1000 tons.

For the Paraná Guazú main piers, 45 piles and one parallelepiped pile cap were adopted. The pile cap has a plant of 30 m x 59 m, and a thickness of 5,50 m and is lightened by hollows in the less stressed areas. The concrete volume for this cap was 8,300 m3, reinforced with 1,100 tons of high strength steel.

For the Paraná de las Palmas, 33 piles and one pile cap, with an "I" type plant of 30 m x 45 m and a thickness of 5,50 m, also lightened, were adopted. The concrete volume was 6050 m3, reinforced with 860 tons of high strength steel.

3 Pile-caps Calculations

Pile cap as a whole is a thick slab bearing on a series of point supports. The load on this slab is applied on rectangular areas noticeably smaller than the slab's dimensions. This slab is lightened by cubic holes in areas far from the load application area. Thus, it might be considered as a grid, supported on every point of girder crossing. However, the girders are joined by very thick slabs, in their upper and lower parts, which increase the grid stiffness considerably.

Hence, we performed a double calculation following two different approaches:

The first one was to use a grid model, solving it by STRUDL. Loads on piles and values for bending moments and shear forces on the different members were thus obtained and the necessary reinforcing steel sections for the different parts of the pile cap was determined.

The second approach was to try to follow the stress paths into the mass of pile cap accepting the same loads on piles as obtained by the first procedure. Concrete stresses were verified and the necessary steel sections for tensioned members were determined. These were compared with those steel sections calculated before, and the bigger one was selected in each case.

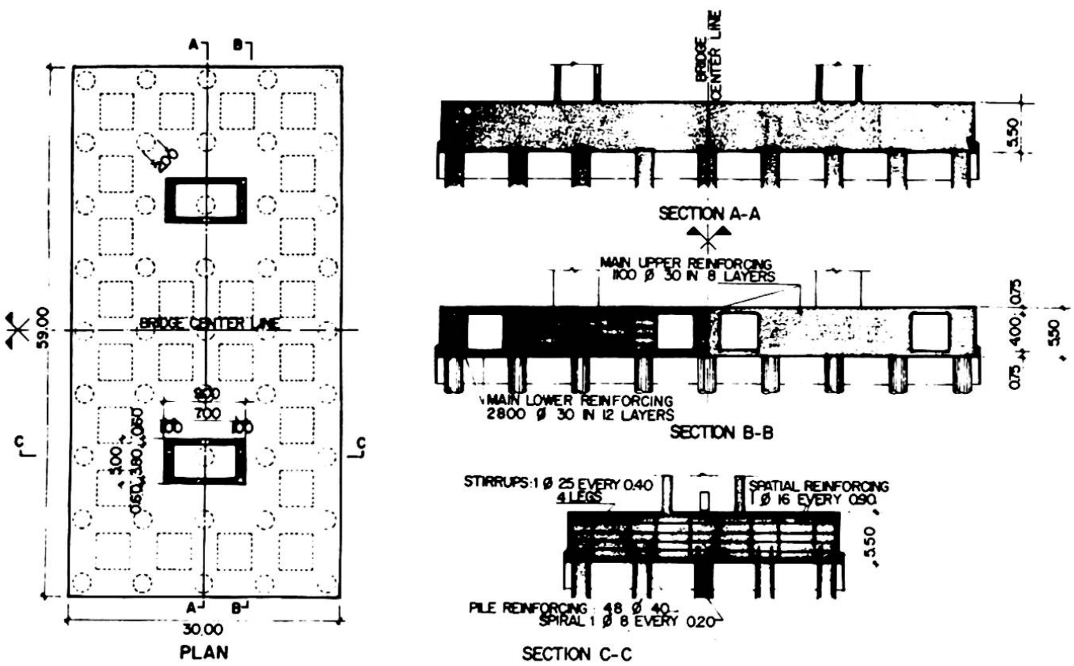

Fig. 2 - Paraná Guazú Main Piers Pile Caps

4 - Piles Calculations

Two questions arose from the beginning of the project regarding dimensioning and verification of piles in water:

a) How to determine the actual pile embedding into the soil, in order to establish buckling length and bending due to horizontal loads.

b) How to consider the pile cross section to take into account steel casing.

Because of scheduling it was impossible to perform horizontal load test in time to use its results for design. Thus, the Winkler elastic model of the pile-soil system was adopted. More sophisticated models, i.e. considering the pile as an elastic element sunk into a semi-infinite elastic medium, or taking into account the soil plasticity and viscosity were discarded due to the lack of enough experimental data.

According to the adopted model, it is acceptable to consider soil horizontal reaction P, at a certain depth x, proportional to the horizontal displacement of this point of the pile, that is: $P = Es \cdot y$

Factor Es is the soil reaction module, which generally varies with depth. Taking into account soil characteristics, it was decided to adopt a parabolic relationship, as follows: $Es = 50 \sqrt{z}$ (z expressed in cm; Es in kg/cm2).

Once the supposed elastic fixing characteristics were thus defined, the solution of the structural problem could be obtained replacing this elastic fixing by a rigid fixing at a certain depth $\Delta \ell$ below the soil level. To obtain this depth, we calculated the length of a pile rigidly fixed at both ends, with the same cross section as the actual pile, which under an horizontal load on its head will deflect the same as the pile perfectly fixed in the pile cap and elastically fixed in the soil would do. In this case, we obtained $\Delta \ell = 7.00$ m.

As for the second question, the problem was to decide if the structural member obtained by filling a steel tube with concrete can or cannot be considered equivalent to a reinforced concrete column.

Several publications mention theoretical studies and test made about this problem. However, there is still no complete treatment which allows the establishment of dimensioning rules, which could be used in our case, mainly because the large diameter.

The following criterion was finally adopted: first, calculate the maximum allowable axial load without bending, using the ACI formula for tubular steel columns filled with concrete; then calculate the maximum allowable bending moment, without axial effort, considering the pile as a reinforced concrete column using Jimenez Montoya's ultimate strength charts.

As the reinforcement for this column we computed the complementary inner reinforcing made up by common steel round bars, with a spiral tie, plus the full useful section of the common steel casing (that is, after deducting 5 mm for corrosion allowance).

Thus established the two end points of the interaction curve M - N , this curve should be determined. The linear relationship joining such points can be considered as a lower limit. Taking into account the convex shape of interaction curves for reinforced concrete columns ultimate strength calculations, we considered our curve could follow a quadratic relationship.

Nevertheless, later comparisons with the recommendations of CIDECT (Comité International pour le Développement et l'Etude de la Construction Tubulaire) indicated the convenience of introducing a correction, reducing the allowable moments in the zone of maximum axial load.

Thus, an elliptical interaction curve was adopted, the ellipse's two semiaxes being given values of N_{all} for M = 0 and M_{all} for N = 0. Where there were high axial force values, the elliptical relationship was replaced by a linear relationship obtained by plotting the line by the two points (N_{max}; M = 0) and (N = 0; $2 M_{max}$).

One detail of the design that merited special attention was the linking of the pile with the pile cap. In the static scheme adopted the piles are fixed in the pile cap. Normally, this type of fixing is materialized by lengthening the reinforcing of the entire pile and anchoring it into the pile cap. In this case, a very important part of the pile's reinforcing is represented by the casing. However, it was totally impractical to lengthen the casing in the pile cap and anchor it in such a manner that the casing's maximum tension load could be transmitted to the pile cap, because it would have produced considerable interferences with the reinforcings of the pile cap.

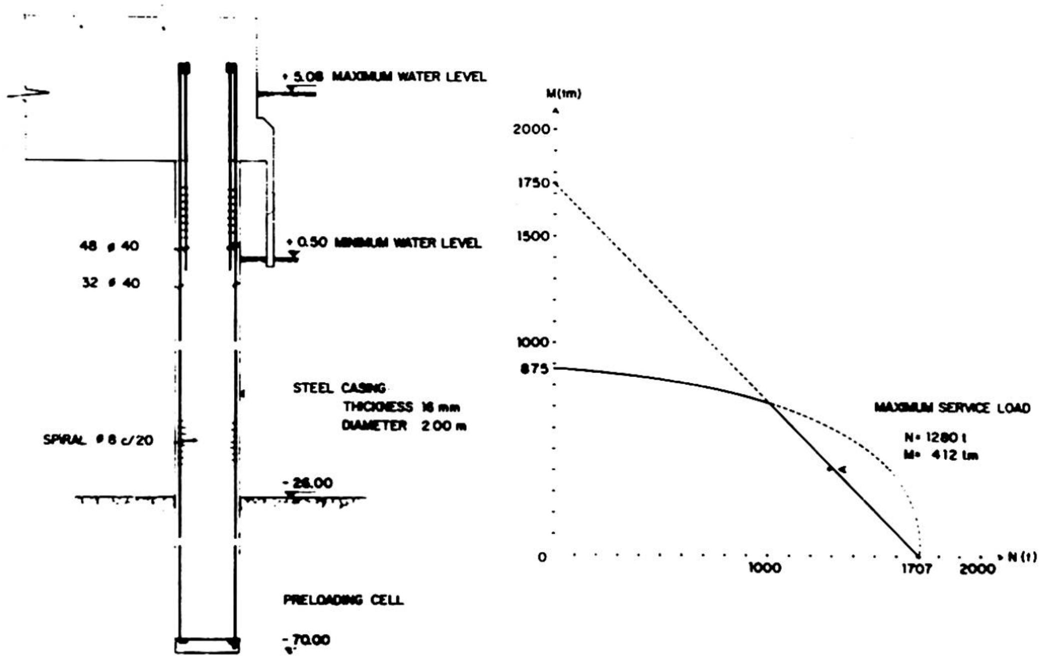

Fig. 3 - Pile Details and Interaction Curve

On the other hand, it must be taken into account that the vertical force on the pile is always compression and that tension could only happen in a very limited sector of the casing under exceptional load conditions, and with very low tension stresses. Thus, the idea of anchoring the casing to withstand tension forces was discarded, adopting instead the transference of the compression force by installing a collar of thick steel plates that provides a contact surface with the concrete ten times greater than the casing's effective section.

On the contrary, about the complementary inner reinforcing it was decided to lengthen it within the pile cap with a sufficient anchor length. In addition, to parcially compensate the discontinuity that occurs in the casing interruption, the complementary reinforcing in the section near and into the pile cap was increased 50 %.

5 - Piles Construction

The equipment used consisted of a floating barge with two cranes, one with a 75 tons capacity plus an excavating attachment, and the other, used for auxiliary service, with a 25 tons capacity. In addition, a hydraulic claw permits the handling of the steel casings.

After securing the barge in the exact position, a temporary steel casing slightly larger than the pile was lowered, penetrating some 5 meters below the river bed.

Then, the hole is excavated by means of a rotating bucket. During the excavation process, both perforation and temporary casing are permanently filled with bentonitic slurry.

Once the perforation reached the prescribed depth, the steel casing, 16 mm thick, is placed. The different parts of the casing are welded together, while they are driven downward, by means of x rays controlled welding. At this point, the temporary casing in the upper part was no longer necessary and it was removed by the claw. Then, the slurry was replaced by clean water and the placing of the pre-loading cell and reinforcing proceeded.

After concreting the pile under water, the job is completed by cutting the casing at the predetermined spot and welding the supporting collar. Finally, the pre-load grouting is performed.

The pre-loading cell consists of a metallic basket filled with crashed stone. After concreting the pile, cement grouting, under pressure of up to 80 kg/cm2, is inserted into the cell by means of a system of tubes and valves.

With this procedure two beneficial effects are obtained for the pile's load capacity: to fill any eventual cavity or area of loose soil that may exist close to the pile tip; and to compress the lower soil with a total load of 2500 tons. Under this load, which approximately doubles the working load, it is reasonable to expect that complete soil settlement is occured in such way that under working loads the pile cap's settlement is due only to the elastic shortening of the pile.

6 - Pile Cap Construction

The majority of the pile caps for main bridges' piers are located in the river bed; thus, the form bottom was supported by a temporary steel structure that rest on provisional brackets welded to the pile casings.

Steel forms are used for the bottom and sides of the pile cap. Concreting is done in several stages planned to simultaneously minimize the shrinkage effects and obtain a good monolithic structure. Thus, the working joints are offset in the different layers and have a serrated surface.

The concrete specified for these pile caps has characteristic strength of 210 kg/cm2, which has been tested with ample margin. The reinforcings use type III steel (cold twisted) with an allowable stress of 2.400 kg/cm2.

SUMMARY

Foundations of two identical bridges of 330 m span over the Parana River include large diameter steel-cased cast-in-place reinforced concrete piles and reinforced concrete pile caps. This paper describes design criteria and construction methods used for these foundations. Due to great diameter and slenderness of piles, special formulae to verify safety conditions were used.

RESUME

Les fondations de deux ponts identiques de 330 m de portée sur la rivière Parana sont composées de pieux de grand diamètre bétonnés sur place dans des tubes en acier sur lesquels reposent les semelles en béton armé. Ce rapport décrit la méthode de calcul et les techniques de construction utilisées. Dû au grand diamètre et à l'élancement remarquable des pieux, des formules spéciales ont été utilisées pour vérifier la sécurité.

ZUSAMMENFASSUNG

Die Fundation der zwei gleichen Schrägseilbrücken über den Parana mit einer Hauptspannweite von 330 m besteht aus Stahlbeton-Pfählen grossen Durchmessers mit einer äusseren mittragenden Stahlhülse und verstärkten Pfahlkopfplatten. Dieser Artikel beschreibt das angewandte Berechnungsverfahren sowie Baumethoden. Wegen des grossen Durchmessers und der grossen Schlankheit der Pfähle, wurden spezielle Formeln angewendet, um die Sicherheit nachzuweisen.