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ANNULAR MONOBLOCK BRIDGE FOUNDATIONS

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ABSTRACT

Annular monoblock foundations are increasingly used in bridge pillar construction, where they guarantee high bearing capacities, safety, speed and ease of execution.

Here we illustrate their main design and calculation features as well as the constructive modalities from some recent examples of Italian road bridges.

The advantage of this foundational typology is evident in the realization of high and medium span bridges in water, where the cost of construction is particularly optimized. The facilitation is significant since the construction operations are all from above and dry compared to the classic foundations of piles and pile cap that require the construction of provisional sheet pilings in water or other shafts, to allow the construction of the pile cap under the water level.

These last elements generally interact negatively on hydraulic behavior around the pillar; this interaction is considerably reduced with annular monoblock foundations.

keywords: bridge foundation, drilled pile, annular monoblock foundations

INTRODUCTION

In the construction of bridges on watercourses, the construction of pillars in the riverbed always poses the problem of defining the interaction between the body of the pillar and the fluid stream, a subject widely studied as purely hydraulic matter. There is also an interaction between the ground at the feet of the pillar and the stream, whose effects are reflected in the geotechnical and structural resistances of the pillar's foundation.

The design and construction method of pillars with the annular monoblock foundation allows us to optimally address the aspects above, offering also significant constructive and economic benefits.

CLASSICAL FOUNDATIONS

The classical foundation construction typology of a pillar in a riverbed includes a reinforced concrete (RC) cap, headed on a series of piles, from which extrudes the pillar elevation. The use of deep pile foundations for this type of work is almost always necessary because, in the case of base erosion, it guarantees the maintenance of static and geotechnical functions. It is well known that the interaction between the motion of the fluid and the overall pillar can produce the phenomenon of "baring the roots", which is manifested first in the erosion of the soil in the area near the pillar shaft and, gradually, at the foundation level, once this interacts with the water flow. The size of this process can be very variable, and basically depends on the speed of water, the size of the immersed body, the shape of the pillar (according to Yarnell's classic experimental approach, 1934, the shape can affect up to 40 % in the erosion process, and a circular shape is one of the least affected) and, finally, on soil characteristics.

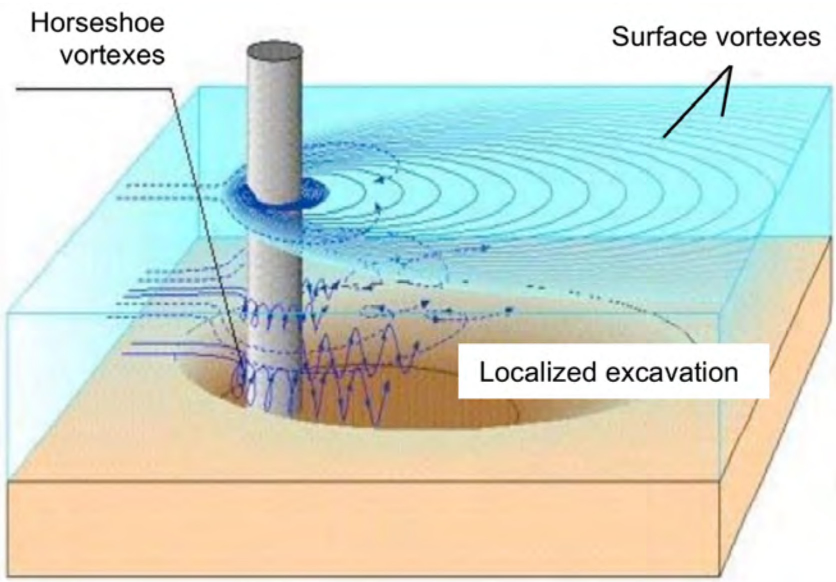

Fig. 1. Schematic representation of the movement field and local excavation process near a circular bridge pillar (Breusers & Raudkivi, 1991)

In order to contain this phenomenon, which can remove the soil to a significant depth, it is frequently chosen to place the pile cap deeper than the bottom of the expected erosion: for this purpose, large excavations must be carried out. It is necessary to build temporary earth support structures and the construction workers will have to operate below the water level, even in deep wells.

ANNULAR MONOBLOCK FOUNDATION

The technological solution analyzed in this paper involves the realization of a single pile, coaxial to the pillar shaft, both with a circular section, and with a diameter suitable for supporting vertical and horizontal loads: for large bridges with spans over 20-30m, this can require foundations with a single pile diameter of more than 2m. By neglecting the cases in which the excavation of the pile can be realized directly with a single digging and casting operation (classic monolithic pile), the method illustrated is equally applied, regardless of the diameter of the final pile. The latter is made by means of a group of deeply intersected piles aligned along a circumference of appropriate diameter and coaxial to the shaft of the pillar. Thus, an annular section pile is obtained, which is achieved by joining each small diameter pile. From a hydraulic point of view this allows one to maintain the diameter of the elevation even at the base, reducing the effects of the interaction with the water flow thanks to the geometric external continuity. From a geotechnical point of view, the execution of a single pile, although large in diameter, avoids the formation of group effects and so the performance reduction concerning both horizontal and vertical loads.

CONSTRUCTION METHODOLOGY

The construction of this type of pile is articulated as follows:

Stage 1: Creating the service area in the riverbed, protected from water and extraordinary flood events;

Stage 2: Insert into the ground the circular self-founder caisson (more easily feasible for diameters not exceeding 3-4m), coaxial to the pillar shaft and the annular pile to be realized. The caissons are generally settled down into the soil a little beyond the level of the maximum allowable erosion so that, in case of an extreme event, the water stream behaves as a smooth flow toward the precast concrete external shape;

Stage 3: Restore the terrain inside the caisson in order to maintain the service area almost at the ground level;

Stage 4: Primary and secondary intersected piles are executed up to the design level;

Stage 5: The top connecting element is realized, which solidifies the head of all the piles and forms the lower part of the shaft of the pillar;

Stage 6: The concrete of the upper part of the pillar shaft is cast.

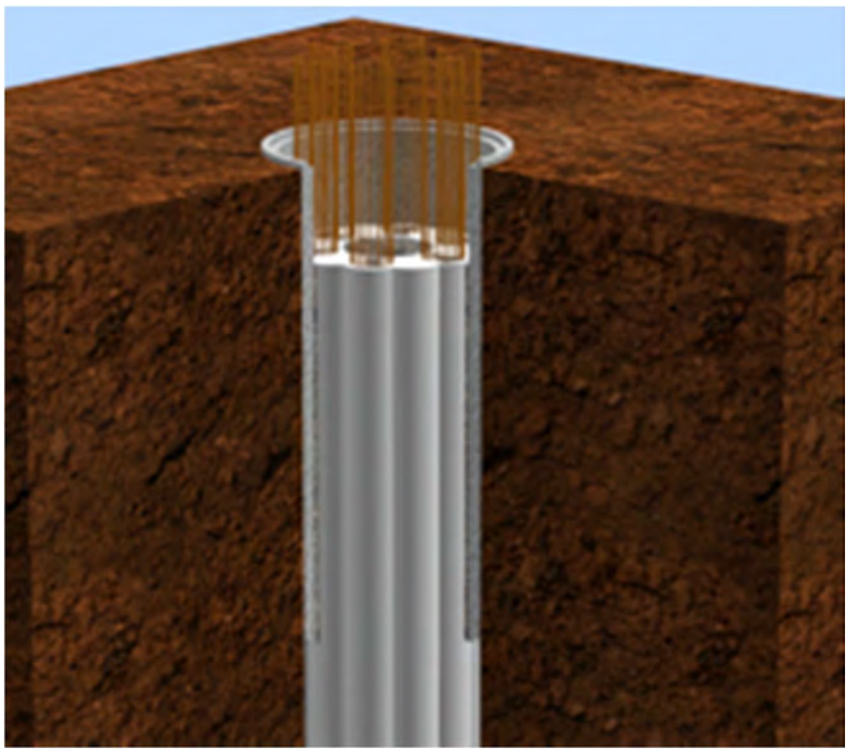

Fig. 2. Foundation structure - detail of the top of the element at the end of stage 4

During all stages, manufacturing is carried out on the ground level, without the creation of wells for staff intervention: this guarantees faster execution times and lower risks for people and machinery, especially in case of possible sudden floods.

IMPROVED ASPECTS IN THE HYDRAULIC-GEOTECHNICAL FIELD

The described construction methodology, besides the "classic" one, has some notable hydraulic and geotechnical advantages:

a. the shape and the transverse dimension of the pillar-pile assembly does not show any increments or variations, hence the hydraulic interaction between the water flow and the obstacle does not change when the depth of localized erosion changes;

b. there are no excavations or fillings in in the prior natural soil of riverbed, except those strictly necessary for pile excavation; this maintains the level of surface protection close to the pile, the so-called "armoring", leaving the original soil in place, generally less affected by erosion;

c. the presence of self-founder caissons throughout the depth potentially subject to erosion preserve the cross-section, and ensure the protection of internal piles (with structural function) from external mechanical actions of water and debris;

d. the use of "average"- diameter piles allows one to reduce risks during the execution (the machines have less power requirements), especially in dense soil with possible presence of boulders.

IMPROVED ASPECTS IN THE STATIC-CONSTRUCTION FIELD

From a static and construction point of view there are several advantages:

a. the presence of the self-founder caissons causes the "annular pile" to be secured (armored) by a high-strength and durable element inserted without causing significant disturbance to the surrounding soil;

b. the use of self-founder caissons serve as a template for the execution of the following piles, thereby giving a greater guarantee of the final geometry;

c. the use of many small diameter piles allows an easier control of the execution, which can be monitored through non-destructive techniques (S.I.T., Sonic Integrity Test, e.g.), optimized with lower casted volume elements;

d. it avoids the construction of a connection element (pile cap) between the head of the piles and the elevation, thereby saving on the quantity of material;

e. the strong intersection between the piles allows for a monolithic behavior of the system, utilizing the adhesion between the non-negligible concrete surfaces that are placed in contact;

f. the operations are all done from ground level; this allows for a greater yield-per-hour and thus shorter working times;

g. there are no significant excavations in the riverbed (except for the self-founder caissons), which is often a problematic operation due to the lack of free areas for temporary soil storage and subsequent reuse.

EVALUATION OF THE EFFECTIVENESS OF THE INTERSECTION BETWEEN PILES

Intersection between piles, even though it involves higher execution costs than a “side by side” arrangement (the greater number of elements to be constructed creates greater potential costs for the used tools and longer time required for execution), it allows one to obtain a monolithic, almost annular cross-sectional structure.

The monolithic structure allows a behavior in which the local compression peaks acting on the individual elements are damped.

Detailed analysis highlights how this function can be obtained utilizing the only shear and adhesion resistance that develops between two concrete surfaces cast in successive phases. Also considering that all the piles are connected to the top by a monolithic casting of concrete and from the following shaft of the pillar, the foundation structure can be considered as a single monolithic element consisting of a ring of reinforced concrete inserted into the ground. Calculation of the load bearing capacity is generally performed by considering lateral friction resistance on the overall outer surface to which the bottom resistance is added assuming the contact surface equal to the overall annular section of the monoblock.

Alternatively, the external lateral resistance mentioned above may be considered together with a bottom resistance calculated from the whole base section (circular section with outer annular ring diameter) reduced by a “scale effect” assessed from Meyerhof’s (1983) or Alessandrini’s et al. (1988, 2015) considerations.

Calculation of horizontal loads (shear and bending moment from pillar) can also be carried out using simple 2D software (e.g. based on the “bed constant method”, using a simplified pile-ground interaction through a double wall of nonlinear Winkler’s springs). This analyzes the pile behavior under horizontal loads, without necessarily resorting to more sophisticated 2D or 3D FEM software, whose results have proven to be very close to the first.

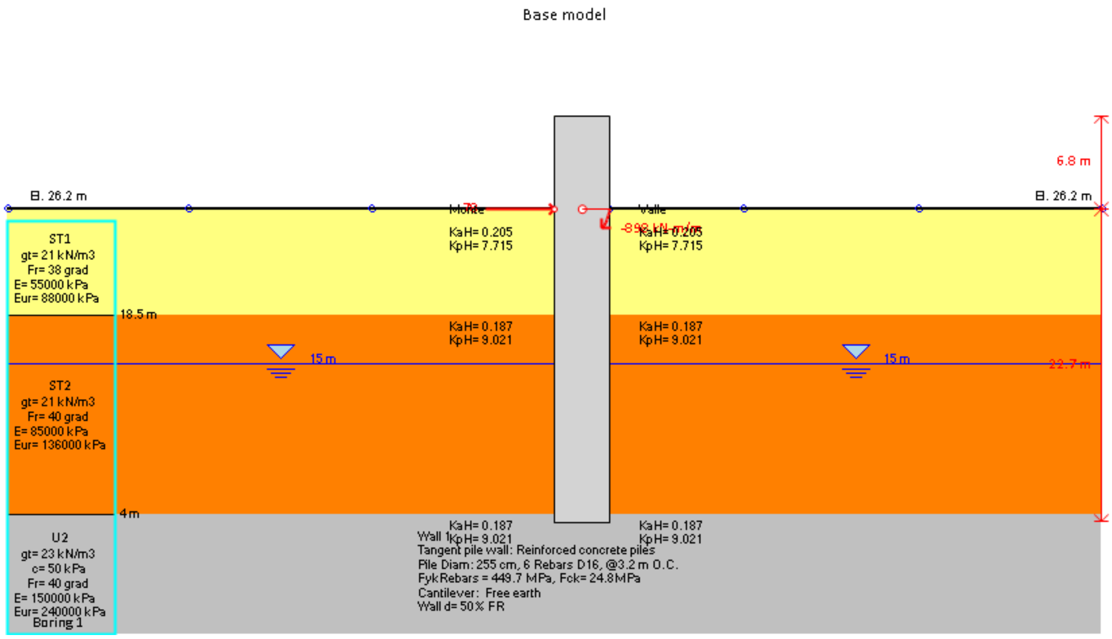

Fig. 3. Annular monoblock calculation scheme using 2D software based on the SRM (Subgrade Reaction Method)

CASE HISTORY

The annular monoblock foundation technology has been used in recent years for the realization of various bridges, including the new one over the river Torre, between the municipalities of Chiopris-Viscone and Palmanova, near Udine, Italy.

The bridge has a total length of 665 m, divided into 15 spans with a typical length of 47.5 m, allowing the river to be crossed alongside the existing bridge (demolished at the end of the work).

The bridge deck is made of a framework steel structure with overall height of 3.5m, at supports, and 2.8m, at the midpoint of the spans.

Each pillar is made up of a single cylindrical element with an outer diameter of 3.25m, which at the top of the frame extends in a transverse direction up to 7m, to allow the positioning of the support devices.

The foundation structure of the pillars consists of the annular monoblock made by 12 intersected drilled piles, with a diameter of 0.75m, nearly 30m long, carried out at constant pitch along a circumference with a radius of 0.99m: thus, the intersection of primary and secondary piles is 23.5cm.

The overall concrete section has a theoretical surface of 4.22m^2, with outer circumference of 8.23m (or a diameter of 2.62m).

The pile is inserted in a soil with good geotechnical characteristics. Low-density alluvial deposits near the surface form the hydraulic movable base of the riverbed. Progressively the coarse gravels become thicker with weak sandy filler. At about 25m depth, a stronger layer can be found, consisting of banks of conglomerates, in which the tip of the piles is based.

Fig. 4. New Torre Bridge rendering; the bridge has the pillars based on annular monoblock foundations

The realized annular monoblock has a calculated capacity at vertical loads of about 25,000 kN in compression and about 15,000 kN in tension. The breaking bending moment, with only 6 reinforced piles out of 12 constituting the annular section, has a value of about 28,000 kNm. The shear strength, estimated as the sum of individual reinforced piles strength, is approximately 2,800 kN.

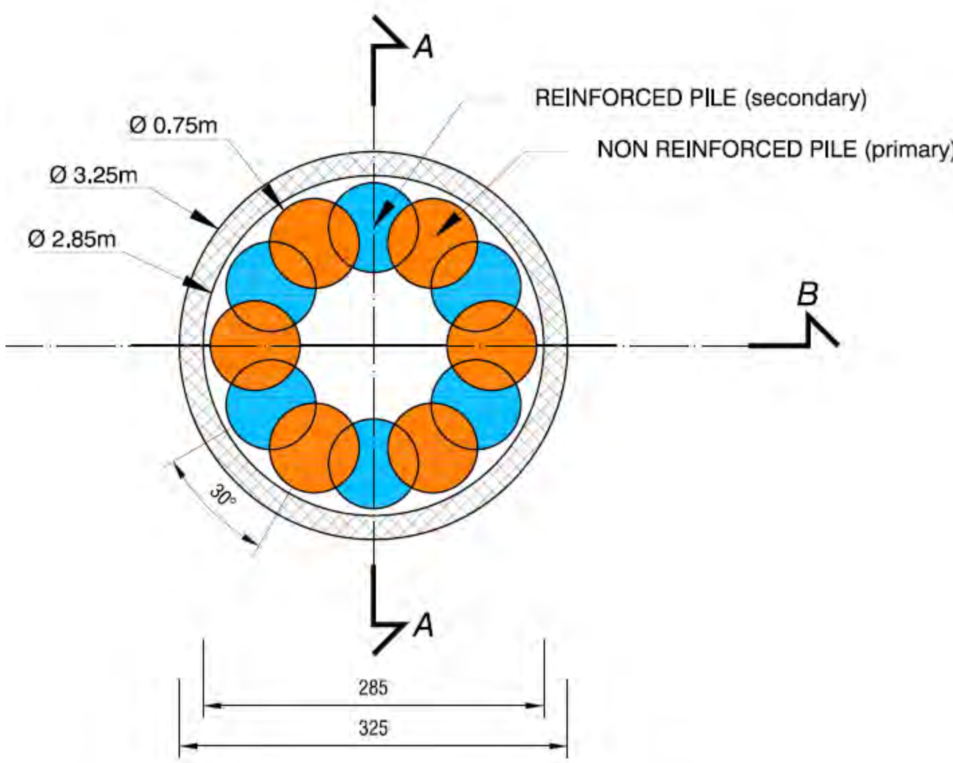

Fig. 5. Horizontal section of the annular monoblock foundation at the level protected by precast caissons

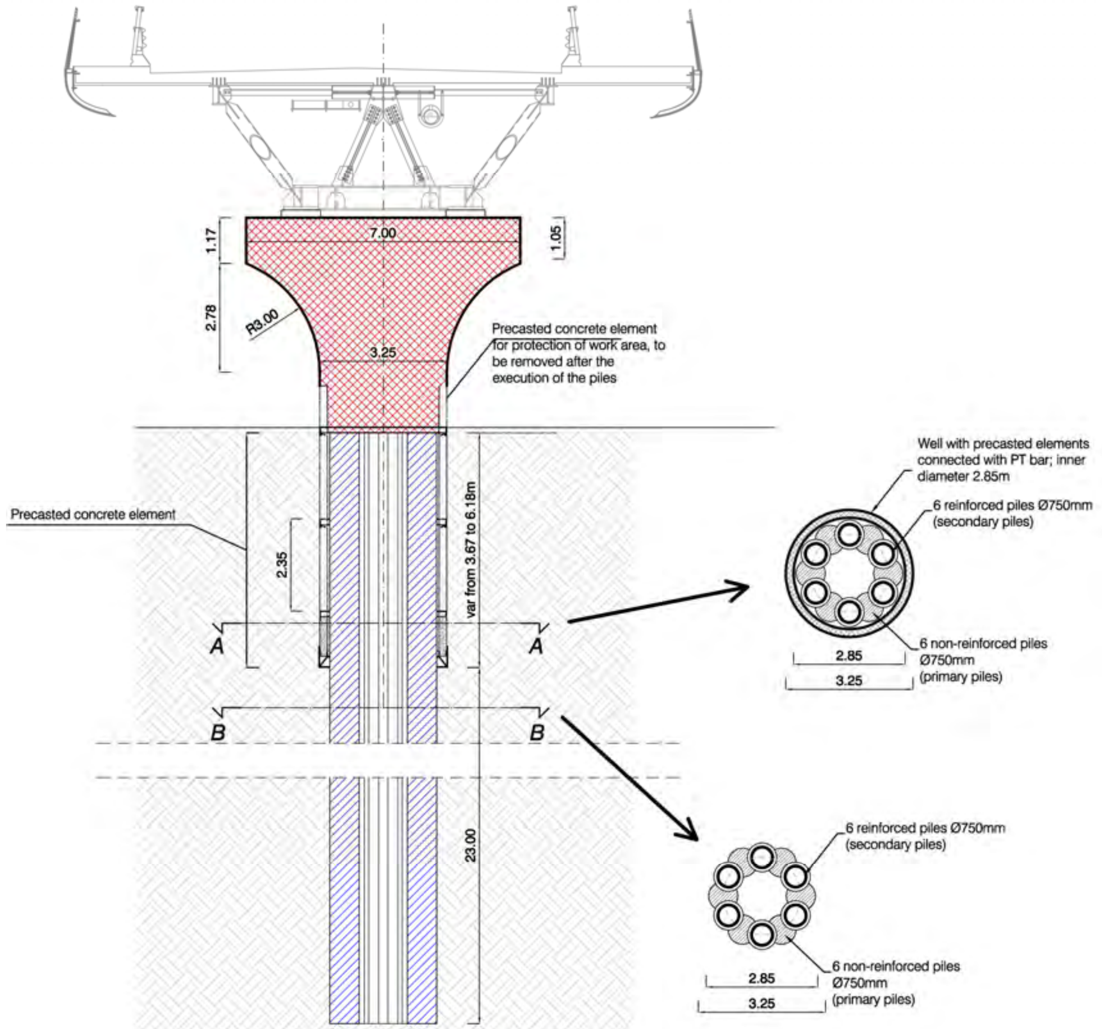

Fig. 6. Vertical section of the whole structure with highlighted annular monoblock foundation and the well with self-founder precast caissons. Above, the foundation section with linings and, below, the same made only by piles

Construction stages are shown in Fig.7:

step 1: inserting self-founder caisson;

step 2: filling the caisson;

step 3: execution of primary piles;

step 4: execution of RC secondary piles;

step 5: provisional protection element removal;

step 6: circular monolithic pillar construction

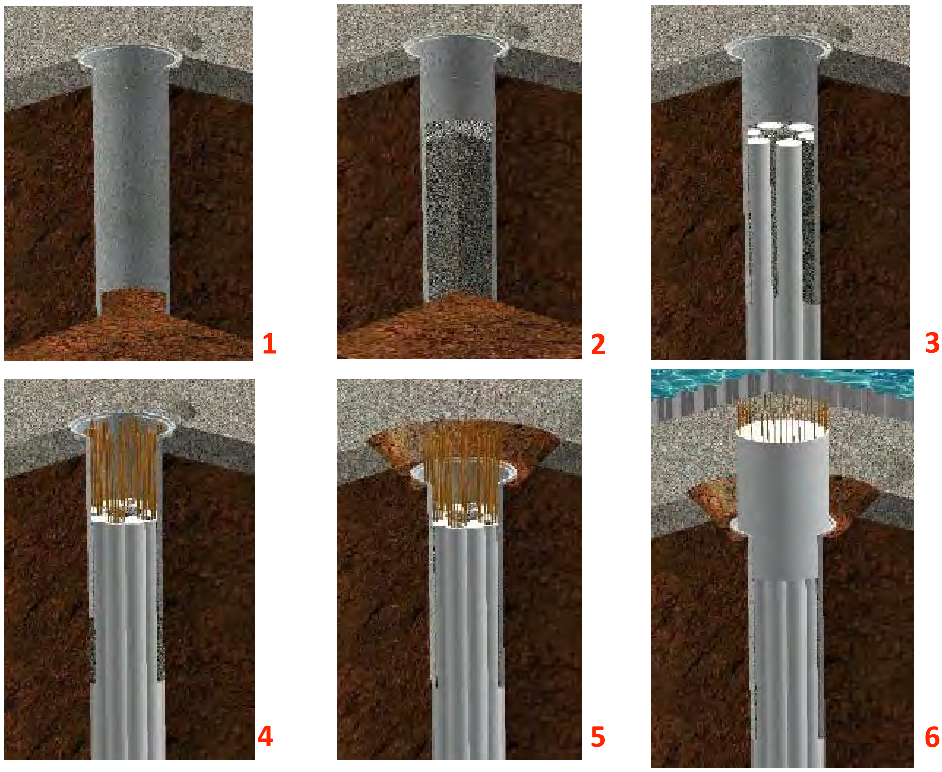

Fig. 7. Construction stages of the annular monoblock foundation. In stage 5 the upper part of the caisson is removed.

CONSTRUCTION COSTS

The foundation typology illustrated, as well as having undoubted constructive advantages, is also cheaper than a classical foundation made up of a deep cap on piles. In the illustrated case, for example, the tender project expected a foundation of this type, then modified in the annular monoblock (during the tender procedure as a technical and economic proposal). For the entire foundational structure, the annular monoblock solution has shown a construction cost about 25% lower than the tender solution with caps on piles.

Furthermore, the construction is faster than the traditional one. In the case shown the expected time to build up an annular monoblock foundation is reduced to about 33% compared to the initial solution.

CONCLUSIONS

This article illustrates the constructive method of the annular monoblocks which allows one to obtain significant technical and economic benefits in the realization of bridge pillar foundations on riverbeds.

The technology is capable of being implemented independently of the pile shaft size, and it is easy to apply in those hard soils where the realization of individual piles is still difficult.

The recent application example presented showed the advantages of the methodology, which can offer rapidity of construction, adequate structural and geotechnical strength and overall economic advantages.

Depending on the specific foundation requirement, the structure can be optimized with particular regard to the pile intersection degrees, and the global bearing capacity assessment.

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