DEEP FOUNDATIONS ASSOCIATED TO PRESTRESSED ANCHORAGES

LES FONDATIONS PROFONDES ASSOCIEES A DES ANCRAGES PRECONTRAINTS

ФУНДАМЕНТЫ ГЛУБОКОГО ЗАЛОЖЕНИЯ С ПРЕДВАРИТЕЛЬНО НАПРЯЖЕННЫМИ АНКЕРАМИ

A.J. COSTA NUNES – Eng. Professor of the "Universidade Federal do Rio de Janeiro" – Director – Tecnosolo S.A.
F. BOGOSSIAN – Eng. Professor of the "Universidade Federal do Rio de Janeiro"
B. PLIVANOV – Eng. Tecnosolo S. A.
S.S.M. TRINDADE – Eng. Tecnosolo S.A. (Brazil)

SUMMARY. The use of prestressed anchorages associated to piles or caissons for foundations of different types of structures submitted to very high horizontal and uplift loads has enabled to solve some special foundation problems in Brazil.

This paper analizes the cases in which the assemblage is convenient, discusses the behavior of such foundations and presents examples of jobs already executed.

INTRODUCTION

As it is well-known, piles and caissons are very often a suitable, technical and economical solution for foundations of structures subject to horizontal and high uplift loads.

Commonly, these foundation types resist efficiently to both the compression and traction stresses resulting from the mentioned loads.

However, in some cases it may happen that for technical and economical reasons the resistance to uplift loads is not easily assured.

One of these cases occurs when, due to the fact that the ground is impenetrable for driving in piles and caissons, mainly rock, the conventional foundations are not long enough to resist high uplift loads.

The problem is still more typical when the ground water level is high which would require the employment of excavated pneumatic caissons anchored in the rock.

Another problem to which the use of anchorages offers an advantageous solution is the one in which the traction loads are more unfavorable for the deep foundations than the compression loads.

The structures subject to uplift pressures are commonly included in this category. Eventually, the solution of drainage may in this case not be a desirable one, as it occurs often with dry docks, locks and basements.

A particular solution of them here presented is also the anchorage of concrete or steel-cased piles in the rock to assure them high traction resistance.

Solutions of this type are known for cast-in-place concrete piles (Franki type) or still for precast reinforced or prestressed concrete piles.

The senior author had opportunity of designing and following up the behavior of such solutions while he was a member of the permanent technical staff of Franki Pile Ltd., about ten years ago.

BEHAVIOR OF THE ASSOCIATED FOUNDATIONS

In general cases, the anchorages associated to piles or caissons would resist to the working loads even without prestressing.

Nevertheless, the main function of the prestressing is to guarantee the mobilization of the loads at the anchorages without being necessary that deformations should occur, running in this case quite high, which would take place if no prestressed anchorages were used.

The inconveniences of these deformations would be of two types:
a) the structures, specially the reinforced concrete ones, could be damaged by the deformations necessary to mobilize the loads of the anchorages.
b) in case of anchored deep foundations in parallel, the common anchorages would not present enough collaboration in the resistance to the traction loads before the elements of foundation being submitted to stresses and deformations incompatible with their normal behavior.

It should be remembered that the associated foundations may be of two types (Fig. 1):

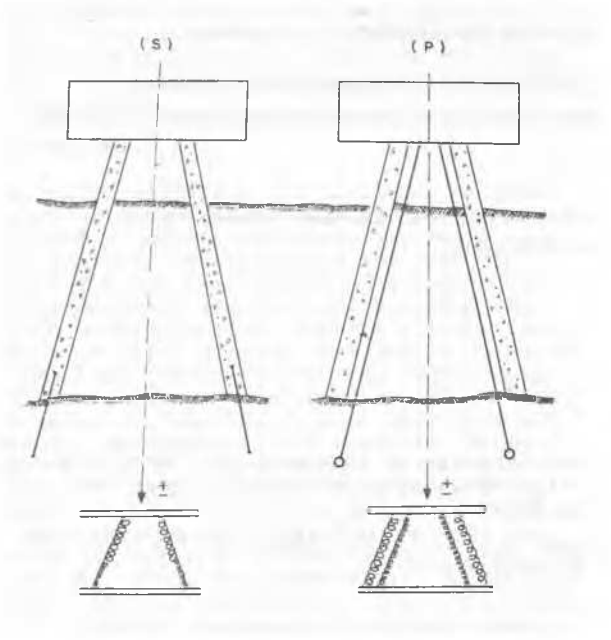

FIG I ANCHORAGE AND FOUNDATION ASSOCIATED (S) IN SERIES AND (P) IN PARALLEL AND THEIR CORRESPONDENT ELASTIC EQUIVALENTS

1 - in parallel, when the deformations of the assemblage are the same and than the loads are distributed proportionally to the respective elastic constants.

Let F, F_f, F_a, K_f, K_a, δ, δ_f, δ_a, S_f, S_a, E_f, E_a, l_f, l_a be, respectively, the total loads, at the foundations and at at the anchorages, the elastic constants, the deformations, the cross sections, the moduli of elasticity and the free lengths of the foundation and of the anchorages.

Hence,

1) $F = F_a + F_f$

2) $\delta_f = \delta_a = \delta$

3) $K_f = \dfrac{F_f}{\delta_f} = \dfrac{F_f}{\frac{F_f\ l_f}{S_f\ E_f}} = \dfrac{E_f\ S_f}{l_f}$

4) $K_a = \dfrac{F_a}{\delta_a} = \dfrac{E_a\ S_a}{l_a}$

5) $F_a = K_a\ \delta_a = \dfrac{E_a\ S_a}{l_a}\ \delta_a$

6) $F_f = K_f\ \delta_f = \dfrac{E_f\ S_f}{l_f}\ \delta_f$

or, according to 1 and 2:

7) $F = \delta\left[\dfrac{E_a\ S_a}{l_a} + \dfrac{E_f\ S_f}{l_f}\right]$

The parcels attributable to each element, foundation and anchorages, will be:

8) $\dfrac{F_f}{F_a} = \dfrac{\frac{E_f\ S_f}{l_f}}{\frac{E_a\ S_a}{l_a}}$

II - in series - when the deformations of the assemblage are the sum of the deformations of the elements and when the elements receive equal loads.

In this case,

1') $F = F_a = F_f$

2') $\delta = \delta_a + \delta_f$

3') = 3)

4') = 4)

5') = 5)

6') = 6)

7') $F = F_a = F_f = \dfrac{E_a\ S_a}{l_a}\ \delta_a = \dfrac{E_f\ S_f}{l_f}\ \delta_f$

More elaborated analysis with plastic hypothesis has been divised but it is less convenient because a precise treatment cannot be expected.

If the system behaves elastically, both type of association have a satisfactory performance since the loads at the anchorages are determined by the prestressing.

When a settlement or a permanent deformation due the traction takes place (negative settlement or heaving) both types of association have different performances.

In the hypothesis of a settlement, the anchorages lose the prestressing as the settlement occurs.

The importance of the prestressing losses

depends on the modulus of deformation of the soil (Costa Nunes 1966).

For grounds with the modulus of deformation higher than 2000 kg/sq.cm the losses are moderate and the system of both types has good performance.

In the case of the system in series the free length of the anchorage may be much reduced (FIG. 1) and consequently even if there are prestressing losses the total load at the anchorage settles with a very small displacement (equation 7').

In the system in paralllel, on the contrary, the free lengths of the anchorages are large and, if there are prestressing losses, considerable deformations are necessary, which frequently are inconvenient, in order to re-establish the load parcel attributed to the anchorage in the design.

Consequently, when the ground is a compressible soil, the association in series is decisively preferable to the association in parallel.

PRACTICAL EXAMPLES

Some applications of this method will be described below as practical examples.

I - Port of Juazeiro - Bahia (Figs. 2a and 2b)

This pier is provided with a conveyor belt for ore transport from which low vertical loads result in comparison with the horizontal ones from wind and currents.

There are also dolphins subject to vertical loads practically due only to their dead weight and to very high horizontal loads coming from impacts and mooring of ships.

The very resistant ground is at little depth allowing to drive only short piles.

The job has been carried out by the "Departamento Estadual de Portos e Vias Navegáveis da Bahia" and had as general contractor the firm "Comercio e Imóveis S.A.". The foundations were executed by FENGEL.

II - Viaduct at "Padre Feijó" street - Salvador (FIG. 3)

It is a viaduct over the "Contorno" Avenue which is an important through road built by the "Departamento de Estradas de Rodagem - DERBA" - of the state. The general contractor was "Construtora Brasil".

Due to the cap level of the piles and to the depth of the rock, the steel piles

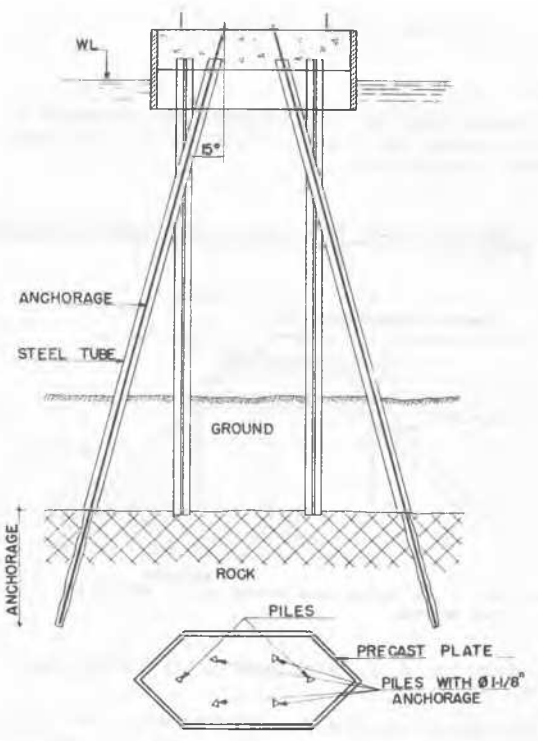

FIG 2a PORT OF JUAZEIRO - BAHIA - ANCHORED PILES FOR THE FOUNDATION OF THE PIER SUPPORTING THE CONVEYOR BELT

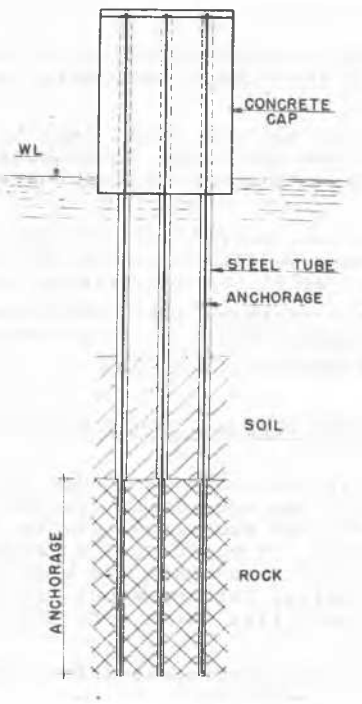

FIG 2b PORT OF JUAZEIRO - BAHIA - DOLPHINS ON ANCHORED PILES

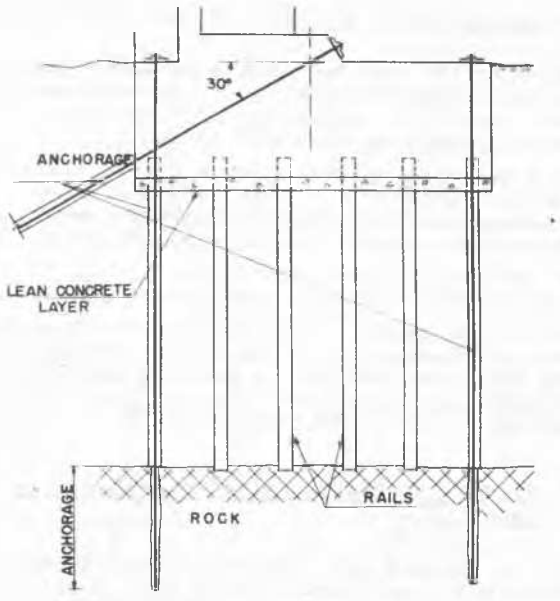

FIG 3 VIADUCT AT "PADRE FEIJÓ" STREET - SALVADOR ANCHORAGES INSTALLED TO SUPPORT THE UPLIFT FORCES AND TO RESIST THE HORIZONTAL LOADS ON THE ABUTMENT

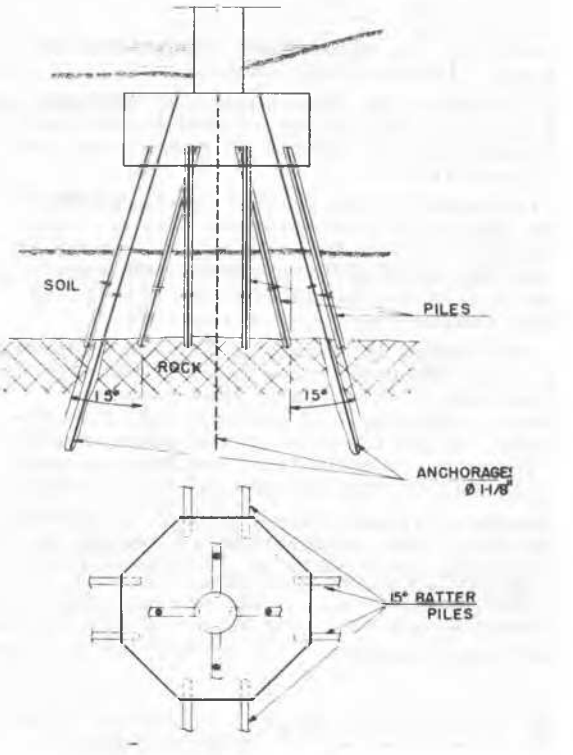

FIG 4 IPITANGA BRIDGE - BAHIA - FOUNDATION ON PILES AND OUTSIDE ANCHORAGE

driven for the foundation of one of the abutments of the Viaduct were only about 2 meters long.

Taking into account the short term to build the job and the high water level observed no other type offoundation would have been suitable.

Load tests were carried out and they showed that the above solution was the satisfactory one to resist the compression loads.

Prestressed anchorages were used to resist the uplift loads resulting in an economic and rapid execution.

III - Ipitanga bridge - Bahia (FIG. 4)

The ground at the Ipitanga bridge linking Salvador with its suburbs is resitant at little depth. The economical studies and the short term for building the bridge led to the conclusion that the best solution under actual circunstances would be to drive steel piles which were only 2 meters long.

The studies also demonstrated that scour was not to be expected.

The calculation showed that the short piles would resist to the compression loads but also showed that they were insufficient to the uplift resulting from the horizontal loads.

The "Departamento de Estradas de Rodagem " was in charge of the job and EBISA was the general contractor.

IV - Capstans for the Aratu Dry Dock - Bahia (FIG. 5)

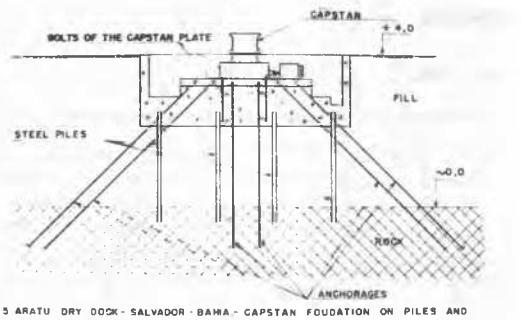

FIG 5 ARATU DRY DOCK - SALVADOR - BAHIA - CAPSTAN FOUDATION ON PILES AND OUTSIDE ANCHORAGES

(Costa Nunes A.J. and Schwab de Souza Menezes M. - 1967).

At the Bases of the Brazilian Navy in Aratu the dry dock was excavated in the local ground formed by water sensitive sedimentary rocks comprising shale, sandstone and siltstone.

The foundation for some capstans of the fry duck was on steel piles set at little depth on the local rock.

Also in this case the compression loads did not present difficulties in being resisted by the short piles designed.

Nevertheless, due to the very high horizontal loads, a solution using only piles would not be suitable.

The problem was technically and economically solved by the employment of prestressed anchorages arranged as shown in FIG. 5.

CONCLUSIONS

The association of prestressed anchorages to piles and caisson foundations is very often an advantageous solution, mainly when the foundations referred to are of short length as it happens when the resistant ground is at little depth.

Whenever possible, the system in series should be chosen, since it presents advantages which are the greater the more compressible the ground is.

REFERENCES

COSTA NUNES A.J.
Anchoring in rock and soil - Discussion- Proceedings of the Sixth International Conference on Soil Mechanics and Foundation Engineering - Montreal 1965 - University of Toronto Press, 1966 - Vol. III - pg. 526.

COSTA NUNES A.J.
Slope stabilization - Improvements in the techniques of prestressed anchorages in rocks and soils. Proceedings of the first Congress of the International Society of Rock Mechanics - Lisbon 1966 - Laboratório Nacional de Engenharia Civil - Portugal - 1966 - pg. 141/146.

COSTA NUNES A.J. AND SCHWAB DE SOUZA MENEZES M.
Problemas Geotécnicos na Construção de Base Naval em solos sensíveis. Segundas Jornadas Luso-Brasileiras de Engenharia Civil - Rio de Janeiro 1967 - Comunicação nº 3.