TECHNOLOGICAL AND CALCULUS ASPECTS OF ANCHORED FOUNDATIONS APPLICABLE TO SPECIAL CONSTRUCTIONS

ASPECTE TEHNOLOGICE ȘI DE CALCUL ALE FUNDAȚIILOR ANCORATE APLICABILE LA CONSTRUCȚII SPECIALE

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pretensioned tie bars creates the possibility of solving some foundation problems that in other solutions would be extremely expensive or impracticable from practical point of view. Anchorages are used at a series of foundation works in the domain of civil, industrial and agricultural constructions (anchoraging some cantilever constructions and some special roof types) and as much for the hydrotechnical constructions. Considering the great number of pretensioned anchorages achieved up to now for a great number of foundations and embankments works, the knowledge about their behaviour is still incomplete. These happen not because there are missing some measurements at natural scale, but because of relatively reduced possibilities of understanding the earth behaviour by its properties in the process of tensioning tie bars, in execution phase, but mainly during their operation in time. Conception and comprising of different types of anchorages or tie bars are not based on calculus. but more on intuition and palpable experiments on site, after that the improving of site technologies is done in general, by the practitioners.

Abstract: The procedure of anchorages with **Rezumat**: Procedeul ancorajelor cu tiranți pretensionați creează posibilitatea rezolvării unor probleme de fundații, care în alte soluții ar fi extrem de costisitoare sau chiar nerealizabile din punct de vedere practic. Ancorajele sunt folosite la o serie de lucrări de fundații atât din domeniul construcțiilor civile, industriale și agricole (ancorarea unor construcții în consolă și a unor tipuri speciale de acoperișuri), cât și din cel al construcțiilor hidrotehnice. Cu tot numărul mare de ancoraje pretensionate realizate până în prezent în cadrul unei game largi de lucrări de fundații și terasamente, cunoștințele legate de comportarea lor încă sunt incomplete. Acestea nu pentru că ar lipsi rezultatele unor măsurători la scară naturală, ci posibilităților relativ reduse de a înțelege exact comportarea pământului prin proprietățile lui în procesul de tensionare a tirantilor, atât în momentul execuției, dar mai ales la funcționarea în timp a acestora Concepția și alcătuirea diverselor tipuri de ancoraje sau tiranți nu se bazează în spetă pe calcule, ci mai mult pe intuitie si experimentări concrete de teren, după care perfecționarea tehnologiilor de execuție este făcută în general, de practicieni.

Key words: anchorages, pretensioned tie bars, foundation soil, foundations and embankment works Cuvinte cheie: ancoraje, tiranți pretensionați, teren de fundare, lucrări de fundații și terasamente

INTRODUCTION

The engineering practice has been recently improved by a new working procedure, which consists in using ancoraging with pretensioned tie bars to solve many works of foundations and embankments. Initially, the anchorages with pretensioned tie bars were used fort earth support of deep foundation excavations executed in an urban special environment (underground garages, deep underground floors, subway stations, etc).

Subsequently, the procedure was enlarged to consolidation works of slopes and banks where the anchorages with pretensioned tie bars had in generally a definitive disposition, unlike the case of supporting the excavations that always had a provisionary disposition. Also, having a definitive disposition, anchorages are used at a series of foundation works in the domain of civil, industrial and agricultural constructions (anchoraging some cantilever constructions and some special roof types) and as much for the hydrotechnical constructions.

MATERIALS AND METHOD

In our country practice, the procedure of anchoraging with pretensioned tie bars is found in incipient phase, reasons for it there aren't some consecrate terminologies and notions concerning the component elements of a pretensioned anchorage. Also, there isn't a unitary terminology in all abroad countries. From this reason it is useful to mention the main components of one anchorage, underlining the role of each component in the working procedure of the anchorage, but also the terminology used.

From constructive composition point of view, an anchorage is compound from the following main components: the active anchoraging head, the tirant and the anchoraging (fixing) bulb into the soil.



Figure 1. The constituent elements of a pretensioned anchorage

The active head of anchoraging represents "the active" part of the anchorage and supports on the structure that is anchoraged (for example, the wall of propping up), receiving the tension force from this or from the tensioning of the tirant. In the area of the active head, it is mounted the press for tensioning of the tirant, which is after replaced by a definitive device of blocking the tirant, at the service state of the anchorage. Also, for time following of anchorage behaviour, in the area of the active anchoraging head there are mounted different devices for the intimation of an eventually tirant detensioning.

The tirant is compound from two main parts: the free part (length) of the tirant L_{ot} and the fixing part (length) L_a . The free part transmits the load from the active anchoraging head to the anchoraging bulb. The fixing part represents the part through which the load from his reinforcement is transmitted to the anchoraging bulb.

The anchoraging (fixing) bulb into the soil represents "the passive" area through which the traction force from the tirant is transmitted to the stable soil in which is anchored the bulb.

From the point of view of execution technology, a pretensioned anchorage can be defined as a tirant made of one or several metallic bars, introduced in a borehole (horizontal or inclined) and fixed in the soil by injection with cement suspension, on a length corresponding to the pulling out force. After fixing into the soil, the tirant is tensioned to a load superior to the service load (exploitation load) and than blocked to the service load.

From the point of view of functioning way, a pretensioned anchorage can be defined as a "device" through which the request of a structure (propping ups, mat foundations) under the effect of earth pressure or water sub pressure is transferred deeply into the soil, in a area where the nature, the mechanical characteristics and the massive weight are able to take over the load received from the exterior, in stipulated safety conditions.

By the action of pretensioning-blocking of anchorage tirant, it is anticipatory expressed to the anchors structure, the reaction necessary to assure its stability in the most unfavourable conditions of loading (from the earth pressure, water sub pressure or other loads).

Because every tirant before being blocked with the necessary service load (exploitation load) is checked through tensioning at a superior service load (very close to the elastic limit of the reinforcement), at the pretensioned anchorages unlike other founding procedures, there can be adopted safety coefficients with a relatively reduced values (1.3-1.5). Obviously, this thing is possible only if all the factors that determine the pulling out load of the anchorage from the earth are known and checked. Concerning this last aspect, it has to be mentioned that in the practice of pretensioned anchorages, these has to be accomplished and dimensioned such as if they will fail, the failure should take place by breaking the tirant reinforcement and not by pulling out from the earth.

The speciality literature presents a wide range of pretensioned tirants types used to execute anchorages in the soil. The main elements that differentiates a type of tirant from another are: the structure of metallic section of tirant reinforcement, anchoraging and blocking system on the prop up, the corrosive protection of the tirant, fixing device of the tirant and the system to accomplish the injection. From all the elements mentioned below, a determinant role in defining any tirant type is the fixing device, because from this it depends the way of transmitting of the efforts from the tirant reinforcement to the anchoraging bulb and from this to the soil.

Considering the extending in practice of pretensioned anchoraged fixed into the soil, the theoretical study and the their dimensioning calculus is not sufficiently well clarified, reason for that the usage of this technique in the practice of constructions works is still based on a lot of empirism.

On the base of some theoretical studies, some researches in laboratory and following the behaviour in exploitation of many anchorages executed works, abroad there are some recommendations and technical prescriptions, but most of them are in the state of designing or they have a provisionary character. It can be quoted, the German norms DIN E 4125, norms-S.E.C.C. from Belgium, but the most complete one are the French norms "Securitas". In Romania, INCERC started some researches and experiments since 1972 and in some aspects they cooperated with The Institute for Researches and Technological Design in Transportations (I.C.P.T.T) and Politechnical Institute of Timisoara. Now, there is laid down a project of provisionary recommendations concerning the design and execution of pretensioned tirants into the soil. Unlike the prescriptions and recommendations existent in other countries, INCERC recommendations foresee the calculus and the necessary checks at limit states.

Designing and execution of anchorages with pretensioned tirants need the following operations:

- determination of exterior loads that acts on the structure provided to be anchored

- static calculus of the anchored structure and the stability of exploitation load (service load) pertaining to an anchorage (so called anchorage reaction)

- choosing the type of tirant for the anchorage depending on the size of exploitation load and soil conditions (nature, stratification, physical and mechanical characteristics) and the checking of its bearing capacity

- checking the general stability of the anchorage (structure+anchorage+earth)

- establishing the execution technology of the anchorage (drilling, injecting, tensioning) depending on tirant type and soil nature

- execution and loading some sampling tirants

- finalizing the project, on the base of results obtained from testing the sampling tirants

To execute the pretensioned anchorages fixed into the soil interfere the following main works categories: the execution of drillings in which are introduced the tirants already made, injecting the anchorages and tensioning and testing the anchorages.

The execution of drillings must correspond to the geometrical elements established at the anchorage designing: total length of the anchorage, diameter corresponding to free area and anchorage bulb, inclination of anchorage towards the horizontal.

Injecting is done in two phases. The first phase is represented by the primary injection executed in order to achieve the anchorage bulb and the second phase is represented by the secondary injection executed on the exterior of protection pipes on the free length of anchorage tirant. The object of testings made on anchorages is to check the safety coefficient fixed "a priori" and to determine the limit tension from the condition of anchoring into the soil (pulling out). The sample testing is always necessary and especially at the soils not very well known susceptible of creeping or when the constructor that has to accomplish the anchoraging works has never executed anchorages of the same type.



Figure 2. Testing Diagrams – a sampling tirant for definitive anchorages: a) in soils with known physical and mechanical characteristics; b) in soils with slightly known physical and mechanical characteristics

RESULTS AND DISCUSSION

For suspended constructions, traction forces are discharged into the foundation soil. These problems appeared before in the case of suspended bridges, but nowadays the problem of anchorages bearing of great traction forces appears often also in the case of hangars for jet planes and big gymnasium halls. In the case of suspended roof of the Olympic stadium from Munich many these problems necessitated to be solved. The suspended roofs that mainly covers the main stadium, sport-halls and the swimming pools having a surface over 70000 sqm is supported by a construction of pretensioned cables. The total traction force of 100000 tones is discharged through anchorages in 120 places.

To select the type of anchoraging depends on the type and physical-mechanical characteristics of the soil, but also depends on the inclination grade of the traction force. Foundation soil from Munich presents very good characteristics. First 8 m consists in densely sandy gravel from Pleistocenum (first epoch of Cuaternarum). Under this layer, there are three layers from Miocene and Pliocene mainly consisting in fine sand up to medium sand. Because of its density relatively big, it is not possible to stick the metallic piles into the soil at a very big deepness.



Figure 3. General view of suspended roof foundations from Munich stadium

At a sticking by tamping with the maul IP-400 at a depth of 1 m, there are necessary 2000 tampings. By in situ testings, it was noticed that this type of soil is proper for construction of foundations of wall types and injected anchorages. Depending on the inclining angle of traction force, there were selected three types of anchored foundations: weight-blocks, trench-wall-anchors and bases fastened by ground anchors.

Weight – blocks were used to take over vertical traction forces or traction forces inclined with a small angle. Using this method, it results the smallest displacements. The settlement δ_1 is the result of the elastic bond between the foundation soil and foundation. At other types of foundations, the maintenance of elastic bond between the foundation soil and the foundation taking over in the same time the traction forces, appear three supplementary elongations: the elongations due to taking over the shearing efforts at the ground level δ_{t} , elongation of the pile δ_p and elongation of the anchorage δ_a in the case of earth anchorages. If the anchorages are pretensioned, the elongation is smaller, but not completely eliminated. Obtaining the smallest displacements was necessary in the case of the swimming pools structures where the vertical force of 2000 tones had to be anchored into the soil and that's why there were used foundations of weight-blocks type. There were also used weight-blocks foundations in the case of peripherical cables of the stadium where big inclined forces of 5000 tones with an angle less than 7^0 had to be anchored. The foundation blocks of the peripherical cables are behaving as a shield to mobilise the passive pressure of the block. When the traction force is brought into this position, the foundation has the tendency to roll over, thus resulting a negative angle of the friction that acts on the foundation block side.



Figure 4. The influence of traction force on the friction and earth pressure

The necessary weight to mobilise the friction under foundation block is mainly the result of the filling material that acts on the foundation base. In this way, there are obtained foundations of concrete blocks weighting 2850 tones for a total traction force of 5000 tones, representing approximatively 57% from the total traction force.

Trench wall anchors are used for traction efforts with small inclinations. This type of foundations is used for traction efforts greater than 4000 tones.

When the efforts act on the walls, it has the tendency to rotate towards a point located on the foundation base. The equilibrium is mentioned because of active earth pressure and even the wall has the tendency to be subjected to bending. In the case of the Munich stadium, there was proposed a trench wall, of T cross-section (26 m height and 6 m width) to take over the traction forces. To take over bigger efforts it is necessary to group a great number of these elements, located together, such as the strength is obtained from a continuous mass of earth (WEIBENBACH 1962). It is necessary to build a belt over these elements, the belt being prestressed towards the trench wall foundation. The purpose of pre-stressing is to have a construction without cracks when is subjected to big bending moments. At the execution of these elements appeared difficulties concerning the friction angle with the horizontal of the traction forces, which was between 30° and 45° . This means that the most part of the vertical component had to be taken over by the soil. In Munich, the previous experience showed that the bentonite suspensions give water nest to the trench wall, where there are permeable soils as sand and gravel. This led to the formation of some silting layers at the surface of opened trenches. When the next layer of concrete is poured, the silting layer persists and it is acting as a lubricant between the wall and the soil, such as the friction angle on the wall is reduced. To increase the friction angle on the lower side of the wall, it was used a rotative machine that cut channels of 15 cm width. The stability analysis at sloping of the wall showed that the strength of foundation soil is completely mobilised, above and under the rotation point.



Thus, the rotation point had to be located somewhere under the below half of wall height. Due to great expenses for a site experiment on a model of T shape, in which the element is subjected to tension, there were made two types of experiments. The first one is on two elements of I section having the width of 9.00 m, such as to be kept the ratio between the height of the element into the gravel and the height of the element into the sand. The second is made on element of I section having the width of 4.00 m, dug only in gravel in order to measure the friction of the wall in gravel. The elements subjected to tension test were loaded vertically, horizontally and oblique. Thus, the wall is rotating towards a point that is located to up and in most of the cases above the middle point of the wall. The rotation point has the tendency to rise as much as the horizontal load increases. The foundation was considered a beam restrained into the soil. The elastic supports on walls sides represent the reaction of the foundation soil and the friction on the wall side when the wall is rotating.

The third foundation type used at Munich stadium is foundations with anchorages and injections into the soil. Ground anchors of small capacity are used to take over great traction forces, considering a group of anchorages as a single element that mobilise a big quantity of earth to take over these forces. This principle was applied to take over traction forces from 200 tones to 700 tones in 40 different places.



Figure 4. Dimensions of earth mass in the case of a group of anchorages

Every group of anchorages has between 6-12 anchorages having lengths from 14 m to 22 m that mobilise a big quantity of earth to take over the traction forces (by lines A-B-C-D and E-F-G-H). The anchorages used are of Bauer/Stump type made from pretensioned steel St 80/105 having the diameter of 32 mm, which are introduced into the bored hole and the inferior head, is filled with the injection mortar. Each anchorage was tested at working force of 1.5 times bigger, meaning 55 tones. Testing one anchorage we don't receive any information concerning the transfer position of the load. To assure that the transfer is taking place into the most inferior part of the anchorage, meaning on the transfer length planed of the anchorage, it has to be established the transfer point of the load. This thing is obtained by injecting a quantity of mortar. In the case of anchorage and located at the end of transfer length of the planed load. If the anchorage is located in two earth layers, namely in the gravel layer injected with cement mortar and in the sand layer non-injected, it has to be specified that the transfer length of the planed load has to be settled only in a certain layer.

Comparing the three anchoraging systems described below, it can be pointed the followings:

- the type of weighting blocks are suitable for traction loads of any inclination and there are used when the traction loads are bigger than 2000 tones;

- trench wall anchors are used for traction loads of small inclination. For traction loads with angles bigger than 60^0 towards the horizontal, these types of foundations are not suitable. This type of foundations are used for traction loads greater than 400 tones;

- the groups of ground anchors are used when the angle between the traction force and horizontal is greater than 30° . If the inclination angle is very small, the layer of 4-5 m necessary to the transfer length of the load can't be achieved oftenly without the danger of slopeing the foundation soil.

A reinforcing work is performed to stop the landslide from cutting or to assure the stability of the soil in the foundation place.

Retaining anchored walls are construction works executed in order to stop the active earth pressure of the supported earth massive. The execution tehcnique consists in execution a retaining wall and while the embankment is created there are introduced the reinforcing bars.

Dimensioning of retaining walls with multiple anchorages is performed by many calculus methods in order to check the stability at sliding.

In generally, the reinforcement bars works at an effort that doesn't have to exceed the elastic limit; the shearing strength of the soil has a safety coefficient of 1.5.



Figure 4. Stability study of a retaining anchored wall by TALREN programme

The retaining walls with multiple anchorages differentiates from reinforced earth constructions by the fact the interaction between the earth and the anchoraging tirant is placed on the free side of the tirant, in the anchoraging area formed in generally, from an injected fixing bulb for the works in filling.

CONCLUSIONS

Considering the great number of pretensioned anchorages achieved up to now for a great number of foundations and embankments works, the knowledge about their behaviour is still incomplete. These happen not because there are missing some measurements at natural scale, but because of relatively reduced possibilities of understanding the earth behaviour by its properties in the process of tensioning tie bars, in execution phase, but mainly during their operation in time. The complexity of this problem is also increased by the intercession of to many factors that are present during the process of transferring the force from the anchoring tie bar at the soil where it takes place the anchoraging. This state of works constitutes the cause for which the conception and structure of different types of anchorages or tie bars are not based on calculus, but more on intuition and palpable experiments on site, after that the improving of site technologies is done in general, by the practitioners.

The main advantages of this modern procedure are represented by the reduction of material consumption and the possibility of a maximum mechanization of execution works.

The procedure of anchorages with pretensioned tie bars creates the possibility of solving some foundation problems that in other solutions would be extremely expensive or impracticable from practical point of view.

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