Experiences with SBMA ground anchors in spanish soils

Etude expérimentale avec les tirants d’ancrage SBMA dans le sol espagnol

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ABSTRACT: The load transfer mechanism of steel, subjected to axial tension, adhered to a soil or rock through a cement grout is not through a uniform stress distribution. This results from the general incompatibility between the modulus of elasticity of steel, grout and soil, causing the phenomenon known as progressive debonding, as it causes the increase of the load of the anchor. The investigation of this phenomenon, the development of this knowledge and its application to industry has resulted in the SBMA System. This system applies much more efficiently the bond stresses available in the field through the use of various units within a single anchor borehole. We present brief guidelines for their design, and case histories within different geotechnical units in Spain.

RÉSUMÉ : Le mécanisme de transfert de charge d'un tirant en acier, soumis à une traction axiale, scellé dans le sol ou le rocher par un coulis de ciment ne se fait pas avec une répartition uniforme des contraintes. Ceci résulte de l'incompatibilité générale entre le module d'élasticité de l'acier, le coulis et le sol, provoquant un phénomène de décollement progressif et d'augmentation de la charge de l'ancrage. L'étude de ce phénomène, le développement d'un savoir et son application à l'industrie sont synthétisés dans le système SBMA. L'utilisation de plusieurs éléments dans un seul forage permet d'augmenter l'efficacité de l'ancrage. La communication présente des directives de conception, et des cas historiques dans différentes unités géotechniques en Espagne.

KEYWORDS: design – ground anchor – multiple anchor - load transfer – efficiency factor – fixed lenght

MOTS CLES: Conception, tirants, ancrage multiples, charge de transfert, facteur d'efficacité, longueur de scellement

1 INTRODUCTION.

Anchor design codes allow engineers to assume load is distributed uniformly through the length of an anchor, but experts acknowledge that the ultimate load is not proportional to the anchor’s fixed length.

Anthony D. Barley’s (1995, 1997, 2003) research and development for over a decade confirmed and extended existing independently works coming to the same conclusion of the non-uniformity of the distribution of adhesion in the fixed length anchor, but finally introducing the efficiency factor for calculating the length of the fixed length of an anchor considering this phenomenon. This research was then applied to the development of a new technology for ground and rock posttensioned anchors called Single Bore Multiple Anchor (SBMA).

In 2004 this technology was introduced in Spain, in which the author was responsible. This was done with the technical support of A. Barley.

2. DESCRIPTION

The system involves the installation of multiple units in a single anchor borehole. Each unit has its own single tendon, his own free length, length of bulb and is loaded using its own tensioning unit. The tensioning of all anchor units is performed simultaneously by a hydraulic jacks synchronized equipment that ensure that the load applied to the various units is always the same. The sum of the loads of the various units loads totaled the anchor total of the SBMA. With the design conception, there is no theoretical limitation on the overall bond length used (the sum of the fixed lengths of the various units), while for the conventional anchors little increase is expected load over fixed lengths of 8 to 10 meters.

Another advantage of the system is the opportunity to take account of the varying strata within the ground, as each anchor within a bore can be designed for different ground conditions. Experts agree that the SBMA system is most effective in weak soils either to enhance capacity or to reduce the total number of anchors. However, they are not economically viable where the structural loading requires only low load anchors at wide spacings.

Figure 1. Adhesion stress distribution in several efficient units

3. DESIGN

3.1 Efficiency factor

The relationship between the stiffness of the fixed anchor (controlled by the steel tendon) and the stiffness of the ground governs the rate of progressive debonding as an anchor is loaded and hence affects fixed length efficiency.

The nonlinearity of the mobilization of the value of the grout/ground bond stress ($\tau_{ult}$ vs. $\tau_{res}$) along the fixed length could be accounted by the efficiency factor for ground anchors.

$$f_{eff} = 1.6 \cdot L^{-0.57}$$

(1)
The ultimate geotechnical capacity of the anchor ($T_{ult}$) is:

$$T_{ult} = \pi d \cdot t_{ult} \cdot f_{eff} \cdot L \tag{2}$$

This formula does not apply to granular soils where the capacity to borehole diameter ($d$) is not linear and has to be establish by meter of fixed length.

All load transfer mechanisms from tendon to grout induce bursting forces in the grout of one degree or another. Generally, the greater the mechanical locking effect (end plate or major deformations) the greater the bursting forces. It follows that the shorter the tendon bond length the greater the mechanical locking to allow the potential transfer of full tendon load capacity. However, this can only be effected where the ground or strong rock will provide adequate confinement of the grout column to prevent bursting failure. So to reduce the inefficiency in load transfer (entire fixed length in shear and tension) it is appropriate to utilize tendon bond lengths long enough to eliminate the risk of bursting failure yet as short as possible to gain maximum efficiency from grout/ground bond (Figure 4).

The high values of bond stress at the grout/ground interface results from the dilatancy effects of the soil in the shear zone, and interlocking at the rough interface, all as a consequence of an increase in radial normal stress.

Figure 4. Probable bond stress distribution in compression and combined shear and tension.

3.2 Preliminary tests

Where preliminary trial anchors are tested to failure, each unit anchor yields its own value of ultimate bond capacity and hence more intensive data than conventional test anchors. The in situ testing of many of these multiple anchors with variable unit lengths has therefore recently extended the knowledge and understanding of the tendon/grout/ground bond mechanism. The SBMA system has been utilized in permanent anchors and temporary anchors (including those with removable tendons).

Test anchors of length 2.5 to 5 metres may easily be taken to failure to establish the ultimate bond stress of that length and then the fixed length of production anchors accurately, designed to provide the required factor of safety. In the trials it is important to control the grouted length tested.

4. CASE HISTORIES

4.1 La China Stormwater management pond (Madrid)

In carrying out the excavation depth of 15.0 meters, were implemented temporary SBMA anchors of 2000 kN design load, using four units in the soil strata called "Peñuela" (gypsum with interbedded clays). The system was used always in combination with an injection unit located in each bulb known in spanish specification as IR that involves a postgrouting procedure and each units had 3x0.6” steel strand.

Research trials conducted according to the standard UNE 1537, allowed to change the original traditional ground anchors design, for less multiple anchors with increased load and efficiency.

Figure 6. Section of diaphragm wall with trial anchor test TA2.
4.2 *Parking La Vega (Murcia)*

For the excavation of a parking 16.0 meters deep, with 9.0 meters of water thrust, one row of temporary SBMA anchors of 1900 kN were executed using four units in a dense gravel. This bearing layer was underlying clays and silts with medium consistency supported by a diaphragm wall thickness of 0.80 m. This solution as an alternative to a 0.60 m thick wall and two levels of traditional anchors.

4.3 *Palacio de los Congresos (Cartagena)*

The Cartagena Convention Centre, located next to the port, run an excavation depth of 13.0 meters, with 10.0 meters of water pressure. The containment wall was formed by a diaphragm wall 1.00 m thick and 2000 kN temporary anchors, bulb units in both compact red clays, and gravelly dense sands according to the geotechnical profile of each sector, and combinations of both soils in the same anchor. The inclination of the anchors was 30 to 40 degrees to the vertical, in order to avoid obstacles and achieve the desired geotechnical units.

4.4 *El Corte Ingles (Albacete)*

In the execution of the excavation depth of 14.0 meters, were implemented temporary anchors SBMA of 1200-1800 kN
design load, using three and four units in clays and silts of medium consistency, supporting a diaphragm wall of 0.80 m thickness with a water head of 10 meters. The were employed four rows of anchors, the first line with traditional anchors and the other three with SBMA.

In the preliminary research trials, within the present cohesives soils ($N_{spt} < 8$), the distribution of the adhesion along the fixed lengths tested was close to linear. The same is known of loose granular soils.

Figure 13. General view of the jobsite at design excavation level.

Figure 14. Execution of acceptance tests in El Corte Ingles

Within the reference work, we tested the use of multiple removable anchors as a modern solution to urban problems of public land use. This anchor also employs several units, each consisting of a single tendon lubricated and encapsulated in its entire length, which is bent in a special chair 180 degrees. The chair has a steel bar and the whole performs as a compression anchor, which transfers the load to the cement grout and ground. Thereof the anchorage capacity determines the number of units. The cable of each unit is then removed by pulling one of its ends. The complete withdrawal of steel anchors once their useful life is due, freeing of "pollution" of the ground for future use (subway/metro, underground pipes, buildings with deep foundations or basements, etc.)

Figure 15. Removable SBMA units, schematic arrangement.

Figure 16. Removing an anchor unit with a force of 50-150 kN.

5. CONCLUSIONS

SBMA ground anchors are currently the most advanced technology for greater efficiency in the use of high adhesion capacity of the ground by the technologies currently employed in the execution of post-tensioned anchors. This system increases the limit loads traditional anchors used in soils, and innovation in paradigms hitherto employed in reference to the design and implementation of the fixed length of an anchor.

The efficiency factor should be complemented with more test data from different soil units with different consistency or relative density; so further detailed test trials research for the better understanding of each geotechnical unit is to be done. Meanwhile, there is experience accumulated in the countries where this technique has been being used the last 20 years.

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7. REFERENCES


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