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Anchored Structures: State of Art in Brazil and in the World

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Abstract- The first application of anchors was in 1880 to reinforce the Cheurfas dam in Algeria. Since then, they have undergone successive evolutions and their applications have become quite frequent in several situations. In Brazil, the first application of anchors in retaining structures was in 1957, at the Rio-Teresópolis highway. The first world standard was published in 1972 in Germany and it was responsible to motivate the publication of the first Brazilian standard in 1975. Since then, mainly motivated by the appearance of new anchors in the market and the change between the limits in the water/cement factor for the cement slurry, the executive procedure have been changed. It is important to understand all the evolution process for the improvement of the current technique. This work aims to present the history and evolution of anchors applications, their constitution, classification and their state of art in Brazil and in the world in the last 40 years. In addition, it highlights the origin of the technical improvements motivated by the development of world engineering.

Keywords- *Anchor, Tie-Rod, Anchored Structure*

I. INTRODUCTION

The use of an anchor technique for stabilization in geotechnical engineering is presented as a viable and economical method. The main and first use of this technique is and was for pre-existing structure reinforcement, slope and excavation stability. But, there are several applications currently available.

Advantages of using this technique can be convenience, fast execution, versatility, and safety. In addition, it ensures small deformation compared to other retaining techniques. However, in Brazil and in the world, the subject is little studied and its knowledge as well as improvement mainly comes from the experience of contractors through the implementation and monitoring of the works.

The objective of this study is to evaluate the anchor technique state of the art, its evolution in the world and in Brazil, the presentation of the currently known applications as well as technical information related to its constitution, classification, and motivation of the standards updates existing in Brazil. This study also aims at the improvement and knowledge of the technique by the geotechnical community.

II. EVOLUTION OF THE ANCHOR TECHNIQUE

A. *Evolution of the anchor technique in the world*

The anchors are elements that when introduced in the ground is able to withstand tensile stresses and transmit these forces to the geotechnical mass to which they were anchored. The uses of anchors in rock mass were a pioneering application of great relevance since 1934 as a retaining solution for the Cheurfas dam in Algeria [1].

The Cheurfas Dam, built in 1880, was designed to work as a gravity structure [2]. However, in 1885, it collapsed, being rebuilt 7 years later (1892). In 1930, the dam again had problems in the foundation. Due to this situation, it became necessary to resort to a new intervention, thus guaranteeing the restoration of the structural integrity of the soil mass. The engineering solution proposed by the engineering André Coyne consisted in the introduction of 37 anchors as shown in Fig. 1 and 2.

In European countries, much is discussed about the pioneering implementation of anchors. It is known that the technique came up from several small applications that occurred in parallel in countries like England [3], Germany [4] and Switzerland [5] in the 1950s. At this time, the anchors operations involved the recovery and construction of dams and the support in tunnels at great depths, predominantly in rock mass. However, at the beginning of the 1960s, the procedure involved anchors in rock and soil mass, using the temporary and permanent type, with a load capacity of 200 to 900 kN.

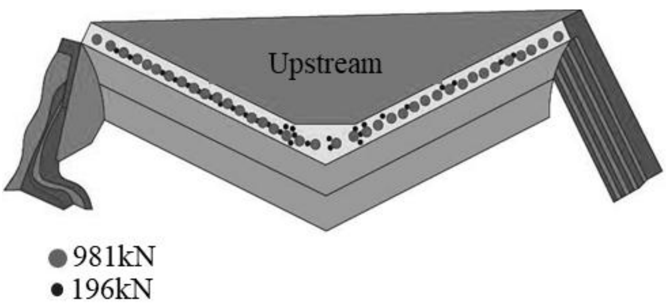

Figure 1. Plan view of the Cheurfas dam in Algeria. Adapted from [6]

The method of building anchors, especially in European countries such as Germany, Austria and England, was the Baüer system. In this method, the injection was performed through the drilling liner by a crown. At the desired depth, the armature was coupled to the crown and inserted into the bore. Subsequently, the coating was gradually removed by injection of the cement slurry simultaneously, completely filling the void between the armature and the walls of the bore. The holes usually had a diameter of 8 cm.

The pioneering applications in Austria aimed at stabilizing slopes in the mountainous areas of the Alps. In France, the initial impulse to use anchor was motivated by the need to occupy underground spaces, for example, by building construction. However, because it is a recent technique, many problems of legal orders related to the executive procedure have been presented.

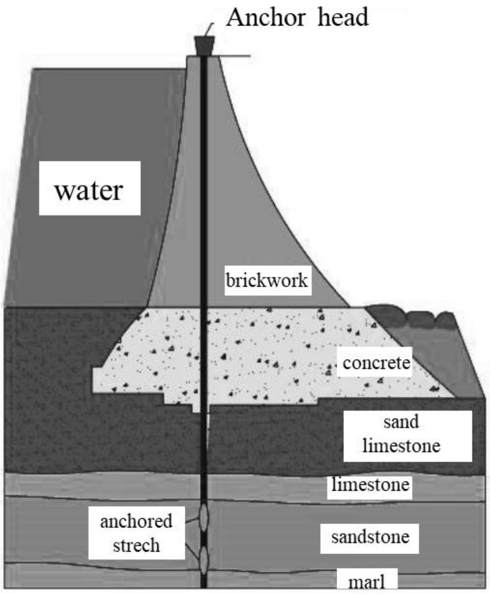

Figure 2. Geological profile and cross-section of the Cheurfa dam in Algeria. Adapted from [6].

In the United States, as well as in European countries, the use of anchors began in the late 1950s. The main application of the method was aimed at the stability of excavations and underground works. However, the high costs generated by execution problems, mainly due to the absence of recommendation standards for projects and tests, limited their use during this period to low load capacities and restricted construction.

In the late 1970s, the anchor technique was extensively developed due to: the improvement of the steel used in the prestress concrete, injection of cement slurry in the soil and creation of the Freyssinet hydraulic jacks that were used to prestress steel.

In the United States, the development of the anchor technique occurred due to the construction of the World Trade Center in New York. In the construction of the building, six levels of temporary anchors were executed in rock mass, with load capacity around 3000 kN, a slope of 45° in a ground anchor wall with a total length of 950 meters and 16 meters of height. In other countries of America, the development of the anchor technique has been concentrated in the big urban centers, advancing along with the innovations implemented by the European countries [6].

From this period, it became possible to carry out safe excavations in large-scale with high productivity and ease of execution. Several other works were carried out in the United States and in Europe for improvements in traffic, such as new subway projects or expansion of the old ones. In addition, several buildings were constructed with garages of great depths and, consequently, considerable excavations.

In 1972, the first standard about anchors was published in Germany, the DIN (Deutsche Norm) 4125 “Soil and rock anchors, temporary soil anchors, analysis, structural design and testing” [7]. This standard was the basis for other countries, such as Brazil, to publish their recommendations, facilitating the executive process and verification of anchors in soils. In addition, it contributed to the absorption of the technique by the geotechnical community spreading its use in the country.

B. Evolution of the anchor technique in Brazil

In Brazil, just as in other countries, the anchor technique is relatively recent, since its use started in the late 1950s. (Fig. 3).

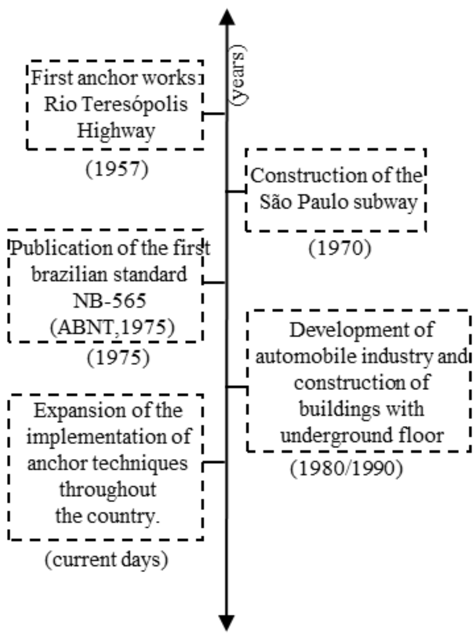

Figure 3. Chronological evolution of the use of anchor in Brazil. Adapted from [2].

The first anchors use in Brazil was in the construction of the Rio-Teresópolis highway (Fig. 4), currently named as

Rodovia Santos Dumont (BR-116) [8]. At the beginning of its construction, the difficulties and limitations of the excavation in rock mass were not known, thus, the work is considered as a reference in the advance of the engineering of that time. This highway was inaugurated in 1959 and it was mentioned by the newspapers as "A work of crazy people".

After the Rio-Teresópolis highway construction, the subways of São Paulo and Rio de Janeiro began to be constructed. The excavation of large volumes of material demanded by these works resulted in further advances related to the study and knowledge of the anchor technique by the Brazilian geotechnical community, contributing to the diffusion of the subject among the engineers.

Figure 4. Construction of the Rio-Teresópolis highway. a)Km 25 (1968) b) Km 88 (1968) [9].

In 1968, the first load tests were executed on anchors with load capacity up to 450 kN. The load capacities, which previously did not exceed 250 kN, reached up to 600 kN in the most central areas, where there was concentration of high-rise buildings.

In the construction of the subway of São Paulo the drilling system used was without spiral winding, being later replaced by the system with washing and rotary survey. The diameter varied from 7 to 20 cm, in some cases, and bentonite mud was used to stabilize the hole. Depending on the required load capacity, the cement slurry was injected either by gravity or under pressure.

About 1400 anchors were executed in the first line of the São Paulo subway [10]. At the end of the work were validated important findings regarding the influence of the injection pressure on the load capacity and the reinjection process. It was also noticed that the absence of standards generated extreme difficulty in standardizing a verification process that would guarantee the later safety of all works. Due to this important construction and the publication of the first standard about achors [7], the first brazilian standard was published: "Structures anchored in the ground - Anchors injected into the ground" [11].

Nowadays, the technique of anchor in Brazil and in the world is in full development. It has gained the engineers confidence in the face of the growing need for constructions that do not allow for re-sloping and excavation in large urban centers and highways. In addition, it offers solutions for a wide range of applications. It can reach high load capacity values, on the order of 1500kN, due to the manufacture of high strength steels and the optimization of constructive technique.

In addition, the technique has good adaptation to the limit equilibrium methods. The simplicity of checking as well as monitoring of loads and the application of known loads (acceptance tests) during the execution process are factors that aid in the acceptance and current application by the engineers.

III. ANCHORS APPLICATION

Over the years, the application purposes of the anchors were diversified, their use have several objectives such as:

A. *Stabilization of underground excavations*

The construction of subways, buildings with underground garages and mining were motivating factors for the use of anchors in the purpose of stabilizing underground excavations. Nowadays, the underground space has been used due to the great appreciation of superficial grounds and to the problems related to urban mobility, which the big urban centers are submitted. Fig. 5 shows a sketch illustrating the use of anchors in tunnels.

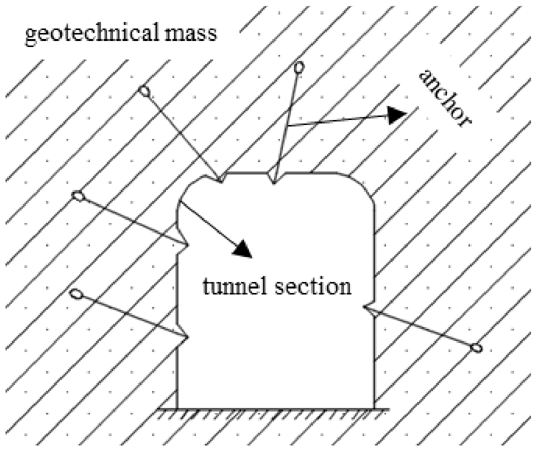

Figure 5. Anchors in tunnels. Adapted from [12]

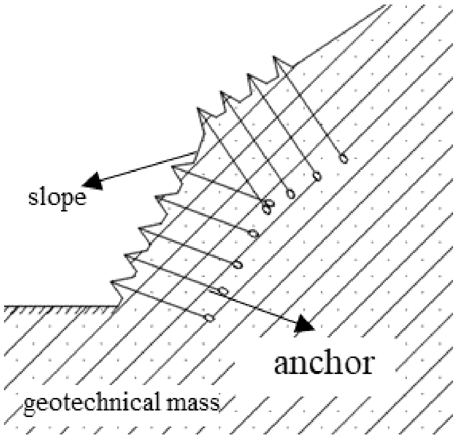

Figure 6. Anchors in the consolidation of slopes – soil nailing. Adapted from[12]

B. Implementation of retaining structures for slope stabilization

The application of anchors for retaining purposes to stabilize slopes is present in cutting and fill works ranging from highways infrastructure to stabilization in large urban centers occupying mountainous and rugged regions. In this category of works, it stands out the system of ground anchored wall and soil nailing. Fig. 6 shows a ground anchored wall as an example of stabilization work.

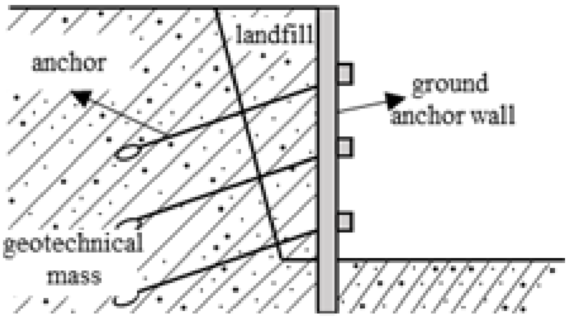

Figure 7. Ground anchored wall. Author (2018)

C. Anchor applied in the construction of dams and auxiliary structures

In addition to being used as conventional retaining structures, the anchors can also be used as reinforcement elements in earth or concrete dams. Classic example is the reinforcement of the Cheurfas dam in Algeria.

The Pacajus and Rosário dam, both located in the State of Ceará, Brazil, are examples of dams that had to be reinforced due to the magnitude of the erosion cavities formed downstream of the structures. The interventions were carried out with the purpose of protecting the foundation of the dam, thus avoiding the expansion of the erosive cavity [13]. The Fig. 8 represents the example of anchor in dams.

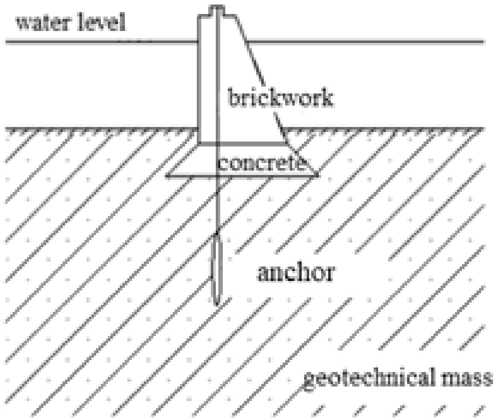

Figure 8. Use of anchors in dams. Adapted from [12].

D. Strength to subpressure forces in buried structures

The use of anchors in channels has several applications, especially: reinforcement of the retaining structure ensuring less horizontal displacement of the structure; sub-pressure control of the bottom slab in case the water level is too high. The Fig. 9 shows the example of an anchored channel.

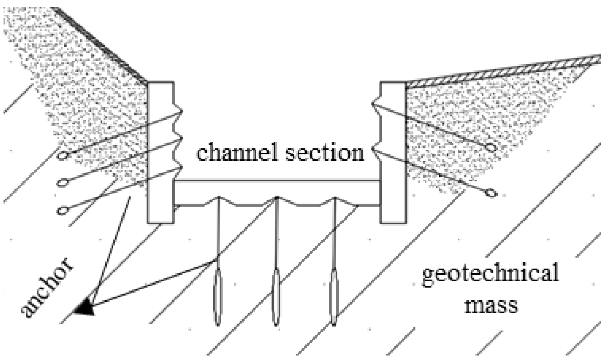

Figure 9. Anchors in channels. Adapted from [12]

E. Foundations of structures subject to inclined stresses

Due to the configurations of some structures that favors the eccentricity, resulting in moments of toppling. The anchors are executed as foundation elements positioned vertically or inclined. They are solutions to stabilize the foundation, since they act as a counterweight that compensates for the actions introduced by the moments of toppling (Fig. 10).

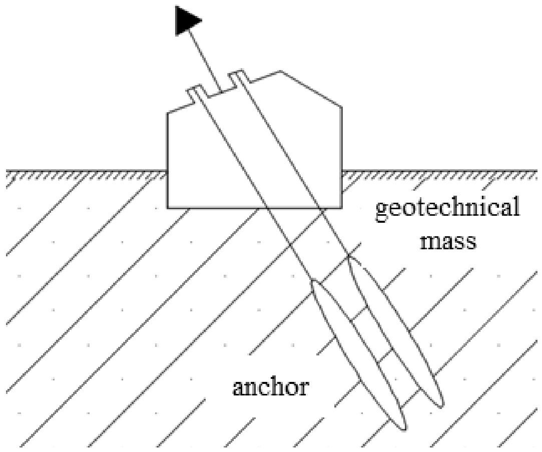

Figure 10. Schematic representation of structure subject to inclined stress. Author (2018)

In this type, anchors with a high load capacity are often required, being the most adequate to anchor in soil mass with N_{SPT} over 30 or in rock mass.

F. Cable Staying of roofs subject, in particular, to the action of the wind

The use of anchors is not limited exclusively to retaining structures. This device can also be used in the cable staying of roofs subjected, especially, to the action of the wind. An example in Brazil is the reinforce work of the João Havelange Olympic Stadium roof, better known as Engenhão, in Rio de Janeiro-RJ. After a technical report about its roof in the year 2013, a reinforcement project was needed. It consisted of the installation of two anchors on the west and east sides of the stadium, in order to distribute the loads of the compromised structures.

G. Foundations of special works, such as masts, towers and cable

The transmission line towers are structural elements that are used as support to cables installation for the purpose of transmitting electric power [14]. They are classified according to the voltage of the line and its structural type in:

1) Self-Supporting Towers: Large metal structures that can be rigid, flexible and semi-flexible. They have the capacity to withstand to great efforts, transmitting them directly to the foundations, being able to reach high values of bending moments along with to the ground line. These towers may vary of suspension, transposition anchor and end of line.
2) Cable Stayed Towers: Flexible structures used in flat locations and in non-angled line stretches. They are stiffened by stains, which are responsible for absorbing part of the stresses that are transmitted to the anchors, and the other part is transmitted by the structure itself. The Fig. 11 shows the anchor in towers.

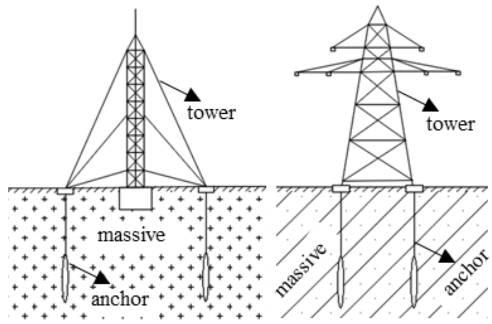

Figure 11. Representation of anchor in towers of transmission lines and telecommunication towers. Author (2018).

H. Execution of micro-piles or presso-anchor type piles as reinforcement of foundations

As alternative to combat excessive settling in buildings there is a possibility of using micro-piles or presso-anchor piles as reinforcement of foundations. In the case of the latter, there is also an option of an improvement of the strength properties of the geotechnical mass, cohesion (c), and friction angle (ϕ).This is possible because the presso-anchor pile type acts as an anchor, so there is an injection of cement slurry under pressure. However, this is an onerous alternative for the executor/contractor. As a result, this solution should only be used in extreme cases. The Fig. 12 shows the anchor in foundation reinforcements.

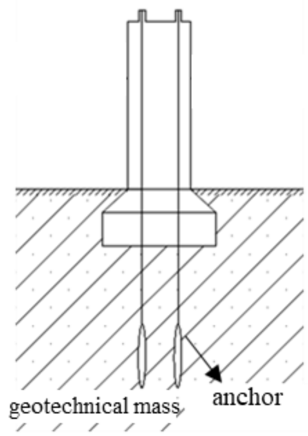

Figure 12. Representation of anchor in foundations reinforcement. Adapted from [12].

I. Installation of "in situ" load tests

"In situ" load tests are usually carried out as an alternative for the technological control of foundations works executed with piles. For each 100 piles executed, one (1) of them must be tested, thus measuring the geotechnical load capacity in the field and comparing with the calculated in the design stage

[15]. For the installation of the load test reaction system, it is usually used reinjectable and prestressed anchors. The Fig. 13 represents a typical anchor model as a reaction system for in situ load tests.

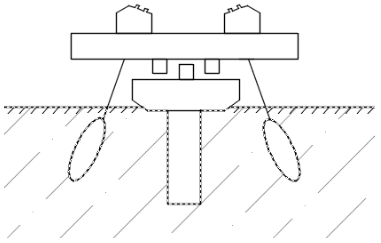

Figure 13. Representation of anchor in in situ load test. Author (2018).

IV. ANCHORS CONSTITUTION

The structural element of load transfer is the tie-rod. It is constituted by head, free length and bulb of anchor.

The tie-rod acts as a structural element responsible for transferring the stresses of the prestress to the bulb of anchor. In order to form the anchor, the tie-rod is installed on the construction site and then inserted into a hole previously made in the ground and attached to it by injection of cement slurry.

The tie-rods must have an armature with sufficient conditions of elasticity and strength that guarantees the safety and durability of the work. They can be made with bars (monobarra or multiple bars), wire or cord.

The bar tie-rod can be a monobar type when using a single bar or multiple bars when several bars are used. The monobar tie-rod (Fig. 14) is generally used in the case of small anchors with small load capacities. Multiple bars are used for situations where greater load capacities are required. The monobar tie-rod is the simplest alternative among all of them since it presents greater ease of anticorrosion protection and low cost when low load capacities are required.

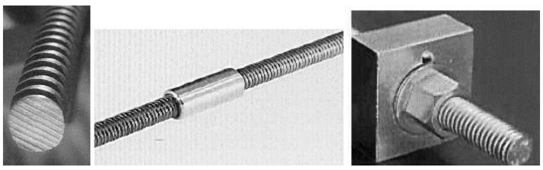

Figure 14. Monobar tie-rod. [16]

In the wire tie-rod the tensile strength is guaranteed by the wire having a minimum area of 50 mm² or 8 mm in diameter. Usually groups of 10 to 100 wires are used. It is little applied because of the numerous problems presented with corrosion. The cord tie-rod is constituted by steel cord with variable diameter (Fig. 15).

The cord and wire tie-rods have greater tensile strength and are easy to transport and store, favouring their application in places with reduced space. However, the load limiting of bar tie-rods is significantly higher than cord tie-rods.

Figure 15. Cord tie-rod. [16]

The rupture of the tie-rods causes a decrease in the safety of the massive to be retained, leading to even total ruin of the structure and, consequently, to its slipping or collapse. In order to ensure the stability conditions, it is necessary the correct dimensioning and calculation of the safety factor of the work and the tie-rod must be protected against corrosive processes to which it is exposed.

Anti-corrosion protections are recommended by standards and generally consist of cement slurry application, PVC pipe, metal sheathing, galvanizing, specific paint or grease on the tie-rod surface (it depends on tie-rods lifespan and the pH of the environment).

The anchor is also composed of the head (Fig. 16). The head is located in the outer region of the ground and it is responsible for securing the anchor armature to the support or retaining structure through the anchored block. In addition, it supports the retaining structure and in the case of active anchors it is the component under which the prestress is applied.

The head (Fig. 16) consists of the anchor plate, grade wedge and anchor block. The anchor plate is responsible for distributing the load applied to the anchor head. It is constituted of sheet metal that are able to transmit the compressive stresses to the retaining structure. The grade wedge, composed of a cylinder of reinforced concrete or formed by parallel plates of steel, is installed to allow the alignment of the tie-rod with the head. The parts responsible for securing the tie-rod in the region of the head are called anchor blocks.

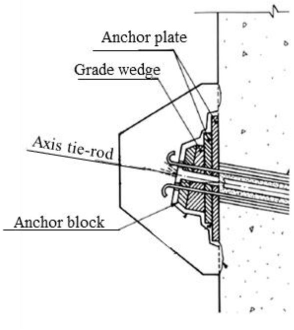

Figure 16. Details of anchor head. [14]

The anchored portion or bulb of anchor corresponds to the extremity end of the anchor (Fig. 17). Its role is to transmit to the ground the tensile load applied to the head and supported by the free section. It consists of the tie-rod, wrapped by the injection of cement slurry.

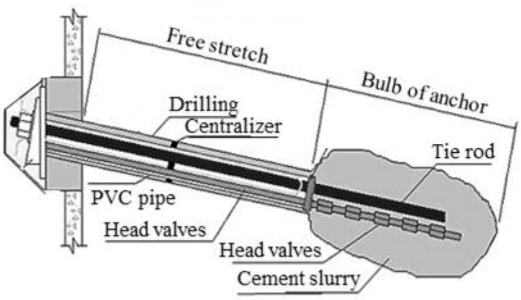

Figure 17. Elements of an anchor. Adapted from [17]

The free stretch is defined by the intermediate stretch between the head and the bulb of anchor. It has the function of transmitting the tensile loads between the head and the bulb of anchor.

It should be ensured that all the load applied in the prestress is transmitted to the bulb of anchor and does not cause any damage to the free stretch. However, the injection of the free stretch must be performed after injection of the bulb of anchor. In addition, through the acceptance tests, the freedom of movement of this section must be checked, since it must strain freely, because if there is any restriction, it is inferred that the anchored section was tested with a load lower than that indicated by the manometer or that there is transfer of load between the free length and the ground.

Centralizers, spacers, PVC pipes and headline valves are accessory components used in tie-rod installation to ensure rectilinear, corrosion protection and wrapping by the cement slurry at the anchor.

The centralizers (Fig. 18) are used to center the tie-rod in the hole, ensuring uniform distribution of the cement slurry. They are placed in the anchored section at intervals of not more than 2 m and the most common type is the plastic half-moon [17].

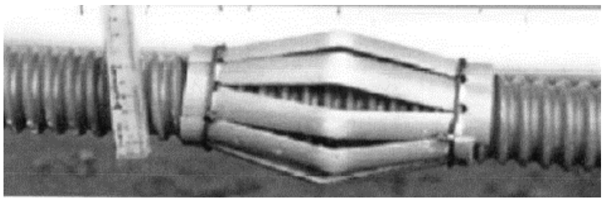

Figure 18. Centralizer and corrugated protection tube. Adapted from [17]

The spacers are also necessary to ensure the centering and straightness of the tie-rod in the hole and to ensure a minimum distance between the steel and the wall of the hole. As a result, they protect the reinforcement against corrosion. In cord and wire tie-rods, this accessory is widely used to ensure spacing between these components.

PVC (Polyvinyl Chloride) pipes are non-degradable pipes, act in the individual or collective isolation of the tie-rod and ground contact, contributing to the anticorrosion protection. The "headline" valves are drilled sections of the injection tube and they are covered by a flexible hose, allowing the cement slurry to escape during injection. They are located at 0.5 m intervals of the anchored portion.

The obturators (Fig. 19) are metal components, threaded at the end of the headline valves. They allow the cement slurry to be injected orthogonally to their axis, confining the cement slurry to the portion being injected.

Figure 19. Double obturator[2]

V. ANCHORS CONSTITUTION

A. *Life*

The classification of anchors in terms of life is necessary for the safety factor calculation, recommendations for corrosion protection and constructive precautions that differ significantly depending of your use time.

In Brazil, the standard ABNT (Associação Brasileira de Normas Técnicas) 5629 [15] classifies temporary anchors as those whose structural elements are temporary, having a life of less than two years. If this time is exceeded, the anchor is classified as permanent. In the European standards of Switzerland [18] and United Kingdom [19] the life of the anchors is classified according to the work in two categories:

- Temporary construction: characterized by not using protection against corrosion due to its maximum durability of six months;
- Semi-permanent support: characterized by having a life between 4 to 6 months, being recommended protection against corrosion;
- Definitive retaining: characterized by life of more than 24 months, requiring the use of protection against corrosion.

B. Prestressed

The prestress of the anchors consists of its pre-tensile by the application of load by a set manometer, pump and hydraulic jack. Anchors can be classified as active, when they are incorporated to the ground with load application and passive, when they are not prestressed, being denominated as nails.

The main functional and constructive differences between the two are:

- Equipment: active anchors require additional equipment (hydraulic jacks) to perform the prestress. In the case of passive, only a few nails are tested.
- Load request: the active anchors are prestressed. Therefore, they are permanently requested independently of the stresses acting on the ground or the retaining structure. In the passive anchors, the strength is mobilized proportional to the movements of the structure, causing them to enter in loading with the deformation of the ground in which they are anchored.
- Cost: the cost of passive anchors is generally three times lower than for active anchors.

Active anchors can be used in association with walls, grilles, plates and buttresses (Fig. 20).

Passive anchors are used in soil nailing. In situations where greater control of the horizontal displacement of the retaining is required, due to the possibility of load control ensuring greater safety, active anchors are more used than the passive ones. The main advantages and disadvantages associated to the use of each type are presented in Table 1.

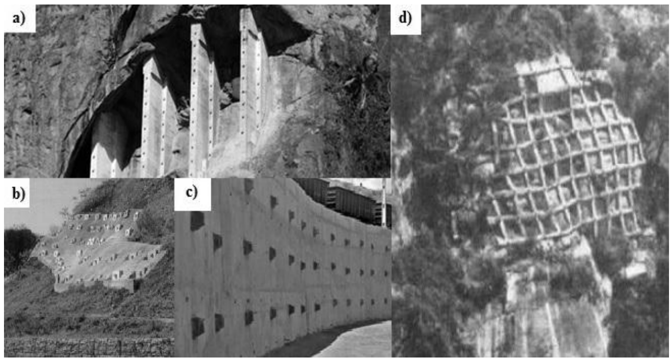

Figure 20. Retaining structures using anchor a) Buttress anchored to stabilize the Cantagalo-RJ, b) Anchored plate for slope stabilization, c) Ground anchor wall, d) Anchored grill, Agulha do Inhangá-Copacabana, Rio de Janeiro. [17]

TABLE I. ADVANTAGES AND DISADVANTAGES OF ANCHOR TYPES.

Anchors	Advantages	Disadvantages
Passive	Practical and fast execution;	Flexible retaining, therefore, it allows high horizontal displacements
	Low execution cost	Unfeasible where large displacements are not allowed
Ative	Rigid retaining, therefore, it does not allow high horizontal displacements	Skilled labor required
	It adapts well to new geotechnical requirements, since the anchors are reinjectable and its geotechnical load capacity can be increased, by new prestress	High execution cost

C. Shape of the bulb of anchor

The bulb of anchor consists of the section formed by the anchor with the cement slurry injected under high pressure. It is responsible for interacting with the soil transmitting the tensile stress and it is fixed or anchored in the stable region of the massive. The anchor load capacity is closely related to the geometry, configuration as well as dimension of the bulb of anchor and these items also have a direct link with the executive methodology. The variation of such factors generates irregular bulbs, which can be grouped according to the type of obturator used and the injection pressure. They can be grouped in three main types (Fig. 21).

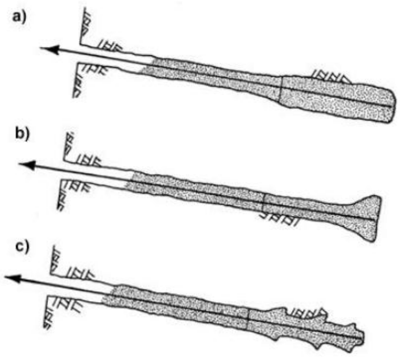

Figure 21. Figure 21. Main types of bulbs: a) Uniform bulb, b) Bulb with larger diameter at its end, c) Bulb in root format. Adapted from [20]

VI. Brazilian Standards

In Brazil, the first attempt to elaborate a technical standard of anchors was proposed by [21] as a project, and executive methodology. The first official brazilian standard only came to be published five years later (1975) motivated by the experience acquired in the works of the subway of São Paulo and Rio de Janeiro and by the publication of the first worldwide standard the DIN 4125 [7]. The first Brazilian standard, NB (Norma Brasileira) 565 [11] would approach with the acceptance, quality and performance of the anchors, regulating the tests for these elements [22].

In 1977, with the accreditation of ABNT to Sinmetro for political reasons, the standard already published should be recognized as brazilian standards. In order to adapt to the new requirement, the cover page should also be changed. Therefore, the standard on anchors started to be called NBR (Norma Brasileira) 5629 "Structures anchored in the ground - Injected anchors on the ground: Procedure" [23] and to have the same scientific content as NB 565 [11], with changes only in its publication format [24].

As a result of the great technological innovations as well as ease of conducting research in the 90's and the beginning of the 21st century, the standard on anchors was updated. They were renamed as NBR 5629 “Execution of tie-rods anchored in the ground” [25]. In general, the modifications facilitated the understanding of the standard for engineers and, at the same time, they have made more flexible certain aspects. In addition, they expedited the execution of the process, in view of the large number of such works requested, mainly, for the construction of the buildings. Other important modifications were carried out to the acceptance tests. The loading cycle and the observation times until the stabilization were changed and clearer measurements on the anticorrosion protection were incorporated.

Ten years later, the standard was again updated, with no change of name. It started to be identified as NBR 5629 “Procedure of ties anchored in soil” [15] and it is currently in force. No significant difference on technical recommendations was introduced in the new publication. This achievement was attributed to the growth of ABNT in the first decade of the twentieth century, to its recognition by ISO and to the change of the logo, which until then had been the same since the date of its foundation. The changes were only in format, so with the modification, the title is now translated into English [24].

In 2013, a new commission was created to update the referred standard, which was analyzed by the Comitê Brasileiro de Construção Civil da ABNT [26] in October 2015. The main reasons for the need for revision are: the insertion of new types of tie-rods; the update of the nomenclatures of the elements that make up the retaining systems according to the terms currently used; the structural dimensioning; the design; the use of protection systems against corrosion; the safety factor and the requirements of the recent standard of cement NBR 7681 [27], which stipulates a water-cement factor of less than 0.4.

VII. Conclusion

Based on the research, it can be noticed that there was an evolution of anchorage techniques in geotechnics, mainly in urban centers with a load capacity of up to 1500 kN. Their application extends from the use in the support of tunnels, support of existing walls, “in situ” test to the anchoring of new containment structures and foundations of wind towers.

It is noticed that the Brazilian standard NBR 5629 [15] is constantly changing (evolution/suitability) due to the improvement of equipment, accessories as well as techniques that can be adjusted with the objective of increasing the effectiveness and safety of an anchor application.

It is also noticed the need to carry out a rigorous executive process and to be attentive to the functionality as well as knowledge of each component of the anchor in order to guarantee the stability and deformability requirements of the works in which they are used.

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