

# Considerations on Characteristics and Improvements of Soft Soils

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**Abstract** — This work is aimed at considerations of soft soils, their origin, behavior against applied tensions and the observation of methods that enhance their safety for civil constructions, such as roads, buildings and bridges on this type of soil, making its construction use. Therefore, case studies on soft soils will be presented, in order to understand their mechanical properties and data referring to some techniques that were developed in the study of geotechnical engineering, for the improvement - stabilization - of these soils, such as landfills on: geosynthetics and enriching of soft clays with Deep Soil Mixing (DSM). This article was based on rigorous bibliographic research, including considerations on the attributes, origin and performance of soft soils, generalized display of some improvement methods. Synthetically, a description of two improvement methods was carried out, observing the case studies of both, commenting on how an application of these best cases is made in a legitimate case and in a virtual simulation, with a justification of having an understanding of solutions that uses used, in order that the soft soil masses are useful.

**Keywords** — Soft Soils. Stabilization of soil. Geotechnical engineering.

## I. INTRODUCTION

The relationship between man-made buildings and the soil on which they were built is as old as the beginning of civilizations. Be it the pyramids in Egypt, the Great Wall of China, the Tower of Pisa or the sumptuous temples of the gods in Greece, man has, throughout history, developed large buildings, and with each new building, given the increase in population and the lack of expanding cities to more and more remote regions, be they small or large works, the man had to deal with the problems that the soil in question offered to the new constructions.

However, even with the appearance of pathologies in the structures, resulting from the soil where they were

found, the studies on soils, arose a short time ago, leading us to the 17th century, to the studies of Vauban (1687), Coulomb (1773) , Rankine (1856), among others, who understood the soils as ideal masses of fragments, imputing them properties of homogeneous matter, that is, observing the soils more mathematically than physically, having been, at the time, of great contribution to the first studies on soils (CAPUTO, 1988).

Over time, it became clear that the behavior of soils was not under the same theoretical laws as the behavior of materials such as concrete or steel, due to the many types of soil, as well as the locations where they are found (PINTO, 2006). For this reason, with the great

constructions of the 20th century, and the countless failures accumulated in major works, such as the ruptures in the Panama Canal and the sliding of embankments in the canals under construction in Europe, the most in-depth study of soils through the perspective of Karl Terzaghi, the father of Soil Mechanics, who in 1925 published his book on soil research, the *Erdbaumechanik*, which was the north of soil mechanics, a discipline that at the time was still very nebula (CAPUTO, 1988).

In the case of soft soils, it is necessary to focus on understanding the main factors inherent to them, such as the fact that they are considered so, soils that have undrained resistance below 25 KPa or consistency index less than 0.5 per example. They have low mechanical resistance, high compressibility and little permeability (FUTAI, 2010), being, therefore, soils that offer little security in the laying of foundations, embankments for highways and social housing, presenting a great challenge to the engineer as to which the best path to take, whether it will be necessary to adapt the project, or whether it will be better to make use of improvements in the properties of the soil or whether it will be better to abandon the enterprise, in favor of finding a location with the most appropriate soil.

Thus, the objective of this study was to analyze case studies on soft soils carried out by other authors, in order to discuss the mechanical properties involved and the techniques related to geotechnical engineering that were applied in each situation to improve and stabilize these soils. , as landfills on: geosynthetics and geo-enrichment of soft clays with Deep Soil Mixing (DSM).

## II. METHODOLOGY

The article was carried out through extensive bibliographic research, making through the research, considerations about the characteristics, the origin and behavior of the soft soils, as well as the generalized presentation of some methods of improvement of the same. A synthetic description of two improvement methods was also made, as well as the analysis of two case studies, where it was approached how these improvements are applied in a real case and in a simulation to better understand solutions that can be used to make these soil masses useful.

## III. LITERATURE REVIEW

### 3.1 Geological formation

Hallal (2003, p. 25), highlights the influence of geological formation on the characteristics of soft soils:

“One of the main indications about the characteristics of soil deposits is their geological history, providing accurate information regarding granulometry, permeability, homogeneity, resistance and anisotropy, among other aspects. Geological history encompasses the source rock (or parent rock), the processes of alteration, transport, and deposition and the post-depositional processes.”

The soft clays of the quaternary period have the most diverse deposition environments, from the fluvial - the delta-lacustrine - to the coastal, also involving the lagoons and bays (CHRISTOFOLETTI, 1980). These environments are broken down by means of deposition activities (fresh, salt, or brackish water), which are fluvial or marine, or even by the characteristics of the deposition site - floodplains or floodplains, beaches or sea channels, among others.

Soils of fluvial origin are those that were formed by deposition of sediments on floodplains or river floodplains. In the poorly drained parts, that is, in the lower parts of the plain, sediments decant, especially the finer ones, such as clays and silts, and in many cases, stratification and intercalation with fine sands occur, becoming subject to dryness, and overdose may occur. (MASSAD, 2010).

In the context of soils of marine origin, it can be said that with regard to soft soils in Brazil, there were some sedimentation cycles, interspersed by a very intense erosion process, during the last glaciation of the globe, 15 thousand years ago and these cycles, according to Massad (2010, p.116): “[...] are directly related to the two episodes of sea entry towards the continent: the Canaanite Transgression, which occurred 120,000 years ago (Pleistocene), of the highest marine level ( $8 \pm 2\text{m}$ ), and the Transgression Santos, started 7 thousand years ago (Holocene), of lower marine level ( $4 \pm 2\text{m}$ ), which gave rise to two different types of sediments.”

Still according to Massad (2010, p. 116-118), these two sediments have their own characteristics, the Cananea Formation, is clayey or sandy at its base and sandy at the top. The Santos Transgression is formed by marine sediments, formed by reworking sediments from the Cananea Formation, sand, and clays, and sometimes by sedimentation of static or calm waters, also having been subjected to rapid and negative oscillations in the sea level.

The soft soils can also vary depending on the lithology of the erosion area, the way the sediment transport and the climate happened, so the sedimentary deposits have divergences between them, due to these variations in space and time under conditions environmental issues. Therefore, the formation of a

uniform deposit, depends on these conditions being stable (MASSAD, 2010).

Clay minerals are formed due to the chemical alteration of the rocks, forming microscopic particles, in a lamellar form, which perpetrates that reveal a large specific surface and, consequently, great sensitivity to the presence of water. The mineral present in its formation directly influences the behavior of the deposit, because the greater the presence of the clay particle, the weaker the geotechnical attributes of the soil (HALLAL, 2003).

### 3.2 Characteristics and composition of soft soils

Regarding the characteristics, we can mention the sedimentary soils that have low resistance to penetration, in an SPT that is less than 4 strokes, in which, the clayey part has the attributes of compressible and cohesive soil, in general, being soft clayey sands or soft clays (MASSAD, 2010). They are also defined as sediments from geologically newly formed soils, in the quaternary period, with dominance mainly of silt or clay particles. In general, they can be found in a dense or slightly pre-dense state, except for exceptions, especially on the surface of the soil, due to the dryness resulting from the oscillation of the water table, or because of the existence of landfills or overlying layers that increase the load. on these soils (HALLAL, 2003).

The methods for ascertaining the usual stability of these soils are based on the hypothesis that there is balance in a mass of soil, considering it as a rigid-plastic body and proximity to initiate a slide. Usually there are: circle of friction, Fellenius, Cunha, Morgenstern-Price, are some of the most common in this stability analysis, having, in most cases, in natural condition, safety factors in low condition or even less than those accepted for projects (MASSOCO, 2017).

Regarding the definitions presented, it is worth emphasizing that although they serve as a guide for understanding what soft soils are and their particularities regarding resistance, they are not used as a well-defined rule for detailing some sediment, so there are differences among the factors of undrained resistance, for example, due to the fact that there is no specific norm for this, which is also the reason that each terrain must be analyzed in a unique way, not assuming the design data.

### 3.3 Improvement methods for soft soils

According to Gerscovich (2010), a landfill based on compressible soils, implies in some phenomena, resulting from the loads applied on the soil, such as primary or densification settlement, a stage where the transfer of efforts between water and the solid framework occurs,

related to the expulsion of water from the void volume, thus generating large deformations in the soil. The secondary settlement, in turn, corresponds to deformations observed in the soil immediately after the primary, occurring with constant effective stresses, due to the fact that the voids index, together with the effective tension are a function of time, as shown in Figure 1.

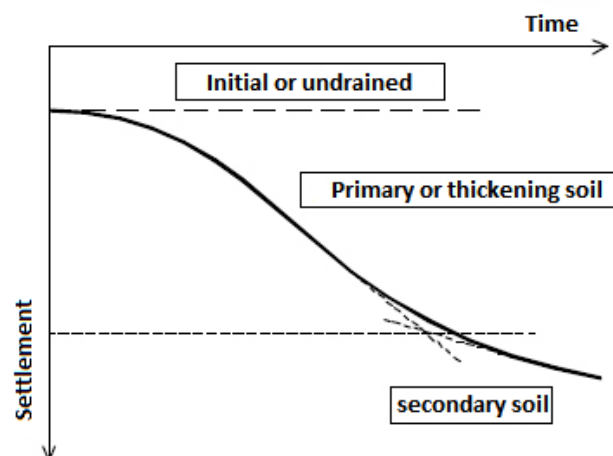


Fig.1: Evolution of settlements

Source: Gerscovich (2010), adapted.

In most soils, the secondary settlement is of little relevance when compared to the primary, however, in very plastic clays and more organic soils, it is significant. These settlements produce a density in the saturated soil, due to the transfer of water efforts to the solid framework, as previously mentioned, and this transfer is only possible by the dissipation of pore pressure surpluses, through water drainage (GERSCOVICH, 2010).

Soft soils present great difficulty for civil construction. Often, soil safety factors, applied directly in their natural condition, are small, and it is not possible to guarantee stability. With soil settlements, the same occurs, because the densification process takes time, as well as the settlement itself, needs a long time to be consolidated (MASSOCCO, 2017).

Many civil engineering projects involve this type of construction on very damp soils. Among them, road, and rail landfills for the construction of industries, earth dams, among others. And because of this need to build in areas with weak geotechnical characteristics, it is necessary to be very careful about defining the geotechnical parameters, how will the analysis of that sediment be done and what is the constructive sequence to be used, because if they are not taken into account these factors, the rapid and unthinkable construction, may cause the foundation soil to

rupture, under undrained conditions (FORMIGHERI, 2003).

One of the means used to alleviate the difficulties resulting from the presence of this type of material, is to completely remove the soft layer and replace it with granular material. However, this method is only economically viable, when there is only 3 m of soft layer, however, this substitution is expensive and inefficient. (DNER-PRO 381/98).

Formigheri (2003) states that landfill construction on soft soils, even if the necessary study has been done, may still surprise, due to the degree of stability that these landfills can achieve or not and the levels of vertical and horizontal displacement observed in the work. For this reason, it is necessary to analyze the soil in question, as well as to understand which type of landfill will be used, depending on which work is intended to be built on it. Then, we have the Class I landfill, which are landfills next to rigid structures, such as at the intersection of viaducts and bridges, and close to pipelines and other more sensitive structures. Class II landfills are not close to sensitive structures, however they are high, by definition, above 3 m. The Class III landfill, on the other hand, is low, that is, it has less than 3 m and is far from sensitive structures (DNER-PRO 381/98).

Massocco (2017) reports that there are many ways to make works on compressible soils feasible, and treatments can be done through measures to increase soil stability. Among the existing techniques, we can mention some of the best known, such as: construction in stages, application of temporary overloads, vertical geodroads to speed up settlement, side shoulders, piles, gravel columns, geosynthetics, among others.

#### 3.3.1. Deep Soil Mixing (DSM) reinforced landfills

The Deep Soil Mixing technique, also known as soil-cement columns in Brazil, consists of making perforations in the soil in the form of columns, with the purpose of making controlled injection of humidified cement grout at low pressure, where this grout is mixed with the revolved soil during the excavation, thus enabling these soil-cement columns delineated in situ, of great resistance and low deformability. This method is widely used for the purpose of building landfills on soft soils, for the construction of roads that can even withstand the traffic of heavy equipment from the naval industry, for example (PINTO, 2016).

This method had its appearance around 1970, almost at the same time, in Japan, Sweden and the United States, due to the need to build in soils with poor geotechnical characteristics, especially in too soft clays,

soils with a high degree of saturation and a large amount of organic material (SANCHES, 2012).

The execution of the soil-cement columns, consists of a method of improving the soft soil, made in the deep regions of the land, without a previous excavation, that is, the machine that makes the drilling (drilling rig), also mixes the grout of cement (binder) with perforated soil, obtaining as a result, a soil with better mechanical characteristics than initially and with less permeability, giving the soil in question, characteristics such as improved resistance, deformability and permeability. (KITAZUME & TERASHI, 2001 apud PINTO, 2016). The stabilizing agents consist of one or two binders, which can also be in the dry state, the most common being lime and Portland cement, as shown in Figure 2.

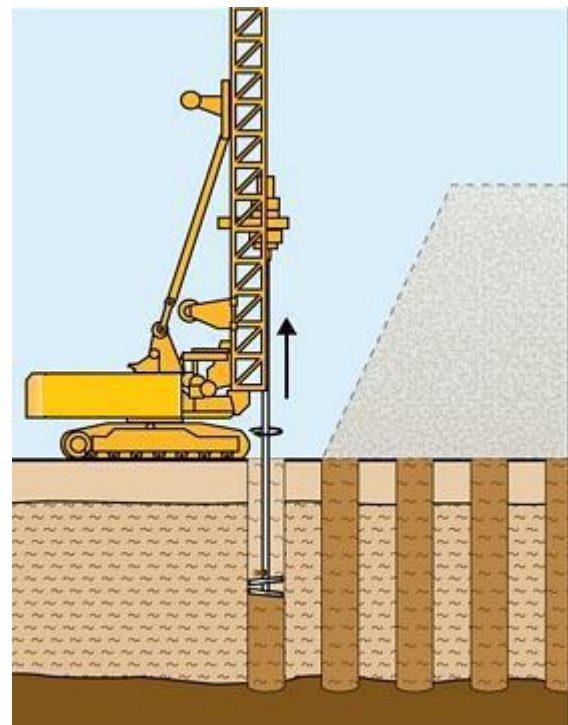


Fig.2: DSM application scheme

Source: Hayward Baker (2003) *apud* Sanches (2012), adapted.

In addition, it is possible to combine additives such as slag, fly ash, plaster, among others, thus enhancing the geotechnical characteristics of the applied soil (SANCHES, 2012).

Regarding the technique, according to Pinto (2016, p.17), we have two methods: Wet method: the wet method is more suitable for soft clayey soils, fine grained sandy soils with little moisture or stratified soils with soft and rigid layers interspersed. It usually uses cement grout. The inserted rod has a tip for drilling at its end and, next to it,



sets of blades that rotate to mix the soil-cement, as well as nozzles for launching the stabilizers. The diameter of these columns can vary from 40 cm to 2.4 m. The vertical drilling rod may eventually move up and down during the process to ensure the homogeneity of the mixture that will make up the soil-cement. The dry method: as a rule, the clay soils are strengthened with lime or cement with lime. Organic soils are stabilized with blast furnace slag. The dry method is only feasible in soils that are moist enough to react with the binders typical of this technique. The drill rod has a mixing blade at its end, near which is also the nozzle for launching the stabilizer. The columns executed in this method are normally 60 cm to 80 cm in diameter. The stem penetrates the soil, revolving it. After reaching the determined depth, it is collected and the stabilizer starts to be launched, while the mixing blade continues to rotate.

In Brazil, the DSM technique is still not widespread, however, in the countries where it developed, it has greater knowledge. According to Oliveira et al. (2012 apud Pinto 2016), there are several reasons for the expansion of the technique around the world, which are:

- i. DSM increases soil stability and simultaneously reduces settlement.
- ii. Faster execution.
- iii. Lower cost.
- iv. In recent years, there has been a development of machinery that allows DSM columns to run at greater depths in non-homogeneous soils, including soft soils, sands, over-densified clays, and even altered soft rocks, that is, rocks that have resistance to simple compression, in the healthy state, less than 2 MPa.

It is necessary to highlight one of the disadvantages of this method in Brazil, which is the fact cited above of not having extensive knowledge and dissemination of the technique. This is because, few companies have the necessary machinery for the execution, increasing the expense of its use, since they would have many costs with the transport of the specific machinery, as well as qualified labor for the execution, besides the cement having a high cost, due to the quantity to be used, and the work must have a large area to be treated to compensate the investment.

### 3.3.2. Landfills with geosynthetics

The lack of building in areas with soft soils requires many innovations to improve landfill works at the lowest possible cost and facilitated labor, without the need to remove the soft soil from the land to be built. For this reason, many studies have been done in the development of construction methods, aiming at soil improvement. Among

these methods, we have polymers, according to Vertematti (2015), such as plastic, elastomers, fibers, adhesives, coatings and geosynthetics. The use of polymers for the manufacture of geosynthetics began in 1960, and there were also records of use on a smaller scale in previous decades.

Geosynthetics have in their structure, polymers and to a lesser extent, some additives. These additives add improvements in the manufacturing processes and can change aspects of the polymer's behavior in the construction issue. In general, they are manufactured based on synthetic polymers, derived from oil, however, natural fibers such as sisal or coconut are also used, which are used in a variation of geosynthetics, the so-called geotextiles or biotextiles and geomantas. (VERTEMATTI, 2015).

A landfill work based on soft soil is a problem that requires a stabilization solution because of the possible problems that the construction of the landfill without some previous preparation of the soil can cause, for this, we can use a reinforcement in the soil with geosynthetics in base of that landfill. In this way, we increased its stability, allowing the land to be used for construction more quickly (VERTEMATTI, 2015).

Based on what Vertematti (2015) states, in the application of reinforcements on soft soil, geosynthetics are normally used: "geotextiles (GTX), geogrids (GGR), geotextiles and resistant geocomposites (GCO-R). Depending on the local conditions of the work and the materials available, one or more layers of geosynthetics can be used at the bottom of the landfill and separated by a layer of compacted soil."

Figure 3 presents a simulation of the application of geosynthetic for separation of the foundation / sub-base of roads, showing the first image (a) without geosynthetic and the second (b) with geosynthetic.



Fig.3: Simulation of geosynthetic application

Source: LOPES (2005) apud FERREIRA (2010).

As we have as main advantage to the use of geosynthetics, the fact that they can simultaneously perform one or more functions as highlighted in NBR ISO 10318-1 - Geosynthetics - Terms and definitions (ABNT, 2018):

- Reinforces mechanical behavior.
- Limits the movement of soil or other particles on the surface due to the control of surface erosion
- Assists in draining rainwater, groundwater.
- Protection or prevention of local damage to a material.
- Can be used as a barrier, limiting fluid migration.

The most common forms of geosynthetics are geogrids, geocells, strips, wires, geomembranes, geoterrains, geomatres, geogrids and geocomposites. According to Sá (2000, p.10), among these, the most used as reinforcement are:

- Woven geotextiles: composed of two sets of perpendicular linear elements systematically interconnected to form a planar structure.
- Non-woven geotextiles: formed by filaments or fibers arranged at random to form a planar structure. This type of geosynthetic can withstand tensile forces, but because the filaments are misaligned, the loading causes much more elongation than an equivalent material with aligned elements.
- Geogrids: plastic grids that can be manufactured by different techniques and with a wide variety of geometric characteristics. Geogrids can be found in the form of strips or wires combined in two perpendicular directions to acquire a grid shape, but with different degrees of mechanical connection in the joints and protective sheaths. Another geogrid manufacturing process is the stretching of previously perforated blankets and Geocells: they are specially made materials so that, when stretched, they form elements like “honeycombs”, whose interior space is filled with soil. Most of the time, they are used to reinforce high embankments on foundations of soils with low support capacity.

The author also emphasizes that geosynthetics have many functions in engineering and various applications such as: improvement of soft soil, walls and embankments, reinforcements in foundations, for stacked embankments, containments, drainages, among others. It can be cited as a disadvantage only the fact that they are solutions that can suffer some unforeseen in the execution if the calculations are not done correctly, from the question of the size of the

area that will be used, to the number of meshes and their thickness for a geogrid for example, but that is not restricted only to that geosynthetic. Thus, its execution requires a lot of care, so that the result is as expected in improving or strengthening the soil (VERTEMATTI, 2015).

#### IV. CASE STUDY ON SOFT SOIL

Soft soils have many problems regarding their usability and with that, it is necessary to use some method that makes the construction feasible, making an improvement of the soil to be used. Then, below, two case studies based on the two methods presented above will be presented, to exemplify in practice how these improvements occur.

##### 4.1. DSM case study

Moretti (2012) developed a practical application of Deep Soil Mixing (DSM) on the coast of Pernambuco, close to the city of São Lourenço da Mata, in an area of 300 m in length in which many landfills built on soft soils are found in large quantities, because the region's soil is characterized by compressible and low resistance soils (FIGURE 4).



Fig.4: Photo of the place where the study was carried out.

Source: Moretti (2012).

##### 4.1.1. Characterization of the geotechnical profile

In the area in question, according to Moretti (2012), three surveys were carried out, detecting which region has a subsoil formed by a layer of sandy-clay silt, about 1.0 m thick, with the next layer of organic clay being 12, 0 to 15.0 m, and after that, a silt clay of 2.0 m each and finally, a layer of clay silt. The water table level was detected at a depth of up to 1.60 m. The same author also informs that

three surveys were carried out, through which the geotechnical profile of the soil was traced, through these data, it was possible to determine the limits of liquidity (LL) and plasticity (LP), the plasticity index (IP), the compression (Cc) and recompression (Cr) coefficients, the moisture percentage (w%) and the specific weight ( $\gamma$ ) of each soil layer. It was also possible to determine the granulometry of soils by means of sieving and the values of resistance obtained by means of UU triaxial tests (MORETTI, 2012). 4.1.2. Procedures adopted Moretti (2012) states, with regard to field procedures, DSM columns with a nominal diameter of 0.80 m and a spacing of 3 m between the axes were performed, using a triangular arrangement and workload to simple compression of 1MPa, these columns being seated at least 1.0 m deep in the firmer material, in a layer below the soft soil, executed according to DSM methodology.

Regarding the sampling of the columns with the rotary drilling equipment, Moretti (2012), says that some of the columns were selected on the job, in a random way, aiming to obtain a result that was more suitable, extracting unformed samples, from the inside of the columns using the equipment in question. Then, these samples were sawn, rectified and packaged in a laboratory in submerged curing, until laboratory tests were carried out. In the section studied, 52 columns of DSM were drilled, and columns were also drilled for testing cement consumption in the field, totaling another 4 columns. Figure 5 presents elements used in the study.

In section (a) we have the sample boxes collected on the spot. Section (b) has a planetary mortar used to homogenize the samples in the laboratory. Finally, in part (c) we have the execution of the compression test in a specimen molded in the laboratory.

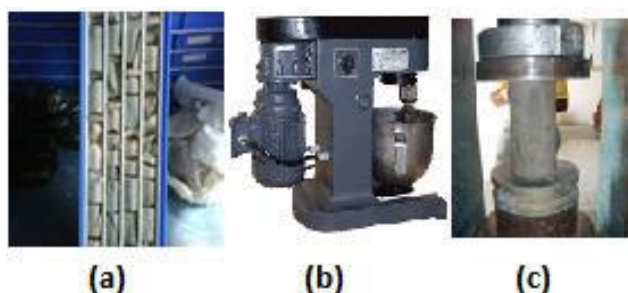


Fig.5: Elements used in the case study.

Source: Moretti (2012), adapted.

Among the laboratory procedures, the specimens for the study were made, mixing the local soft clay with water, until reaching the liquidity limit, and then, afterwards, these samples were homogenized with a planetary mortar,

after that, they were kept in full rest in a cool place, so that, knowing the specific weight and masses, they could calculate the volume (MORETTI, 2012).

Also according to the author, for the finalization of the specimens, a quantity of CP II-32 cement was added to the mortar, which quantity was obtained by means of dosing in terms of cement mass per volume of sample to be treated, the specimens were molded in metal cylinders and care was taken to prevent bubbles and discontinuities from forming through small blows on the outer wall of the molds, also protecting the cylinder ends, and finally, the compression tests axial, leading the specimens to ruin, in order to quantify how much there has been improvement in resistance (MORETTI, 2012).

#### 4.2. Geosynthetic case study

Batista's case study (2007) describes three types of soft soils, with parameters for clays typical of the State of São Paulo, such as Sediments Flúvio Lagunares and Transitional Clays (MASSAD, 1999 apud BATISTA, 2007) and Argila Vermelha de Brasília (ALMEIDA et. Al., 1996 apud BATISTA, 2007). The author chose the soils of the places in question, because they cover cases of soils that have low, medium, and reasonably good resistance to soft soils. However, in this work, only the soil of São Paulo Transitional Clays will be approached.

##### 4.2.1 Characterization of the geotechnical profile

Batista (2007) states that in the soil in question, an undrained resistance of about 14 kN / m<sup>2</sup> was shown in Table 1, with the soft soil layer being approximately 12.5 m deep. Related to the landfill, the following characteristics were adopted: Specific weight ( $\lambda$ ) = 19 kN/m<sup>3</sup>, permeability (K) = 1 m / day, Young's modulus (E) = 60000 kN/m<sup>2</sup>, Poisson ( $\nu$ ) = 0.3, cohesion (c) = 20 kN/m<sup>2</sup> and friction angle ( $\phi'$ ) = 29 °.

Table 1. Undrained resistance varying with depth, adapted.

Depth (m)	Cu (kN/m <sup>2</sup> )	Depth (m)	Cu (kN/m <sup>2</sup> )
0,5	10,13	7,5	14,88
1,5	10,08	8,5	15,91
2,5	10,27	9,5	16,94
3,5	10,69	10,5	17,96
4,5	11,75	11,5	18,28
5,5	12,08	12,5	20,00
6,5	13,84	Média	14,17

Source: Batista (2007).

This layer of soil where the factors of undrained resistance were tested, was divided into 13 layers of 1 m, being able to observe a constant undrained resistance as we increase the depth. And yet for this characterization, the over-stressing stresses were considered, that is, effective vertical stresses added to a load increase of 9 KN / m<sup>2</sup> (BATISTA, 2007).

#### 4.2.2. Procedures adopted

The German software GGU-Slope was used, which among its functions, allows to analyze the balance of embankments and embankments, being of paramount importance for safety to have these data, since, it is possible to avoid ruptures that interfere in the assessment of the rigidity of the reinforcement (BATISTA, 2007).

For comparative analyzes of soil displacement without reinforcement in the software, Batista (2007), said the landfill with 28 m of base and slope of 1V slope: 1.5H was arbitrated, being this loaded with 19 kN / m<sup>2</sup> each landfill layer, operating the load for 0.6 days, which is the shortest time accepted by the software for the case. After removing the static layer, the layer could thicken for 0.6 days, to imitate the rapid construction process, which is the most critical in an engineering work.

However, building the landfill directly on the soil without the reinforcement of geosynthetics, resulted in the rupture of the soil, generating numerical instabilities. The author also chose to execute landfills without balances, however, the fluvial lagoon soils have a low capacity to support, with a large amount of plastification in the soil, which made the study impossible, for this reason, it was used balance shoulders with the same material as the landfill, in order to better stabilize the settlements and plasticization that the soil would have (BATISTA, 2007).

#### 4.3. Results and discussions

The study developed by Moretti (2012), makes some tests related to the increase of simple compressive strength of laboratory and field samples, however, this article will only address laboratory tests, in order to demonstrate this improvement through of one of the examples used by the author, who used different dosages of concrete, with 200 kg/m<sup>3</sup>, 400 kg/m<sup>3</sup> and 600 kg/m<sup>3</sup> with 7, 28, 56 and 120 days, however, according to Table 2, here it will be only the data referring to the cement consumption of 200 kg/m<sup>3</sup> are presented.

Table 2. Resistance to simple compression (MPa). Cement consumption 200 kg/m<sup>3</sup>

Sample	Curing time (days)			
	7	28	56	120
<b>1</b>	1,30	2,90	2,90	4,00
<b>2</b>	1,10	3,00	3,30	3,60
<b>3</b>	1,00	2,70	3,00	3,70
<b>4</b>	1,20	2,50	3,50	3,70
<b>Medium 200</b>	1,15	2,78	3,18	3,75
<b>Sd</b>	0,13	0,22	0,28	0,17
<b>COV</b>	0,11	0,08	0,09	0,05

Source: Moretti (2012)

As shown in the table, it is possible to verify that as we increase the curing days of the sample, the resistance to simple compresses increases, as expected from curing the material, Moretti (2012) still makes comparisons with higher dosages of concrete, the which also shows that the higher the cement consumption, the greater the resistance of the DSM columns, as shown in Figure 6.

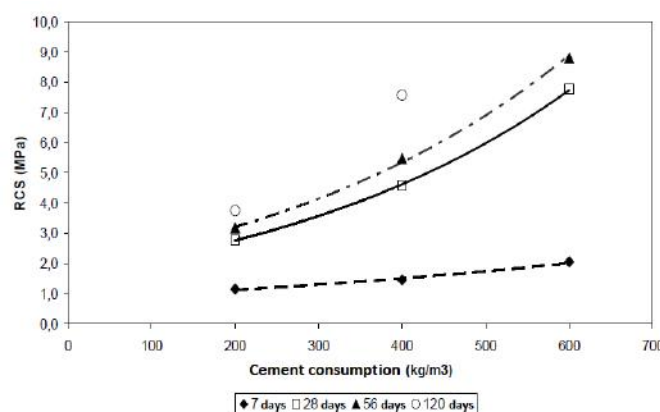


Fig.6: RCM x Cement consumption.

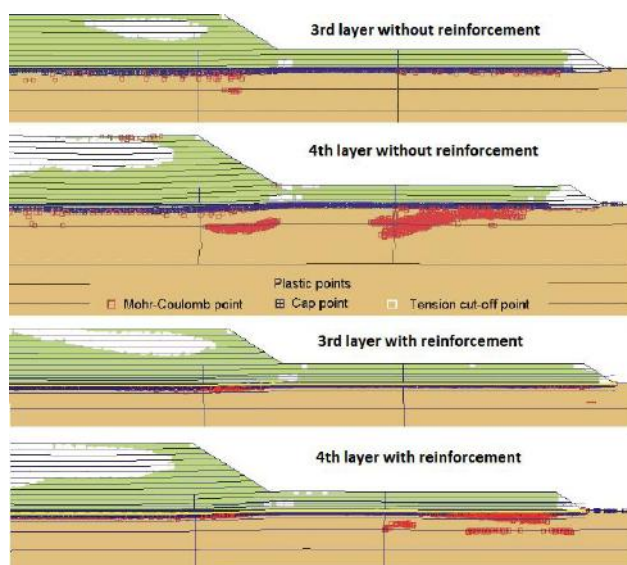
Source: Moretti (2012), adapted.

Batista's geosynthetics (2007) that were used, had nominal reinforcement of 1000, 4000 and 16000 kN/m, each being tested in the software and observing the behavior of the landfill with and without these reinforcements. For the 1000 kN/m and 4000 kN/m reinforcements, the results were similar. Figure 7 shows layers with and without reinforcement of 1000 kN/m.

Figure 7. Layers with and without reinforcement of 1000 kN/m.



Figure 8 shows layers with reinforcement of 16000 kN/m.



Fonte: Batista (2007), adapted.

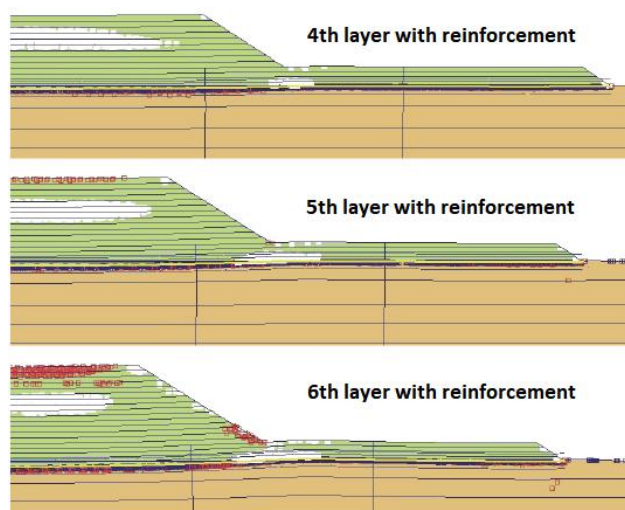


Fig.8: Layers with reinforcement of 16000 kN/m.

Source: Batista (2007), adapted.

In Table 3 it is possible to identify that, as we use geosynthetic reinforcement, less displacements occur in the soil formed by transitional clay, that is, it is clear that the reinforcement of geosynthetics contributes significantly to the improvement of a compressible soil in order to make it usable for civil constructions.

Table 3. Maximum total displacements (cm) for the AT soil.

Layers	Stiffness (kN/m)			
	Without reinforcement	1000	4000	16000
1	3,59	3,64	3,50	3,20
2	6,44	5,82	5,37	4,96
3	8,88	8,60	8,22	7,61
4	21,04	15,65	13,96	12,44
5	89,36	56,75	35,55	21,12
6	-	-	68,83	33,95

Source: Batista (2007).

Therefore, in relation to which method should be used or not, it is necessary to establish the type of work to be carried out, the client's budget, the facility to find the necessary materials and manpower necessary to use the method to be used to be employed. However, as previously mentioned, in Brazil, the DSM technique is still a little unknown and little practiced by companies at the national level, so for our reality the use of geosynthetics as a method of greater diffusion, knowledge and a large amount of skilled labor to use it, since in this sense, as Vertematti (2015) said, our country has a reference. In addition, it should be mentioned here that in the case of a soil with extremely poor properties in terms of its resistance, we can use the two methods together, in order to perform the geoenrichment of the soil and the mechanical reinforcement through some of the geosynthetics. Finally, we can summarize in Table 4, some of the advantages and disadvantages of both methods, as well as making some comparisons regarding the same.

Table 4. Advantages and disadvantages of DSM and Geosynthetics Methods.

Compared item	Method	
	Deep Soil Mixing (DSM)	Geosynthetics
Advantages	<ul style="list-style-type: none"> <li>• Increased resistance inside the soil.</li> <li>• Decrease in differential settlements.</li> <li>• Makes the soil mechanically richer.</li> </ul>	<ul style="list-style-type: none"> <li>• Increased resistance of the soil on its surface.</li> <li>• Decrease in differential settlements.</li> <li>• Protects the landfill from ruptures.</li> </ul>

Disadvantages	<ul style="list-style-type: none"> <li>• High cost.</li> <li>• In Brazil, it has little labor.</li> </ul>	<ul style="list-style-type: none"> <li>• Material that can generate environmental impact in the case of materials made of polymers;</li> <li>• More superficial improvement, not foreseeing internal improvements in the soil.</li> </ul>
Phases	<ol style="list-style-type: none"> <li>1. Soil drilling and cement mix plus additives.</li> <li>2. Wait for the curing time of the columns.</li> <li>3. Land the ground.</li> </ol>	<ol style="list-style-type: none"> <li>1. Drainage.</li> <li>2. Leveling.</li> <li>3. Application of geosynthetics on the soil to be used.</li> <li>4. Land the ground.</li> </ol>
Description	Improvement through geo-enrichment of the foundation soil, inside the soil.	More mechanical improvement than soil chemical characteristics, being carried out on its surface.
Application	Building or road works.	Building or road works.

Source: Vertematti, 2015.

## V. CONCLUSIONS

Through all observations, it is clear that constructions on soft soils are a great challenge for engineering, taking into account all the obstacles that these soils can cause during a landfill work aimed at the construction of roads, foundations and works of social interest, since the characteristics inherent to soft soils such as high compressibility, high saturation level, low undrained resistance and low shear resistance, for example, make the execution of these works much more difficult, having to take into account many variables, aiming at the safety of buildings built on these soils.

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