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Comparative Analysis of the Mechanical Behavior of the Lateritic Natural Soil of Brasília and the Soil Mixed with Vermiculite on the Composition in the Cavas of Urban Regions

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Abstract. Civil construction is one of the areas of civil engineering with high demand for new procedures, technologies and constructive methods capable of generating better results in numerous situations throughout the process. Nowadays, cavas in urban areas are commonly used due to the implantation of commercial and residential developments with more than two floors, seeking a better use of the nobler areas of the big cities. In geotechnical terms, the filling of these cavas, with the local soil, especially in the Federal District, lateritic soils, can represent additional efforts for the structures and foundations and lead to a compromise of the technical and functional performance of the same, compromising the efficiency and the economy of the enterprise. In this sense, this research evaluates the mechanical behavior of the mixtures, using GEO5 Software, Containment Design and Verification Modules, presenting an alternative to fill cavas in urban regions, with a mixture of material with lower specific density in relation to the soil Natural. Proctor Normal compression tests, simple direct shear saturation and sample expansibility were performed. The results showed a reduction of 38% in the strength of the reinforced concrete curtain, as well as a 25% reduction in maximum bending moments and 31% in maximum shear forces, and a reduction of about 32% in the displacements of the structure to the soil with addition of expanded vermiculite for tests obtained in the saturated condition. For the compositions of cement soil, expanded vermiculite soil and soil cement and expanded vermiculite, the deformations were of the order of 0.3%; 0.4% and 0.2%, respectively.

Keywords. Soil mixed with vermiculite, reconstitution of cavas, reduction of specific density.

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1. Introduction

Urban cavas are becoming more frequent, in general, due to the implantation of commercial and residential developments with more than one subsoil. In geotechnical terms, the backfill of these cavas, with the soil of the site, especially in the Federal District, lateritic soils, may represent additional efforts to the structures and foundations and lead to a compromise of the technical and functional performance of these works.

An alternative is the recomposition by compaction of pitches with natural soil which, in general, may present high efforts of active thrust due to the increase of its specific weight, and depending on the type of work.

The density of the material to be used in the work may influence the final costs, due to the need for more robust and reinforced structures, and the development of studies with less dense materials is essential. Some studies were carried out with the addition of cement, such as Crispim [1] and Cunha [2], which presented some studies on the changes in the densities of the compound (soil-cement), according to the percentages in addition to the cement in the mixture.

An interesting material for the mixing and reconstitution of cavas is expanded vermiculite, which has a relatively low density compared to other materials, such as cement. The vermiculite is produced in scale in some regions in the world, like South Africa, the United States, China and Brazil. Their marketing can take place either in the expanded or concentrated form, depending on the destination purpose. In geotechnical engineering, vermiculite is used after the process of transformation of the matter, resulting in expanded vermiculite.

Therefore, the present research has the purpose of verifying the mechanical behavior of the soil compound and vermiculite for cavitation recomposition in urban regions. With this purpose, a study was carried out during the construction of a residential building, located in Brasília, in the Federal District / Brazil.

The research was divided in two main steps: At first it was obtained the material characteristics (natural soil, expanded vermiculite, Portland cement) followed by the mechanical and expansion behavior of the materials. Silva *et al.*, [3 & 4].

Next, the geotechnical parameters of the local soil were defined for the numerical simulations, using the GEO5 Software, Design Modules and Containment Verification, to calculate the buoyancy and forces acting along the reinforced concrete structure of the building containment. The deformations and tensions acting on the structure were evaluated, according to the design of containment of the work for comparative analysis.

Expanded vermiculite is a mineral that comes from the process of rock extraction, for example, feldspar, granite and syenite. After the vermiculite extraction process, the material is washed and passed through a process of transformation of the material at high temperatures between 1,073.15 and 1,373.15 K, from a lamellar structure to flakes called expanded vermiculite and is subsequently the process of crushing the flakes.

The vermiculite has a density of 640 to 960 kg/m³ before being carried to high temperatures, after submitted, can obtain density of 56 to 192 kg/m³, being able to have expansion of 90% of the volume.

The lateritic soil of Brasília presents a characteristic red, yellow, brown or orange color depending on its formation process and degree of weathering. Through the Miniature Compressed Tropical (MCT) the soil presented a classification as soil clayey lateritic (LG '). Figure 1 shows the granulometry of the local soil.

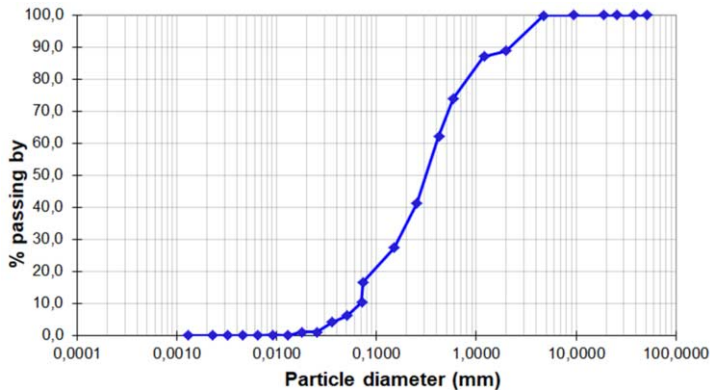


Figure 1. Granulometry of the local soil.

Was used Portland cement CP II Z 32 compound with the addition of pozzolanic material, in which the material has lower permeability, being great for underground works. Bauer [5] reports that Portland cement is a fine material that has agglomerating properties, in which after adding water, it hardens and then remains stable even with the presence of water.

2. Casy Estudy – Materials and Methodology

Materials and Methodology In the work under study to allow the excavation of the 02 basements, a provisional containment was initially performed on juxtaposed piles, with a diameter of 60 cm and a total length of 11.50 m. The piles were filled with concrete of $f_{ck} = 20$ MPa, slump test 12 ± 2 cm and cover of the reinforcement of the piles of 5 cm. Longitudinal reinforcement with 7 bars of ϕ 20 mm of 12.00 m and stirrups of ϕ 8 mm to each 20 cm. The axis of the pile containment structure (provisional work) was 1.30 m away from the reinforced concrete curtain (definitive work) that limited the subsoil (Figure 2).

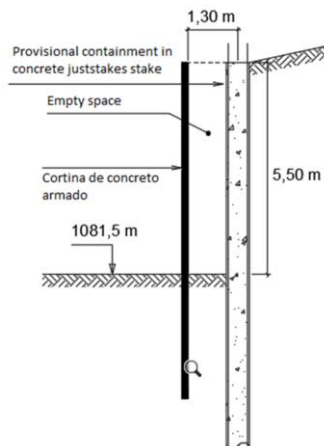


Figure 2. Cutting the region for recomposition at the subsoil boundary.

For the closure of the subsoil it was foreseen the execution of a reinforced concrete curtain, definitive structure, separated to 1.3 m of the juxtaposed stakes. The said curtain with 40 cm of thickness and 9.60 m of total length (go free + plug). Curtain concrete with 20 MPa f_{ck} , Slump test 12 ± 2 cm and containment armor cover of 5 cm. Longitudinal reinforcement with 5 bars of ϕ 16 mm with 9,60 m and stirrups of ϕ 8 mm every 15 cm.

As it would be necessary to fill the cell, by means of the compaction of natural soil, in a width of 1.3 m, between the provisional containment and the definitive curtain, analyzes of the local soil with addition of vermiculite and/or Portland cement were carried out.

2.1. Materials for restoration of cavas

Simple shear tests were performed in the saturated state, expandability and compression, Proctor Normal for the soil with and without addition of expanded vermiculite and / or addition of Portland cement, according to standards NBR 9895 and 7182 [6 and 7] and ASTM D 3080 [8]

After the determination of the optimum moisture of the natural soil, mixtures of vermiculite-expanded soil with different levels of vermiculite (0%, 6%, 12.5%, 19%, 25%, 30% and 100%) were performed. determined in relation to the total mass of the mixture. The percentages were determined by attempts to reduce the specific soil weight with the mixtures to the extent that they did not impair or that excessive cracking occurs in the test bodies after compacting them. The ideal limit was 25% of expanded vermiculite.

Mechanical behavior studies and soil expansibility were carried out without addition of mixtures and with addition of 2% Portland cement, soil with addition of 25% of vermiculite, soil with addition of 25% of vermiculite and 2% of cement. Table 1 shows the symbols used in the identification of the blends:

Table 1. Symbols used in the identification of the blends.

| Author | Soil (%) | Vermiculite (%) | Cemente (%) | Symbol |
|--------------------|----------|-----------------|-------------|--------|
| Silva et al., [9] | 0 | 0 | 0 | SN |
| Silva et al., [9] | 75 | 25 | 0 | SV |
| Silva et al., [10] | 98 | 0 | 2 | SC |
| Silva et al., [10] | 73 | 25 | 2 | SCV |

The present research presents the results for the contents of SN, S + 25% V, S + 2% C and S + 2% C + 25% V as material for recomposition of the cavas in urban regions.

2.2. Foundation system modeling

In order to evaluate the buoyancy of the soil with and without addition of the mixtures, GEO5 Software - v.18, Containment Design and Containment Verification modules were used. The GEO5 - Containment Project module does not consider the deformation / displacement of the structure, obtaining moments and shear greater than those found in the GEO5 - Containment Verification module, where the program considers the displaceability of the structure associated with the active buffers.

The analyzes performed in GEO5 are calculated by means of excavation stages where the buffers and forces acting along the structure are obtained. For the calculations was adopted the Classical Theory, where the active thrust was calculated by Coulomb and the passive by Mazindrani. The coefficient of minimum active thrust and reduction of the passive thrust provided by the program were considered as being in favor of safety. It was adopted in the calculations $F.S = 2.0$, according to Negro *et al.*, [9].

Since the work does not have shear tests to obtain the necessary parameters for the dimensioning of the containment and the designer did not present the parameters considered in the design, they were estimated based on the local experience and on results of tests of similar soils in works around.

3. Result Analysis

A Table 2 presents the geotechnical parameters used in the analyzes.

Table 2. Parameters adopted.

| Mixture | Parametres | Depth | | |
|---------|-------------------------------------|---------|------------|-----------|
| | | 0-5,5 m | 5,5-11,5 m | 11,5-18 m |
| SN | k_h (MN/m ³) | 25 | 30 | 30 |
| | ϕ (°) | 27 | 28 | 28 |
| | c (kPa) | 10 | 15 | 20 |
| | Ψ (°) | 0 | 0 | 0 |
| | γ_{nat} (kN/m ³) | 17 | 18 | 18 |
| | γ_{sat} (kN/m ³) | 20 | 20 | 20 |
| SC | k_h (MN/m ³) | 22,72 | 30 | 30 |
| | ϕ (°) | 16,4 | 28 | 28 |
| | c (kPa) | 24 | 15 | 20 |
| | Ψ (°) | 0 | 0 | 0 |
| | γ_{nat} (kN/m ³) | 15,35 | 18 | 18 |
| | γ_{sat} (kN/m ³) | 17,25 | 20 | 20 |
| SV | k_h (MN/m ³) | 15,92 | 30 | 30 |
| | ϕ (°) | 15,4 | 28 | 28 |
| | c (kPa) | 11 | 15 | 20 |
| | Ψ (°) | 0 | 0 | 0 |
| | γ_{nat} (kN/m ³) | 11,47 | 18 | 18 |
| | γ_{sat} (kN/m ³) | 15,25 | 20 | 20 |
| SCV | k_h (MN/m ³) | 38,05 | 30 | 30 |
| | ϕ (°) | 20,4 | 28 | 28 |
| | c (kPa) | 40 | 15 | 20 |
| | Ψ (°) | 0 | 0 | 0 |
| | γ_{nat} (kN/m ³) | 11,5 | 18 | 18 |
| | γ_{sat} (kN/m ³) | 15,16 | 20 | 20 |

The subsoil reaction module (k_h), internal friction angle of the particles (ϕ), cohesion (c), structure-soil friction angle (Ψ), natural specific weight (γ_{nat}), saturated specific weight (γ_{sat}) and optimum compaction humidity (w) of the mixtures were identified. Used for the filling of caves in urban areas.

The values of the reaction module of the subsoil were estimated based on the results of the tests presented in the works of Magalhães [10], Medeiros [11] and the Chinese Standard JGJ 120 [12].

It is verified that the soil with addition of vermiculite was the composition that presented the lowest values of natural specific weight, later, the soil with addition of cement and vermiculite. Third, the soil with addition of cement and fourth, the soil without additions. The density of the materials can directly influence the efforts of the structures and thus can alter the geometry and the consumption of steel in the structure.

3.1. Results obtained in the Containment Project module

Table 3 presents the results for the simulations in the software Containment Project in GEO5 Software. It can be verified that the soil without addition of mixtures presented the highest results of maximum bending moments and maximum shear stresses.

Table 3. Results of internal forces acting on the structure.

| Mixture | Mmax (kNm/m) | Qmax (kN/m) |
|---------|-----------------|----------------|
| SN | 210,97 | 187,15 |
| SC | 136,89 | 140,62 |
| SV | 149,9 | 155,27 |
| SCV | 89,62 | 110,4 |

The SC mixture showed a reduction of 35% for bending moment and 24% for shear. In the SV mixture there is a reduction of 29% for bending moment and 17% for shearing.

The SCV blend had a reduction of 57% for bending moment and 41% for shear. The simulations show that there are significant reductions in the internal forces acting on the containment structures. In which they could be less requested and reduced in their geometry, and in the armature rate of the same.

The simulations carried out in the Containment Project module show that the natural and saturated densities of the compounds influenced the internal forces acting on the reinforced concrete structures.

3.2. Results obtained in the Containment Verification module

For the results of the simulations in the GEO5 software, the natural soil, without additions, presented the largest displacements, reaching up to 32.9 mm of structure displacement and thrust on the reinforced concrete structure, reaching up to 114.17 kPa (Table 4).

The SC mixture presented reductions of 41% in the displacement of the structure and 42% for the buoyancy of earth. The SV mixture showed a 32% reduction in structure displacement and 38% reduction in ground thrust. SCV presented a reduction of 61% in the displacement of the structure and 57% for the buoyancy of land.

Some factors can influence the results, they are: the length and the geometry of the contention, angle of friction, cohesion and the densities of the materials. It is observed in Table 4 that the soil without addition of cement and vermiculite presented 158.21 kNm/m for the bending moment and 82.93 kN/m for the shear force.

The SC mixture showed a reduction of 32% in the bending moment value and 38% in the shear force. The SV showed a reduction of 25% in the value of the bending moment and 31% in the shear force. And SCV presented a reduction of 52% in the value of the bending moment and 58% in the shear force.

Table 4. Results of internal forces and active displacement in the structure.

| Mixture | Mmax (kNm/m) | Qmax (kN/m) | Mov.max (mm) | Pressure max. (kPa) |
|---------|-----------------|----------------|-----------------|------------------------|
| SN | 158,21 | 82,93 | 32,9 | 114,17 |
| SC | 107,81 | 51,49 | 19,3 | 65,68 |
| SV | 117,99 | 57,59 | 21,3 | 70,86 |
| SCV | 76,52 | 34,78 | 12,7 | 49,10 |

It is observed that in terms of deformation the SN presented 0.6% in relation to the free span of the concrete curtain (5.5 m), a high value, which requires attention because it compromises the performance of the structure. The SC, SV and SCV mixtures obtained lower values, of the order of 0.3%; 0.4%, 0.2%, respectively.

4. Conclusion

The simulations carried out in the Containment Project module are more conservative than in the Containment Verification module, regarding maximum bending moments and maximum shear forces.

In the Containment Project module, it is possible to obtain smaller bending moments about 29% and 17% for the shear forces for the soil with the addition of vermiculite expanded in relation to the soil without addition of mixture. However, greater reductions can be obtained with respect to the addition of Portland cement in the blend.

In the Containment Verification module it was possible to reduce the pressure in the reinforced concrete curtains by 38%, thus reducing the demands of the reinforced concrete structures in relation to the use of soil without additions.

The maximum bending moments for soil with addition of vermiculite were 25% and maximum shear force of 31%.

For the SC, SV and SCV combinations, satisfactory results and significant reductions were obtained for cavas filling in urban regions, with deformations of 0.3%, 0.4%, 0.2%, respectively. However, the choice of the type of compost will be the responsibility of the designer according to each work.

The specific weight, angle of friction, cohesion can directly influence the behavior of the reinforced concrete structure, as was observed in the present research.

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