# STUDY OF SHEAR STRENGTH OF SOILS FROM AN OPEN TRENCH IN A SLOPE OF SERRA DO MAR, SUSTAINABLE TO LANDSLIDES

***Riadh Ferreira Awadalla El Hajjar**, School of Civil Engineering, Architecture and Urban Design (FEC), University of Campinas (Unicamp)*

***Miriam Gonçalves Miguel**, School of Civil Engineering, Architecture and Urban Design (FEC), University of Campinas (Unicamp)*

## INTRODUCTION

Gravitational mass movements are phenomena of gravitational displacements of soils and / or rocks characterized by the shear rupture of these materials. In addition, they are the main geomorphological processes responsible for the transformation and evolution of the relief, and, many times, they cause great socioeconomic damage, and may even result in fatal victims.

Among the processes of mass gravitational movements, the most frequent in Brazil are landslides, which are fast movements and with short duration, with well-defined volumes of displaced materials. Landslides, as well as floods, are one of the main phenomena related to natural disasters in Brazil, and although floods cause the greatest economic damage, the landslides cause the greatest number of deaths.

The Brazilian region most susceptible to landslides is Serra do Mar, where they occur naturally, regardless of anthropic actions, although these actions can greatly enhance their occurrence. Serra do Mar is a mountainous range that stretches for 1500 km from the south to southeast, located on the Brazilian coast. The average rainfall of Serra do Mar exceeds 3,300 mm/year and occasionally reaches 4,500 mm/year, with the highest total between October to March (spring and summer seasons).

## OBJECTIVES

This research aimed to study of shear strength of soils collected from an open trench on the slope in Serra do Mar, susceptible to landslides. The objectives were specifically the physical and geotechnical characterization of the collected soils, the determination of shear strength envelope of the soils with different moisture contents and, finally, the evaluation of the variation of the shear strength parameters (cohesion and the friction angle) aiming at the landslide stability analysis.

## MATERIALS AND METHODS

The study area of this research is a large slope with vegetation cover of Serra do Mar, located in the city of Santos, on the coast of São Paulo State, southeast Brazil, whose urban occupation is dense and the economy is of great importance, with emphasis on the port sector.

On this slope, 10 trenches were opened and Gobbi (2017) diagnosed at least three horizons of soil in each of them. In this research, trench 3 (TR3) was studied, from which disturbed and undisturbed samples of soils from horizons B and C were collected, since horizon A did not diagnose shear rupture in the slope, as reported by Perdomo et al (2018).

Disturbed soil samples were subjected to physical and geotechnical tests, such as particle density, particle-size distribution with and without the use of deflocculant in the sedimentation phase, and liquid and plastic limits. Perdomo et al (2018) performed and analyzed these tests.

The direct shear test was used to determine the shear strength envelope of the soils of both horizons (B and C), following the recommendations of ASTM D3080 (2004), under drained conditions. Variations of the effective cohesion and the effective friction angle with the moisture content of the soil were evaluated. Specimens (D = 5cm and H = 2.5cm) were trimmed of the undisturbed soil samples and they were subjected to three different moisture contents (25%, 35% and 44%), including the one related to the degree of saturation 100 %. The values of the effective normal stress applied were 50, 100 and 200kPa.

## RESULTS

- TR3-B

The results obtained in the direct shear test for horizon B were not consistent. During the trimming of the specimens, poor quality was detected in the structural integrity of the undisturbed soil samples; it was probably caused during the transport from Santos to Campinas city (approximately 200km). This fact caused difficulties in the trimming of the specimens and, consequently, failures in the performance of the test that presented results not consistent with the theoretical models.

Therefore, a new collection of undisturbed samples would be extremely necessary to carry out new tests, but this was not possible, due to the great difficulty of accessing the slope during rainy period, as well as the pandemic of the new coronavirus (Covid-19) that culminated in the suspension of classroom activities, including laboratory activities, at Unicamp since March 2020. Therefore, the results of the TR3 horizon B soil were not considerate in this analysis.

- TR3-C

The results of the direct shear tests of TR3-C were consistent with the expected. As an example, Figure 1 shows the effective shear strength *versus* horizontal displacement curves of the specimens with 25% moisture content, under different effective normal stresses.

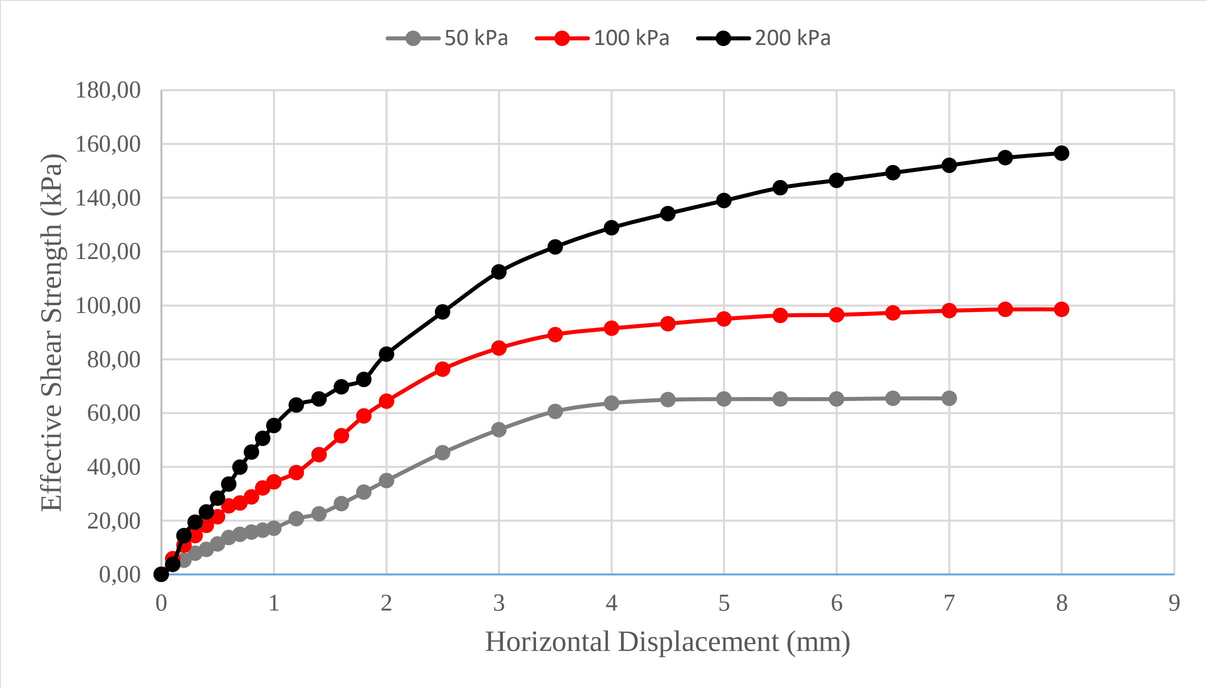


Figure 1. Shear strength x horizontal displacement of TR3-C with 25% moisture content

The effective values of normal stress (σ') and shear strength (τ') at rupture, for each test specimen tested, are shown in Table 1. The specimens were designated with the following acronym CP3Xyz, where X is the trench horizon (B or C), y is the order referring to the applied normal stress (a, b and c, "a" referring to 50kPa, "b" to 100kPa and "c" to 200kPa), and z is the moisture content value. For example, CP3Ca25 corresponds to the first specimen tested with a normal stress of 50kPa and under a moisture content of 25%, trimmed from the C-horizon of trench 3.

Table 1. Effective normal and shear strength for each specimen from TR3-C

| Specimen | σ'(kPa) | τ'(kPa) |
|---|---|---|
| CP3Ca25 | 50 | 65.42 |
| CP3Cb25 | 100 | 98.52 |
| CP3Cc25 | 200 | 156.62 |
| CP3Ca35 | 50 | 57.03 |
| CP3Cb35 | 100 | 86.31 |
| CP3Cc35 | 200 | 145.11 |
| CP3Ca44 | 50 | 42.69 |
| CP3Cb44 | 100 | 72.75 |
| CP3Cc44 | 200 | 128.58 |

The shear strength envelopes for specimens with the same moisture content were obtained using the Mohr-Coulomb fracture criterion and, consequently, cohesive intercepts and internal friction angles were obtained with a linear regression performed with the aid of *Excel* software. Figure 2 illustrates an example of a shear strength envelope, referring to the specimen with a moisture content of 25%.

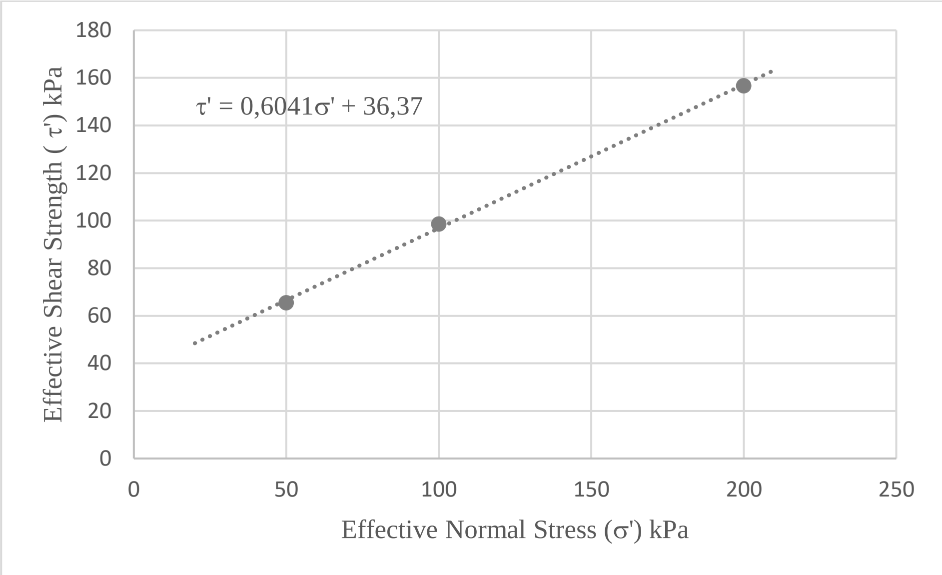


Figure 2. Shear strength envelope of TR3-C with a moisture content of 25%.

Table 2 shows the effective values of cohesion (c') and friction angle (ϕ‘) of the C horizon soil, considering the moisture content values studied.

Table 2. Parameters of shear strength envelope of TR3-C with values of moisture contents of 25%, 35% and 44%

| Parameters | Moisture content (%) | | |
|---|---|---|---|
| | 25 | 35 | 44 |
| c' (kPa) | 36,37 | 27,63 | 14,78 |
| ϕ‘ (°) | 31,14 | 30,43 | 29,71 |

The moisture content decreases when there is a rise in the value of the cohesive intercept that, consequently, leads to an increase the shear strength, since a greater shear strength is required to reach the rupture, considering equal stress normal values. The effective friction angle values change slightly.

This rise in the value of the cohesive intercept is the manifestation of a cohesion defined as apparent, in addition to the real cohesion of the soil. As the moisture content of the soil decreases, the apparent cohesion appears along with the real one, increasing the soil cohesion and, consequently, its shear strength.

The capillary forces inherent in partially saturated soils (or unsaturated) represent apparent cohesion. These forces come from the presence of water in the pores of the soil in the form of a meniscus, that is, with the surface of the water tensioned due to adhesion with the particles. The smaller the pore size of the soil, the greater this capillary force and the greater the apparent cohesion of the soil. As the soil has its moisture content increased, the capillary forces decrease, because the water in greater quantity becomes free to percolate through the pores and it is no longer adhered to the particle.

The real cohesion of the soil comes from the physical-chemical forces between fine particles (clay and silt fractions) and cementing agents. The particle-size tests classified the soil of horizon C as sandy-clay silt with the use of deflocculant and as silty sand without this use. This confirmed the presence of fine fractions (clay and silt) and indicated the micro-aggregated structure, existing due to cementing agents. Thus, the cohesion obtained with the tested specimens with a moisture content of 44% (degree saturation 100%) is the real cohesion of the soil. The cohesions obtained for the other specimens, with lower moisture contents, refer to the sum of the real cohesion and the apparent cohesion, whose values increase with the loss of moisture.

## CONCLUSION

There were many difficulties during the collection of undisturbed samples from horizon B of the TR3, studied in this research, which did not allow the trimming of intact specimens. This fact affected the results of the shear strength tests using direct shear, making them inconclusive. Thus, unfortunately, the results of these tests were eliminated from the analysis.

A clear interference of water in the shear strength of the soil of horizon C was verified. The effective friction angles did not show significant variations. However, cohesion was greatly affected, increasing considerably when the moisture content of the soil decreased. This fact was due to the capillary forces that the water exerts inside the pores in contact with the particles, when the soil is unsaturated, which characterizes the apparent cohesion. The decrease in the apparent cohesion of the soil justifies the instability of the slope in long rainy periods, since the water infiltrates the horizons A, B and reaches C, thus being able to trigger the landslides.

## REFERENCES

ASTM D3080-04, Standard Test Method for Direct Shear Test of Soils Under Consolidated Drained Conditions, ASTM International, West Conshohocken, PA, 2004,www.astm.org.

PERDOMO, C.V; NOGUEIRA, L.C.; BLISKA, A.M.; GOBBI, E.S.; LADEIRA, F.S.B; MIGUEL, M.G. Características geotécnicas de solos de trincheiras abertas na vertente de uma encosta da serra do mar, susceptível a escorregamentos. In: 16º Congresso Brasileiro de Geologia de Engenharia e Ambiental, São Paulo/SP, 2018 (In Portuguese).

GOBBI, E. S. Variação do manto intempérico nas encostas dos morros residuais de Santos-SP. 2017. Thesis (pH in Geosciences) – Institute of Geosciences. University of Campinas (Unicamp) (In Portuguese).