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Physical 1:1 scale model studies on geogrid reinforced soil walls

Etude de modèles physiques de murs de sols renforcés avec des géogrilles à l´échelle 1:1

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ABSTRACT
This paper presents a physical model study of the compaction influence on the behavior of reinforced soil walls with extensible reinforcements. The experiments have been accomplished in a new facility at COPPE/UFRJ's Geotechnical Laboratory. Two model soil walls 1:1 scale reinforced with geogrids were performed. For soil compaction two different types of hand-operated compactors were used: a light vibrating plate and a vibratory tamper. Results show that soil compaction does not limit to the reduction of the soil void ratio. Compaction may lead to a significant increase of the horizontal stress inside the reinforced soil mass and generate a kind of preconsolidated material. Analyses of results show that compaction may be a decisive factor on reinforcement tensions and post-construction movements.

RÉSUMÉ
Cet article présente l´ étude d´un modèle physique de l´ influence de la compactation dans le comportement des murs de sols renforcés avec des renforts extensibles. Les essais ont été développés avec facilité dans les laboratoires de geotechnique de la COPPE – UFRJ. Deux modèles de murs de sols renforcés avec des géogrilles ont été expérimentés à l´échelle 1:1. Pour la compactation, ont été utilisés deux différents types de compacteurs manuels: une plaque vibrante légère et un vibrateur à marteau. Les resultats montrent que la compactation du sol ne limite pas la réduction de l´indice de vide. La compactation peut conduire á une augmentation significative de la tension horizontal de la masse de sols renforcés et peut produire un type de material préconsolidé. Les analyses des résultats montrent que le compactage peut être un facteur décisif sur les tensions de renforcements et les mouvements d´aprés construction.

1 INTRODUCTION

Cousens and Pinto (1996) report that the effect of compaction has been relatively well studied on traditional unreinforced retaining walls, but that is not the case for reinforced soil walls, where very little investigation has so far been undertaken on such matter.

Conventional procedures for analysis and design of walls do not take into consideration the induced stress due to soil compaction, no matter whether the backfill soil is reinforced or not. In general, compaction is considered merely a procedure that aims reducing the soil void ratio and thus, increase its resistance characteristics and decrease its compressibility.

Despite the fact that conventional procedures disregard the compaction effect on the analysis of the backfill internal stress, Aggour and Brown (1974) report studies accomplished already at the end of the 19^{th} century by Darwin (1883), in small cookie cans and repeated by Terzaghi (1934), in larger scale models, which show the increase of the horizontal stress of the soil when the material is compacted.

Ehrlich & Mitchell (1994) present an analytical procedure that takes into consideration the induced stress due to soil compaction on the determination of the internal stress of a reinforced soil wall. Such procedure has been validated by numerical and case studies results. However, most of the studies reported in literature are related to soil walls reinforced with metallic elements. Rowe and Ho (1993) assert that the effect of the soil compaction upon the internal stress in soil walls reinforced with extensible reinforcements is still not appropriately addressed.

The main objective of the research reported in this paper was verify under well controlled physical model conditions the importance of the induced stress due to soil compaction in the internal stresses and in the overall behavior of soil walls reinforced with extensible reinforcements.

2 PHYSICAL MODEL

Tests in a 1:1 scale have been accomplished at COPPE/UFRJ's Laboratory of physical models. In this article results of two model soil walls reinforced with geogrids are presented. In the first study, the soil was compacted with a light vibrating plate only and, in the second, besides the vibrating plate a vibratory tamper was also used for soil compaction. Tension along the reinforcements and wall face displacement were monitored during the wall construction and under the external loads application.

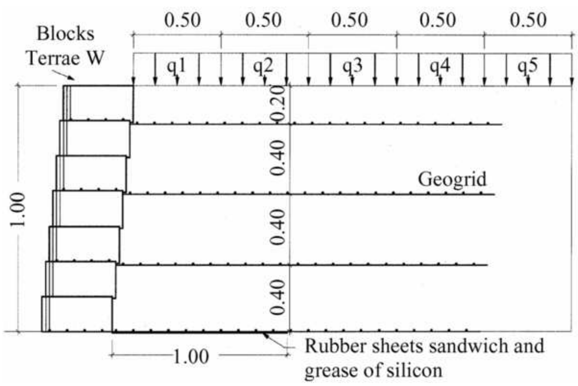


Figure 1 – Model wall section

The soil used for the construction of the models wall was a well-graded crushed quartz (Cu = 8.9) and the reinforcement was a flexible polyester geogrid (Fortrac 80/30-20). In all of the assemblies a face of precast blocks of 0.20 m height each were used (Terrae-W). In Figure 1 a section of the model is shown. The box of the model is a U shape concrete wall with 2 m of width, 3 m of depth and 1.5 m of height. Air bags allow the application of overloads up to 100 kPa on the top of the backfill.

3 MODEL WALL CONSTRUCTION

For model wall construction four layers of grid reinforcements, 0.4 m vertical spaced and 2.12 m length were used. The first layer located at the base of the wall, is partially upon a sandwich of rubber sheets and silicon grease (Figure 1). The objective of this lubricated 1 m width zone was to move the potential failure surface, moving it away from the wall face, in order to increase the dimension of the active zone and facilitate measurements of the tension along the reinforcements. The other reinforcement layers were located at 0.4 m, 0.8 m and 1.2 m height from the bottom of the wall (Figure1).

In Figure 2, the construction sequence of the model wall is presented. Soil layers 0.20 m thick were placed dry and compacted. After compaction the measured soil unit weigh was 21 kN/m^3. Triaxial tests performed at specimens compacted at this density lead to a soil friction angle equal to 42^o. In Figure 3 an illustrative photo of the model wall construction is shown.

To reduce the effect of the lateral friction at the interface of the soil and the concrete wall, plates of ultra-high molecular weight polyethylene were installed in all lateral faces of the wall that composes the box of the model. In addition, a thin layer of silicon grease was applied and plastic sheets covered it.

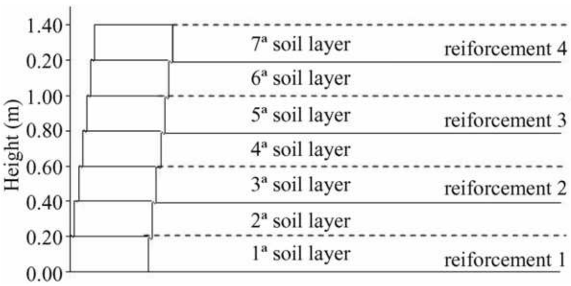


Figure 2 - Construction sequence of the model

Figure 3 – Model wall construction

For soil compaction two hand-operated compactors were used: a light vibrating plate (Dynapac LF 81) and a vibratory tamper (Dynapac LC 71-ET).

The determination of the equivalent static load of each compactor was performed through Kyowa accelerometers installed in the body of the compactors. Note that the concept of equivalent static weight for this case is the one presented by Ehrlich and Mitchell (1994), not the classic definition that associates the work carried out by a force. An equivalent vertical stress of 8.0 kPa and 73 kPa for the vibrating plate and the vibratory tamper were measured, respectively.

4 INSTRUMENTATION

The reinforcements numbered 2 to 4 were monitored. Load cells were installed at four points along each reinforcement, two in the active zone and two in the resistant zone. In Figure 4, an illustrative photo of those load cells is shown. The cells allow monitoring the mobilized tension along the reinforcements, without need of determination of the reinforcement stress-strain curves that is time dependence. The load cells are also capable to counterbalance the temperature effects and the bending moments, and are strong enough to resist the stress induced during the compactors operation. Further details about these load cells could be found in Saramago (2002).

The horizontal displacements of the face were monitored through four LVDTs. The internal horizontal displacements were monitored using five tell tails. The readings were performed by an automatic acquisition system: 52 signs readings derived from the load cells (μVolts) and four signs from the LVDTs (Volts).

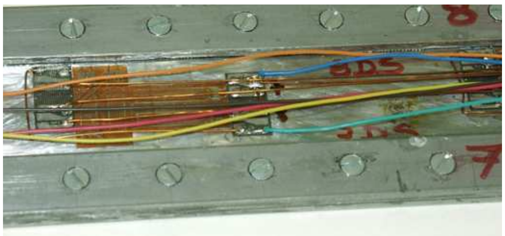


Figure 4 - Load cells without the protection resin.

Figure 5 – Wall model front view

5 RESULTS

5.1 *Loads in the Reinforcements*

Figures 6 and 7 show the measured tension along the reinforcement numbered 4 for the Wall 1 and Wall 2, respectively. In these figures curves related to different construction stages and different steps of external load application are shown. Note that for Wall 1 the light vibrating plate was used for soil compaction only, while for Wall 2, the soil compaction was accomplished using both the vibrating plate and the vibratory tamper.

In Figures 6 and 7 it could be observed a clear tendency of the reinforcement tension to be higher next to the face of the wall when the 7th soil layer has been placed. This tendency has remained unaltered after the compaction of the layer with the vibrating plate (for both Wall 1 and Wall 2) and also during the period of the external load application (for the Wall 1, Figure 6).

Anyhow, for Wall 2 the mobilized reinforcement tension next to the wall face fell down drastically and became null after the compaction of the soil layer with the vibratory tamper (Figure 7). For this wall it could be observed that reinforcement tension next to the face always kept lower values after this stage of construction. Note that the compaction of the soil layer with the vibratory tamper leads to a significant increase of the maximum tension in the reinforcement, T_{max}. In Figure 7 it could also be observed a significant increase of the tensile forces in the reinforcements at the last stages of the external loads application.

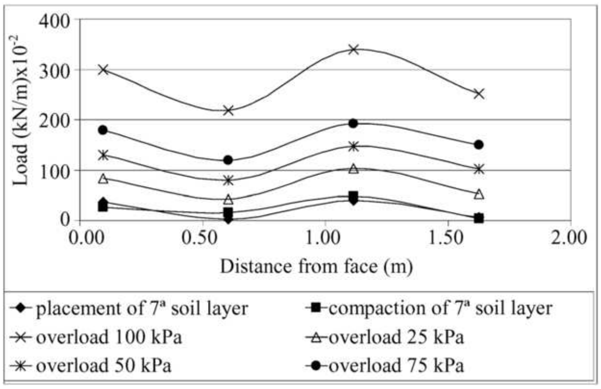
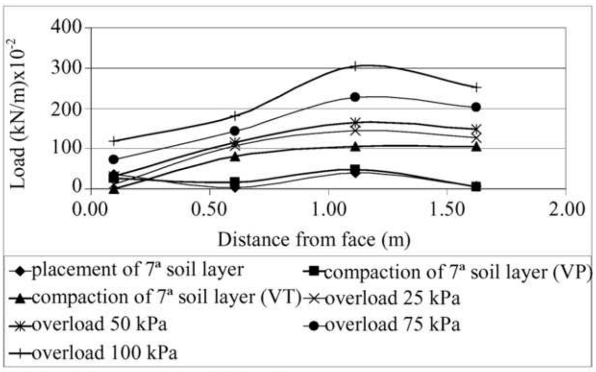


Figure 6 - Measured tension along the reinforcement in the 4th reinforcement layer - Wall 1

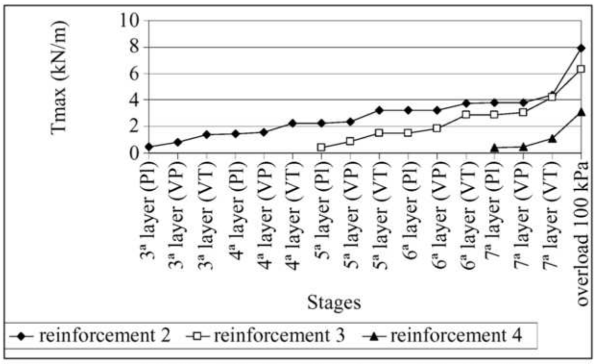


(VP) – Vibrating Plate; (VT) – Vibratory Tamper

Figure 7 – Measured tension along the reinforcement in the 4th reinforcement line - Wall 2

In Figure 8 measured values of T_{max} in the 2nd, 3rd and 4th layers of reinforcements for the Wall 2 are shown for different stages of construction and external loads application. Note that for all layers the soil compaction with the vibratory tamper promoted a significant increase of the maximum tension in the corresponding reinforcement. Nevertheless, in this figure it is also shown that placement and compaction of a soil layer with the light vibrating plate, and also the placement and compaction of the soil layers above, do not mean a great variation in the value of the mobilized tensile forces in the reinforcements.

Figure 9 shows for the 4th reinforcement layer of Wall 2 the variation of T_{max} with the equivalent depth, Z_{eq}. Where the equivalent depth of a soil layer corresponds to the value of the external load applied at the top of the wall divided by the unit weight of the soil (Q / γ), added to the real depth of that layer relative to the soil surface.



(Pl) – Placement; (VP) – Vibrating Plate; (VT) – VibratoryTamper

Figure 8 - Measured values of T_{max} in different layers of reinforcements - Wall 2

In Figure 9 the dash and point vertical line means the equivalent depth, Z_c, related to the maximum vertical stress induced during soil compaction. The equivalent vertical stress for the vibratory tamper is equal to 73 kPa. Thus, Z_c for Wall 2 is equal to 3.5 m. It can be observed that T_{max} keeps very low values variation for Z_{eq} lower than Z_c. On the other hand, for higher Z_{eq} values it could be seen a linear relationship between T_{max} and Z_{eq}. These results demonstrate that compaction can be considered as a kind of soil preconsolidation, in accordance to Ehrlich & Mitchell (1995).

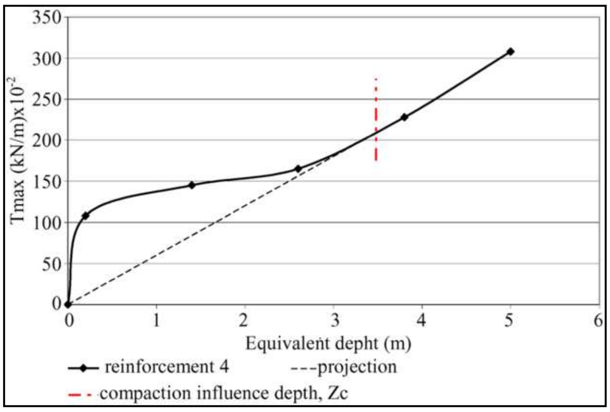


Figure 9 - Tmax vs. equivalent depth for the 4th reinforcement layer – Wall 2

5.2 *Horizontal displacements at the face*

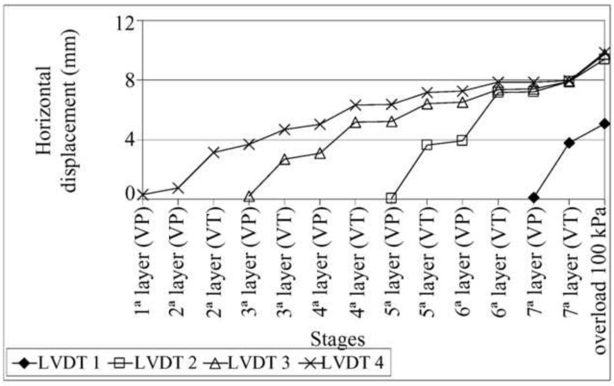
Horizontal displacements at the face were measured at the blocks layers: 1st (LVDT4), 3rd (LVDT3), 5th (LVDT2) and 7th (LVDT1). Figure 10 shows the measured horizontal displacements of the Wall 2 at different construction stages and during the external load application (100 kPa).

At the end of the construction it was verified that the measured displacements values were very similar for LVDTs 2, 3 and 4, in the order of 8mm. For LVDT1 positioned next to the top of the wall the displacement at the end of the construction period was of 5.08mm (see Figure 10).

In Figure 10 it is also verified that the greatest displacement increments occur during the soil layers compaction with the vibratory tamper and for the other stages of construction the increments of movement kept low values. As above discussed, compaction may lead to the reinforced soil mass a kind of preconsolidation that promotes a stiffer behavior after construction.

It was observed that only after the applied external load had got higher values than the equivalent vertical stress induced by the vibratory tamper (73 kPa) a significant increase in the lateral movements has occurred. The horizontal displacements during the construction period corresponded to approximately 81% of the total displacement of the face verified at the end of the tests under the external load of 100kPa.

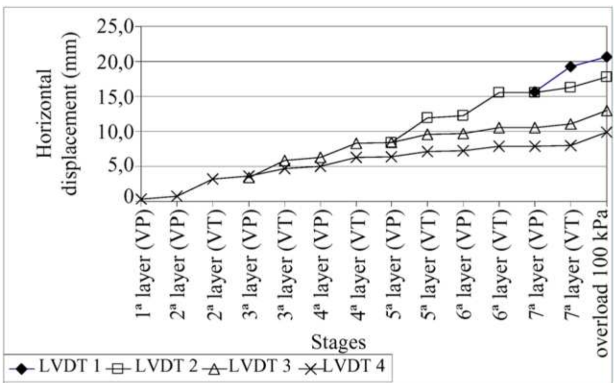
It should be noted that the reinforced soil wall construction occurs in steps and thus, the horizontal positioning of each block layer occurs in an accumulated way, i.e., at installation a new layer of blocks includes the accumulated horizontal displacements of the previous stages of construction.



(VP) – Vibrating Plate; (VT) – Vibratory Tamper

Figure 10 - Measured horizontal displacements of the Wall 2 face at different construction stages and external load application.

Figure 11 shows the accumulated lateral movements of the Wall 2 at different construction stages and during the external load application (100 kPa). The higher the reinforced soil layer, larger is the verified accumulated displacements. The movements induced by the soil compaction itself were responsible for approximately 1^{o} variation of the wall inclination (from 84 to 85^{o}).



(VP) – Vibrating Plate; (VT) – Vibratory Tamper

Figure 11 - Accumulated lateral movements of the Wall 2 face at different construction stages and external load application.

6 SUMMARY AND CONCLUSIONS

Two real scale soil walls reinforced with geogrid were built under laboratory control conditions. These two walls were constructed keeping, in general, the same soil, geometry and construction procedure. Anyhow, for the first wall the soil compaction was performed using a light vibrating plate only, and the second wall besides the vibrating plate a vibratory tamper was also used for the soil compaction.

It has been verified that compaction does not limit to reduction of the soil void ratio, but it may also be considered as a pretensioning of the reinforced soil mass. Compaction may lead to the reinforced soil mass a kind of preconsolidation that promotes a stiffer behavior after construction, in accordance to Ehrlich & Mitchell (1995).

The compaction of a soil layer with a heavier compactor may lead to a significant increase of the maximum tension in the reinforcement. Until the geostatic pressure exceeds the value corresponding to the vertical stress induced during the compaction operation, placement and compaction of the above soil layers does not alter substantially the movements in the layer and also the mobilized tensions in the reinforcement. Results show that compaction promotes movements during the construction period and reduces both the settlement and the horizontal movements in the post-construction period.

It was also observed that low compaction of a reinforced soil mass may lead to a tendency of the reinforcement tension to be higher next to the face. Nevertheless, the mobilized reinforcement tension next to the wall face may fall down drastically if a heavier compactor is used.

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