Influence of facing type and external loads on the behavior of geogrid reinforced soil walls

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ABSTRACT: Full-scale physical modeling studies of reinforced soil walls have been accomplished in a facility at COPPE/UFRJ's Geotechnical Laboratory. It is evaluated the significance of facing type and external loads on reinforced soil wall behavior. The experiments are performed in box composed by a U shape concrete wall with 1.5 m height, 3.00 m length and 2.00 m width. Vertical loads up to 100kPa are applied at the top of the backfill using air bags. Geogrids were used as reinforcement and the backfill material was constituted by well-graded sand. Two different types of facings were used on tests: sacks of sand and sacks of sand protected by rocks, supported by a metallic grid. Wall face inclination was 90º. Mobilized tension along the reinforcements and external and internal movements of the wall were monitored. Higher tension along the reinforcements was measured in tests where sacks of sand protected by rocks were used as facing. Tests where the base of rock facing was lubricated showed higher mobilized tensions in the reinforcements comparing to the non lubricated ones. It was also verified that re-loading of external load leads to lower mobilized tension in reinforcements comparing to the first virgin one.

1 INTRODUCTION

Conventional methods for design of reinforced soil walls have been largely empirical, being applicable only to similar cases to those on which they are based. Methods based on the limit state are also usual, having inherent limitations to represent the actual wall behavior, performing analysis under ultimate conditions.

Conventional procedures usually do not explicitly take into consideration facing. However, Tatsuoka et al. 1989 showed that stiffer faces promote a higher confinement of the soil near the face, reducing the structure deformations. Tatsuoka 1993 & Tajiri et al. 1996 demonstrated that a rigid face can reduce the required tension along the reinforcements.

In the present paper it will be verified the significance of facing type and also external loads application, including re-loading, on the behavior of the walls.

2 PHYSICAL MODEL

The tests were performed in 1:1 scale in a facility developed in COPPE Geotechnical Laboratory (Saramago and Ehrlich 2005).

The box of the model is a U shape concrete wall with 1.5m height, 3.0m length and 2.0m width. Lateral faces of the concrete wall received a polyethylene coating (UHMW 1900), being lubricated in order to assure a plane strain condition during the tests (silicon grease covered by plastic sheets).

Reinforced soil walls were built considering two different types of facing: (a) sacks of sand (fig 1); (b) sacks of sand protected by rocks supported by a metallic grid (Fig 2). In both cases the wall face inclination was 90º. Geogrids – Fortrac 80/30-20 – were used as reinforcement. Reinforcement spacing was 0.40 m. The sacks of sand were wrapped by the geogrids. Considering the rock facing supported by metallic grid, 40 metallic bars (Fig 3) were used to connect the metallic grid to the geogrids.

In all tests 1m width zone at the bottom of the wall was lubricated (sandwich of rubber sheets and silicon grease) in order to move the potential failure surface, keeping it away from the wall face. This 1m lubricated zone include the base of the sacks of sand that compose facing. The dimension of the active zone was therefore increased, improving the measurements of the tension along the reinforcements.

Tests were performed for base of rock facing under lubricated and non-lubricated conditions, in order to verify the difference of performance.

The backfill material was constituted by well-graded sand, composed by crush quartz powder. Table 1 presents the results of triaxial tests performed at different soil densities.

Table 1: Soil shear resistance parameters (Saramago 2002)

Unit Weight (kN/m³)	void ratio	Friction Angle (°)
16.2	0.64	37
20.5	0.30	44
23.1	0.14	51

Vertical loads up to 100kPa were applied at the top of the backfill using PVC air bags. The constructed model simulates the behavior of a 7-meter high wall, representing a portion of the prototype.

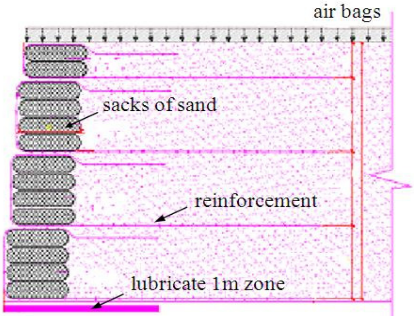

Figure 1: Sacks of sand

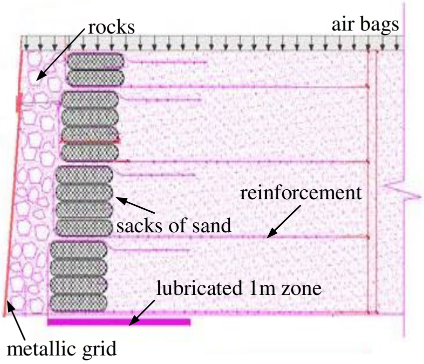

Figure 2: Sacks of sand protected by rocks, supported by a metallic grid

3 MODEL WALL CONSTRUCTION

The construction of the model was performed in layers, totalizing 7 soil layers, 0.20m thick, placed dry.

Four layers of reinforcement were installed along the height of the wall, being placed: on the bottom, at 0.4m, 0.8m and at 1.2m high from the bottom. The reinforcement layers were 2.12m long.

Two different types of compactors were used: a light vibrating plate (Dynapac LF 81) and a heavy hand ride compactor (Dynapac LC 71-ET). The vertical induced pressure of the light vibration is 8kPa and of the heavy hand compactor is 73kPa.

The sequence of construction was developed in 3 stages per layer of soil: (1) soil placement, (2) light compaction and (3) heavy compaction of the placed soil. The rock facing were positioned (Figure 2) after the end of the first performed test with sacks of sand as facing only (Figure 1).

Figure 3: Metalic Bar

4 INSTRUMENTATION

The reinforcement loads were monitored by groups of load cells installed at four points along each reinforcement. Further details about these load cells could be found in Saramago and Ehrlich, 2005.

The horizontal displacements of the face were monitored through four LVDTs. The internal horizontal displacements were monitored using five tell tails. Figures 4 and 5 illustrate the built walls with the instrumentation installed.

Figure 4: Face of sacks of sand

Figure 5: Face of sacks of sand protected by rocks, supported by a metallic grid

5 RESULTS

5.1 *Influence of external load*

In Figures 6 and 7 are showed results for the increase of measured tension along the 3rd layer of reinforcement under two cycles of external load, the 1st and 2nd loading cycles, respectively. Loads up to 100kPa were applied in steps. The 2nd load cycle was applied just after the first one. Those results are related to the wall with face of sacks of sand.

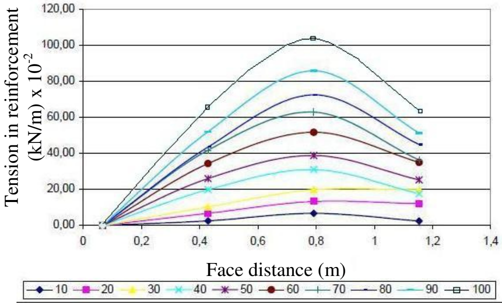

Figure 6: Increase of measured tension along the 3rd reinforcement layer – face of sacks of sand – 1st load cycle (base of facing lubricated)

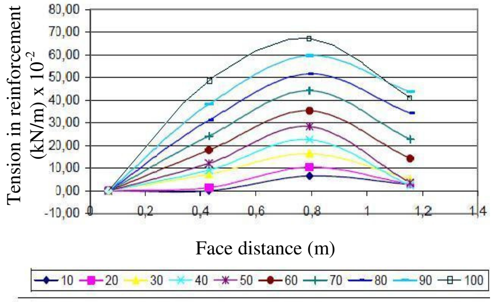

Figure 7: Increase of measured tension along the 3º reinforcement layer – face of sacks of sand – 2nd load cycle (base of facing lubricated)

It could be observed a similar mobilized tension distribution along the reinforcement for both cycles of external loading. Note that the location of the point of maximum tension in the reinforcement keeps the same in both cases. Nevertheless, the 2nd cycle of external load showed increase value of maximum tension in the reinforcement, ΔT_{max}, 35% lower than the corresponding value in the 1st cycle.

Nevertheless, the total T_{max} may be considered the same for both 1st and 2nd loading cycles at the end of the aplication the external load (100 kPa). The lower values observed in the 2nd cycle are related to the non elastic behavior of the soil. A residual tension of 37% of ΔT_{max} has remained in the soil after the first load and unload cycle, thus the total T_{max} were almost the same for the both cycles. The 1st load and unload cycle has promoted a kind of a pretensioning on the reinforced soil mass. The observed behavior is similar to soil compaction (Ehrlich & Mitchell, 1995 and Saramago & Ehrlich, 2005).

5.2 *Performance of walls with base of rock facing lubricated and non-lubricated*

In Figures 8 and 9 are presented results of wall tests performed for the base of rock facing under non-lubricated and lubricated conditions, respectively. Those values are also related to the 3rd layer of reinforcement.

For test where the base of rock facing was under lubricated condition, it was verified higher and more uniform mobilized tension along the reinforcement in comparison with the observed values for non-lubricated condition. Note that the location of the point of maximum tension in the reinforcement may be considered the same in both cases.

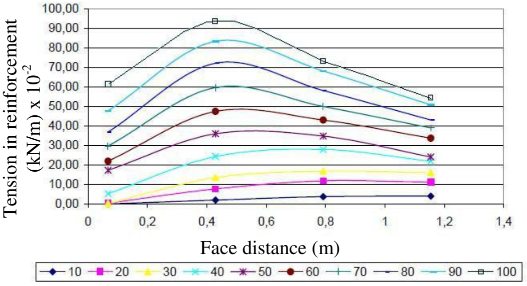

Figure 8: Increase of measured tension along the 3rd reinforcement – base of rock facing non-lubricated

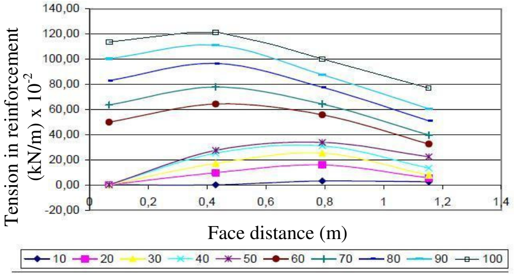

Figure 9: Increase of measured tension along the 3rd reinforcement – base of rock facing lubricated

5.3 *Significance of facing type*

In Figures 6 and 9 it could be observed an expressive difference of mobilized tension in the reinforcement considering tests with face composed by sacks of sand only and with face of sacks of sand protected by rocks, respectively. Results show higher reinforcement tension mobilization in the wall with face of sacks of sand protected by rocks.

Note that test with facing with sacks of sand only no tension was measured close to the wall face no matter the applied external load. Nevertheless, for test with sacks of sand protected by rocks and external load of 100 kPa it was verified that the tension mobilization near to the wall face was 98% of the maximum measured value along the reinforcement.

In Figures 10 and 11 it is shown measurements of lateral movements of the wall face using LVTDs for tests with face composed by sacks of sand only and with face of sacks of sand protected by rocks, respectively. It could be observed that the placement and compaction with light vibrating plate induce small increments of displacements compared to values corresponding to the heavy hand compactor application.

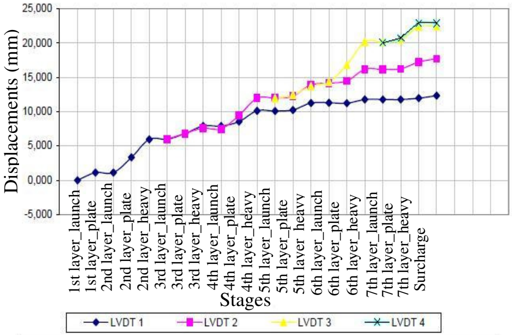

Figure 10: Face horizontal movements – face of sacks of sand

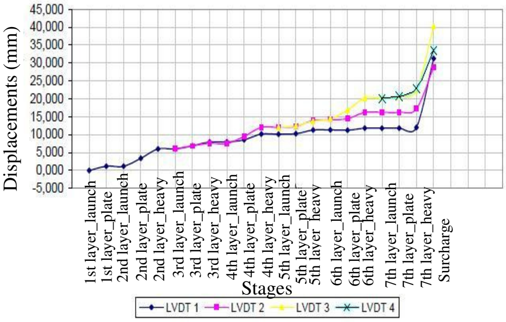

Figure 11: Face horizontal movements – face of sacks of sand protected by rocks

The facing composed with sacks of sand showed significant lateral movements only during the wall construction, presenting reduced values during the external load application (see Figure 10). Compaction provides a kind of pretensioning on the reinforcements, increasing stress and deformations during the wall construction and decreasing post-construction movements (Ehrlich & Mitchell, 1995, Saramago & Ehrlich, 2005).

Nevertheless, in the test where sacks of sand protected by rocks were used as facing it was observed expressive lateral movements during the external load application (see Figure 11). These movements may be mostly due to rock facing deformation under the external load application. Note that the rock facing were not compacted.

6 CONCLUSIONS

Similar mobilized tension distribution along the reinforcement during cycles of external loading was observed. Lower increments of reinforcement tension were observed in the second load cycle. A residual tension has remained in the soil after first load and unload cycle. This load and unload cycle has promoted a kind of a pretensioning on the reinforced soil mass.

According to Ehrlich & Mitchell (1995) and Saramago & Ehrlich (2005) tests show that compaction provides a kind of pretensioning on the reinforcements, increasing stress and deformations during the wall construction and decreasing post-construction movements. Nevertheless, in the test where sacks of sand protected by rocks were used as facing it was observed expressive lateral movements during the external load application. These movements may be mostly due to rock facing deformation under the external load application. Note that the rock facing were not compacted.

Lubrication of base of rock facing leads to higher and more uniform tension mobilization along the reinforcement compare to determined values in the test under non-lubricated condition. Higher reinforcement tension was observed in the test with facing composed by sacks of sand protected by rocks. Test with facing with sacks of sand only no tension was measured close to the wall face no matter the applied external load.

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