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Evaluation of connection loads between a geogrid and concrete blocks based on laboratory tests

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ABSTRACT: Internal stability analysis of segmental geosynthetic reinforced soil walls includes the verification of connection strength at the geosynthetic-block interface. The calculation of the connection load (T_o) has been a hard task as mechanisms are still not completely understood. This paper presents an evaluation of geogrid-modular blocks connection forces based on a laboratory test device developed to simulate load transfer mechanism at the face of geosynthetic reinforced soil walls. A reinforced system with a sand backfill, a woven geogrid and concrete blocks were subjected to incremental vertical loads while lateral earth pressures, horizontal displacements at the face, as well as reinforcement strains and load at the geogrid-block interface were monitored. and the strains of the reinforced layer were monitored. Results show differential settlements of the backfill and the facing wall leading to a down-drag effect on the reinforcement. This effect associated to face wall displacements led to a significant impact on connection loads at geosynthetic-blocks connection.

1 INTRODUCTION

The use of geosynthetic reinforced soil structures has gained increasing popularity, being used in containment systems, slope stability, load-bearing walls, or for bridge abutments. This type of structure stands out for the flexibility of project design, being adaptable to various environments, having a fast execution process, without the use of skilled labor, due to its low complexity, besides having a good cost benefit (Ngo 2016) The good performance of this type of structure depends on many variables, of which the backfill soil, type of face and the reinforcements have been reported to have significant influence (Brugge *et al.* 2012; Liu *et al.* 2009, 2011; Portelinha *et al.* 2014; Saghebfar *et al.* 2017).

In this type of structure, the geosynthetics are connected to the face in some way. In case of segmental reinforced soil walls this connection occur often by friction and extend to the anchorage zone. When reinforcements are loaded, stresses are developed at the geogrid-block connection (Soong & Koerner 1997). The structure must be able to generate sufficient interlock between the face and the reinforcement to resist the horizontal forces in the soil mass in the connection zone (Collin 1997). Morsy (2021) reports the importance of the type of face and how it affects the distribution and magnitude of stresses at the face, where connection loads tend to be greater in rigid than flexible faces.

Currently, design recommendations, such as BS-8006 (2010) and FHWA-NHI-10-024 (2009), treat connection stresses in a simplified manner, suggesting percentages of 50% to 100% of the maximum mobilized tension in the reinforcements (Tmax), depending on the structure configuration. The present study is part of a large experimental program that investigates the mechanisms involved in the connection loads at the interface between geosynthetic reinforcements and face elements. Specifically, this paper presents results of a

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laboratory test conducted to investigate connection loads developed in a sand reinforced with geogrid in modular block reinforced system.

2 MATERIALS AND METHODS

2.1 *Materials*

In this study the soil used was a well-graded medium sand with friction angle of 33.2°, dry density of 17.2 kN/m^3 and maximum and minimum voids index of 1.10 and 0.6, respectively. Figure 1 shows the grain size distribution of the sand. The geosynthetic reinforcement was a polyvinyl alcohol polymeric (PVA) geogrid with properties indicated in Table 1. As facing revetments, commercial concrete masonry units (CMU) were used, with a compressive strength of 3.0 MPa, with dimensions of 390 X 150 X 190 mm (width X length X height).

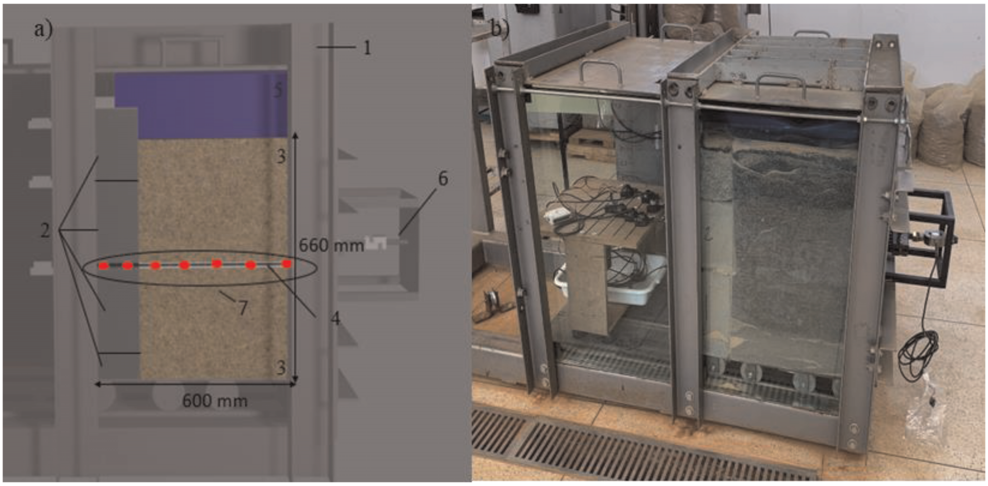

Figure 1. Illustration of test (a): instrumentation) used in the test Legend: 1) Metal Box, 2) Face wall, 3) Soil mass, 4) reinforcement and 5) Air pressure device. 6) load Cell, 7) "Tell-talles" and b) a Picture of the box before the test.

Table 1. Physical and mechanicals properties of the geosynthetics.

Properties	Standard specification	Value	Unit
Thickness	ASTM D5199	2,18	mm
Ultimate tensile strength	ASTM D54595/ D6637	53,74	kN/m
Elongation at failure	ASTM D54595/ D6638	4	%
Aperture size MD*	–	114,8	mm
Aperture size CMD**	–	10,3,4	mm

*MD – Machine direction, **CMD – Cross- Machine direction.

2.2 *Physical model and testing procedure*

The apparatus used in the present study simulates a geosynthetic MSE wall with concrete blocks face, in a working stress condition. The physical model consists of a rigid metal box

Table 2. Soil Propreties.

Properties	Standard specification	Value	Unit
Specific gravity	ASTM D7263 – 09	2,64	g/cm^3
Min. Void ratio – emin	ASTM D 4253-16	0,66	–
Max. Void ratio – emax	ASTM D 4253-16	1,10	–
Dry density of soil	ASTM D1557 – 12	1,73	g/cm^3
Water content	ASTM D1557 – 12	3,00	%
Cohesion	ASTM D3080 -11	0,00	kPa
Friction angle	ASTM D3080-11	33,18	°
Classification SUCS	ASTM D2488-69	SW	–
Uniformity Coefficient – C_u	ASTM 112-13	2,08	–
Coefficient of curvature – C_c	ASTM 112-13	1,14	–

with internal dimensions of 600 X 760 X 800 mm (width X length X height) where one of the lateral walls of the box is made of transparent glass and the others are stationary, all walls were lubricated to minimize frictions between then.

The MSE wall were constructed above two plates, one fixed and one that was able to move horizontally with bearings that run internally along rails. The mass of soil was compacted in layers to 98% of density, the reinforcement was placed between the soil mass and had been connected to wall only by attractive forces. The blocks were able to move free and independently.

The working system of the equipment is to apply vertical pressure in the top of the reinforced soil unit, thereby inducing a horizontal stress on the front moving wall. For that, were used an airbag system up to 180 kPa.

The instrumentation includes measurements of tensile loads, geosynthetic internal displacements and horizontal and vertical soil pressure. A load cell was attached to the reinforcement at that back wall of the model to measure the mobilized load on it. For the internal displacements were used seven potentiometer-type 'tell tales', with 100 mm spacing, to be possible capture the displacement inside of the wall, which were used to calculate internal strains. Figure 1a show an illustration of the equipment and the instrumentation used during tests and 1b shows the physical model before the start of the test. PIV (Particle Image Velocimetry) technique was used to capture the displacement field from the lateral transparent wall. Figure 2 shows the lighting system used during tests.

Figure 2. Lightning and recording system.

3 RESULTS

Figure 3 shows the tensile load mobilized by the geogrid at 20, 60, 100, 140 and 180 kPa of vertical loadings. Tensile loads along the on the reinforcement were calculated based on reinforcement strains obtained from the tell-tales technique and the corresponding value of tensile load using wide-width tensile test results. It should be observed that tell-tales measurements generate total strains. The peak tensile load was registered to occur close to the connection between the geogrid and the modular block at the face with a value of 9.16 kN/m under 180 kPa of loading. It was observed because tell-tale points were located inside the modular blocks which is not usual. Otherwise, peak loads would be around 400 mm from the facing, which corresponded to the location of the potential failure surface. This result agreed with the images taken during the procedure and the results using the PIV methodology as indicated in Figure 4.

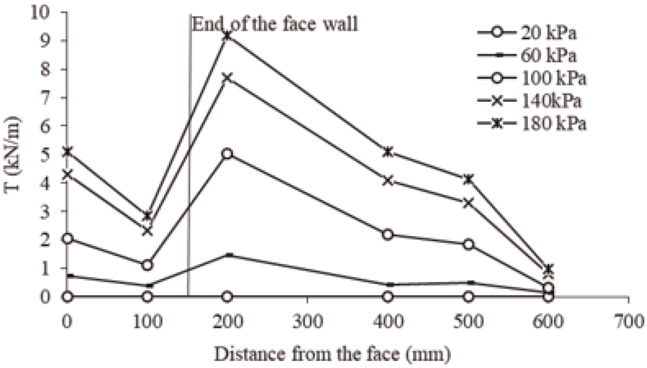

Figure 3. Tensile load mobilized by geosynthetic versus distance from the face.

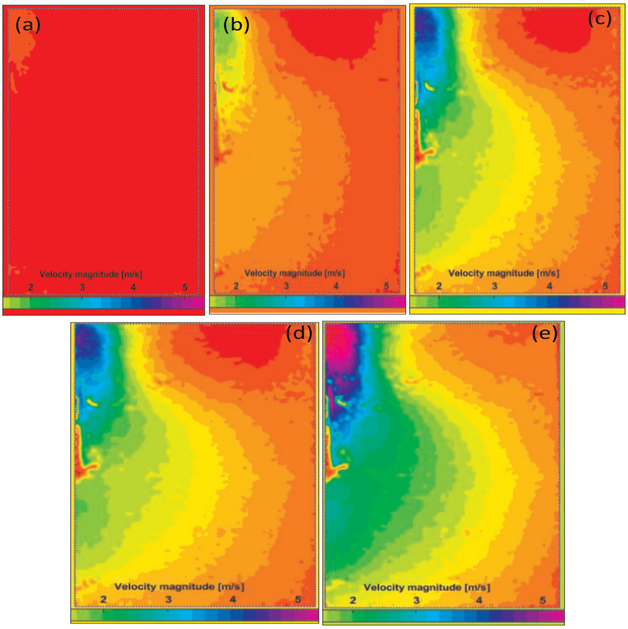

Figure 4. Displacements field from the PIV-Lab at the end of loading of: (a) 20 kPa; (b) 60 kPa; (c) 100 kPa; (d) 140 kPa; and (e) 180 kPa.

Figure 4 shows the displacement field at the end of each loading stage. It can be observed the formation of displacement zones that intensified near the wall facing, which is intensified with loading increasing. A very relevant fact was the creation of a small area of displacement concentration under the connection of the geosynthetic to the wall. This zone is a void created by the down-drag effect on the geosynthetic as reported by Morsy (2021).

In order to capture the down-drag effect, Figure 5 shows the total displacements of the reinforcement in each loading stage. The reinforcement has a maximum settlement of 2.3 mm close to the face due to the down-drag effect, and it was noted that the trend is that the settlement values reduce as more distant from the face. This type of deformation described as asymmetric deformation occurs due to the relative difference of rigidity of reinforced soil and block facing wall (Soong & Koerner 1997). It is observed that this effect is relevant for the connection load even in small magnitude, in this case, 2.3 mm.

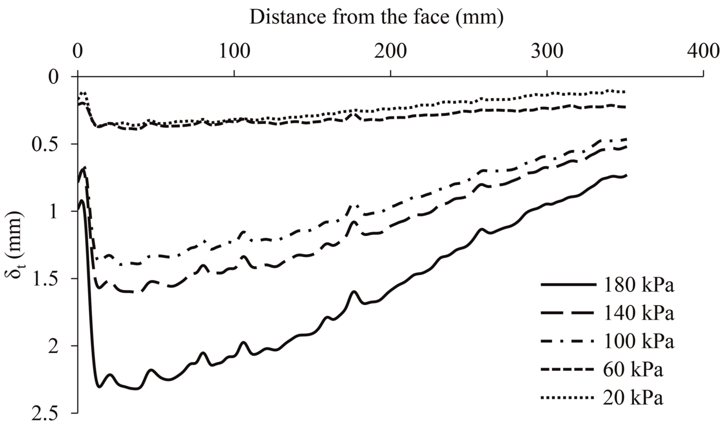

Figure 5. Total displacements of the geosynthetic inside of the soil mass for 20,60,100,140 and 180 kPa load stage.

Figure 6 compares the tensile load measured by the load cell with that calculated at the connection in each loading stage. This comparison aims to evaluate the magnitude of the

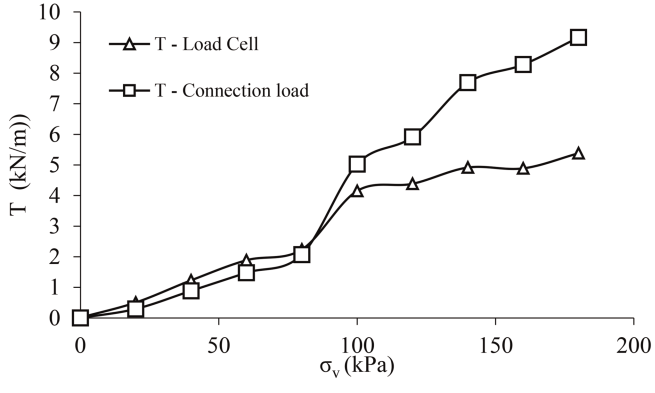

Figure 6. Comparison between stresses requested on the geosynthetic measured by the load cell, the tell-tale farther from the blocks face and the tell-tales at the connection.

connection load in respect to the maximum along the potential failure surface. Usually, design standards recommend a percentage of T_{max} to obtain the connection load, which is between 50% and 100%, depending on the type of the face wall and the capacity of movements at connection. Note that for loading up to 80 kPa, the test results follow the same design recommendation of 1.0 of T_o/T_{max} indicated in the BS-8006 (2010). Lower vertical stress turn this relation greater than 1.0 because of the down-drag effect.

4 CONCLUSIONS

The testing system and the physical model consist of innovative methodology to evalu-ate the connection loads in geosynthetic reinforced soil walls. The drown-drag effect was observed to be the main factor for the high values of loads at the connection between the reinforcement and the face wall, resulting in an asymmetric deformation behavior of the reinforcement, it is important to point out that the drown-drag effect is also due to the relative settlement of the reinforced soil mass and the modular blocks. The use of digital im-age analysis programs proved to be very valuable for this type of study. The most relevant aspect observed herein is that the connection load can be greater than the maximum tensile load at the potential failure surface, which is dependent of the relative settlement between block facing and reinforced soil.

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