Pull-out behavior of a draining geogrids embedded in waste cohesive materials

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ABSTRACT: The possibility of using poor quality fill materials in soil reinforced structures is becoming attractive due to the high costs of quarrying and transporting good coarse grained materials to the building sites. It often happens that available soils contain significant fractions of fine particles so that the behavior of the structure is negatively affected by the development of high excess pore water pressures caused by the applied load, both during construction and service life. This paper deals with the preliminary investigations and studies that were carried out for the construction of a stabilizing embankment at the toe of a very wide canyon landfill, for which geogrids formed by strip elements with superimposed filter strip have been utilized in silty and clayey soils. Pull-out tests on 70 cm x 150 cm specimens, reconstituted at the in situ soil compaction conditions, were performed using both smooth conventional geogrids and geogrids having draining capabilities. The tests have been executed under different confining pressure values. The load-displacements response and pore pressures were monitored at different locations along the geogrids. The results showed a relevant acceleration in the dissipation of the excess pore water pressure and an important increase in the pull-out strength of the geogrids having draining capabilities compared to the conventional smooth geogrids, confirming the opportunity of choosing geogrids of the former type when silty and clayey soils are involved.

1 INTRODUCTION

One of the main advantages of reinforced earth structures is their cost effectiveness if compared with conventional structures such as cantilever or gravity walls. However this requires that soils of adequate geotechnical properties suitable for use as fill material are economically available.

One of the basic design assumption for reinforced earth structures is that the fill material must be free draining. In fact, such structures are negatively affected by the development of high excess pore water pressures caused by the applied load within the soil mass; the increase in the pore pressures causes a reduction of the strength characteristics in the short term and the development of settlements in the long term. Besides, the effective stresses reduction connected with the pore water pressures increase causes a reduction of the pull-out resistance. In staged construction such as that used in reinforced earth technique pore pressure build-up can cumulate at each lift increasing the level of the risk as the construction proceeds. For these reasons, it is required that the soil used as the fill material should be predominantly coarse-grained. Some examples of the recommendations concerning the fine particles content are the following:

- not more than 10% of the particles should pass the 63 μm BS sieve (Craig, 1992);
- less than 15% of the particles should pass the U.S. No. 200 sieve (Bowles, 1991; U.S. Federal Highway Administration, 2001);
- less than 35% of the particles should pass the U.S. No. 200 sieve (U.S. National Concrete Masonry Association, 1997).

Recommendations are given also on the plasticity index (PI≤6 for walls and PI≤20 for slopes, FHWA). The above mentioned criteria have been successfully applied over the years, and most of the experiences regarding reinforced earth structures are related to those materials; so, knowledge about internal stress distribution, pullout resistance, and failure surface shape should be strictly referred to them. However, soils specified for use are often not available or not economically feasible for use.

Difficulties in providing suitable soils near the building sites, high transportation costs, environmental impacts of quarrying are giving urge towards studies and researches on porous geotextiles which can permit the acceleration of the excess pore water pressures dissipation by drainage through the reinforcement when significant fraction of fine is present in the soil. The possibility of filling a reinforced earth structure with borrow material obtained from cuts or excavations in the same (or in other) building sites - even if the soil would not be 'ideal' from the particle size distribution and geotechnical properties points of view - is a great opportunity to retain the costs of such structures and to keep the advantage over cantilever or gravity walls.

Previous studies on the behavior of draining geogrids embedded in cohesive soils have been reported by: Zornberg & Mitchell (1994; 1995); Boardman, (1998); Zornberg & Kang (2005); Feng et al. (2008).

All the authors generally agree about the improvement of the geogrids performance in cohesive soils when coupled to a draining system. However the results obtained seem to be significantly affected by several factors such as: test equipment, confining pressures, soil properties and compaction procedures. Due to this fact, at present time it is difficult to draw quantitative conclusions of general validity, so enhancing the role of preliminary pull-out tests to be carried out before any specific reinforced earth design in poorly draining soils.

This paper is focused on the preliminary investigations and studies that were carried out for the construction of a stabilizing embankment at the toe of a very wide canyon landfill in Italy, in which geogrids with draining capabilities have been used with silty and clayey soils. Figure 1 shows a construction stage of the embankment.

Figure 1 Construction stage of the embankment.

The aim of the study was double: a) verify the capability of the investigated draining geogrids to meet the design requirements in terms of pull-out resistance b) verify that pore pressure build-up induced in each lift by both construction and pull-out processes will dissipate before starting the placement of a new superimposed lift.

2 MATERIALS USED

Specimens of waste cohesive material used in the tests were taken directly from the building site and were submitted to laboratory tests (soil classification tests, soil compaction according to the Modified Proctor standard, permeability tests in triaxial apparatus and triaxial consolidated-undrained tests).

Table 1 summarizes the properties of the investigated soil obtained from laboratory tests, figure 2 shows the particle size distribution curve and figure 3 shows the dry unit weight-water content relationship.

Table 1 – Soil properties

Liquid limit (%)	25.8
Plastic limit (%)	15.7
Plasticity index (%)	10.1
Optimum moisture content (%)*	11.24
Maximum dry unit weight (kN/m^3)*	18.93

(*)According to Modified Proctor test

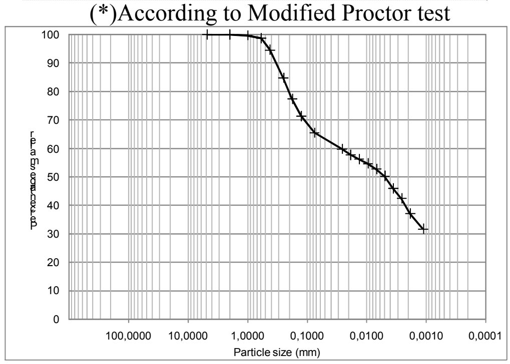

Figure 2 Particle size distribution curve.

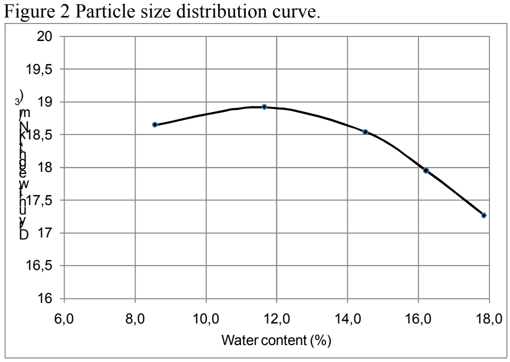

Figure 3 Dry unit weight-water content curve (Proctor Modified).

The soil classifies as CL according to the Unified Soil Classification System (USCS), and almost 66% of the particles pass the U.S. No. 200 sieve.

Two commercially available geogrids were used in the testing program: a 'conventional' polymeric geogrid (Type A) and a polymeric geogrid with draining capacity (Type B). Type A geogrid (Paragrid^{TM}) is made by a polyester filament core with polyethylene sheath, type B geogrid (ParaDrain^{TM})

is made by a biaxial array of geocomposite geosynthetic strips, which comprise a core of high modulus, made up of a low creep polyester yarn tendons encased in a tough, durable polyethylene sheath.

3 TEST APPARATUS AND PROCEDURE

The pullout apparatus is a rigid soil container formed by two superimposed halves of iron boxes having dimensions of 150 cm long x 70 cm wide x 74,5 cm high (22,5 cm + 52 cm) operated at ISMGEO in Seriate (Bergamo, Italy).The loading system consists of a oil dynamic piston fixed to a rigid loading plate taking the geogrid pullout load reaction. A rubber membrane placed in the container at the top of the soil fill provides the uniform normal pressure. A load cell measures the pullout load. Dial gages are used to measure the displacement of the geogrid respectively at three (type A geogrid) and six (type B geogrid) selected locations. Pressure transducers are placed during soil deposition to measure the pore water pressure at five selected locations. Fig. 4 outlines the selected locations for the pore pressure and displacements measures.

The soil is placed in 5 cm lifts, each one vibrated and equalized, over a first 2,5 cm compacted sand layer containing a conduits system to produce and to maintain the proper saturation level in the model. After the test completion, the pullout load is applied at constant displacement rate. Two different confining pressure values are used for the tests, namely 8 kPa and 60 kPa.

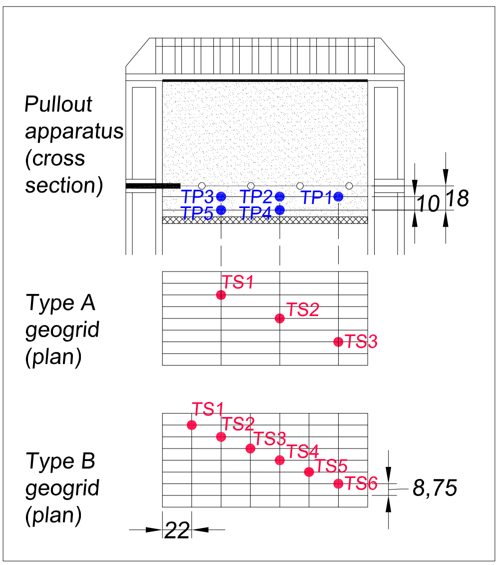

Figure 4 Sketch of the monitoring systems in the pullout apparatus (quotas in cm).

4 ANALYSIS OF RESULTS

The preliminary results obtained herein are consistent with previous studies (Boardman, 1998; Zornberg & Kang, 2005). The comparison between the Type A and Type B geogrid load-displacement curves at different confining pressures (figs 5 e 6) shows the benefit introduced by the draining element: the increase in the pullout resistance obtained is approximately 20% at 60 kPa and even higher (approximately 30%) at 8 kPa. The response of the pore water pressure to pullout loading clearly appears from inspection of the Δu-displacements curves (fig. 7): it can be seen that the excess pore pressures measured with Type B geogrid are about one magnitude order inferior to those measured with Type A geogrid.

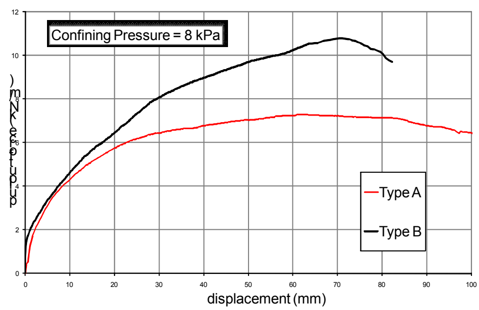

Figure 5 Load-displacement curves at 8 kPa.

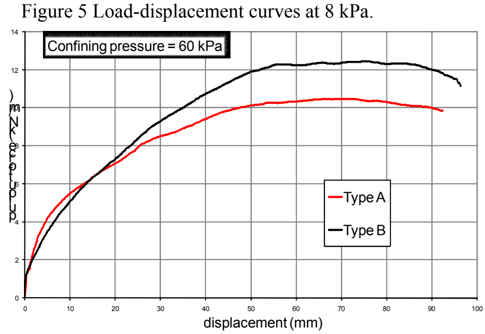

Figure 6 Load-displacement curves at 60 kPa.

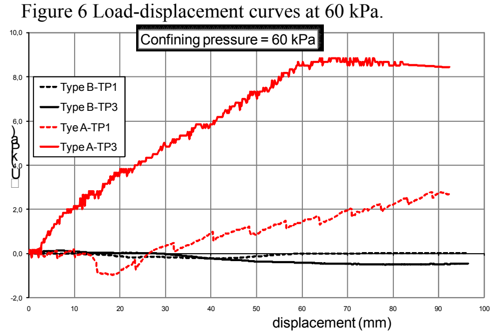

Figure 7 Excess pore pressure-displacement curves at 60 kPa.

The observed differences of the pullout resistance increase when confining pressures change may be related to the $\Delta u/\sigma_n$ ratio, that is higher - and therefore more relevant in determining the pullout resistance - when the confining pressures are lower.

It is worth noting that soil properties, compaction and moisture content used for the tests were chosen to be representative of the site condition during construction. Better performances are to be expected with higher moisture content.

Anyhow, the performed test confirm the expectations, that is the significant contribution of the geogrids with draining capacities in dissipating the excess pore pressures.

5 CONCLUSIONS

It is generally understood that choosing cohesive soils as fill for reinforced earth structures requires special consideration in selection of suitable reinforcements, due to some issues related to cohesive soils like lower shear strength compared with coarse grained soils and high interface creep potential. Besides, geotechnical properties of clayey soils are adversely affected by water, and change with moisture content. However, incorporation of a draining element in the reinforcements can positively influence a reinforced soil mass by promoting drainage and minimize excess pore water pressures. A comparison of the pullout behavior between two polymeric geogrids, one of a conventional type and one with a drainage capacity, has been made at the aim of choosing a proper geogrid to reinforce an embankment constructed with clayey and silty materials coming from excavations inside the building site. Pullout tests have been conducted in a large box (150 cm long x 70 cm wide), and the obtained results have confirmed the results of other similar researches, that is an increase of the pullout resistance between 20% and 50% for the geogrids with draining capacity. The differences in the values of the pullout resistance increase may be attributed to different test equipment, confining pressures, soil properties and compaction procedures. Properties like plasticity, density, water content, can affect the soil-geogrid interaction in a way that makes the comparison of pullout resistance in different soils very difficult. So, while increase of the pullout resistance in reinforced earth structures filled with cohesive soils by means of geogrids with draining capacity can be considered a general assumption, use of laboratory pullout test results and literature data for design purposes should be susceptible of attention. It is important to verify that test conditions can comply with the actual design conditions. Furthermore, proper Quality Assurance and Quality Control are essential for reinforced structures constructed with cohesive soils; special care must be taken of moisture control and soil compaction during the soil placement.

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