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Effects of sustained loads on geogrid pullout behaviour embedded in a recycled construction and demolition waste

Effets de charges soutenues sur le comportement d'arrachement des géogrille intégrée dans des déchets de construction et de démolition recyclés

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ABSTRACT: A suitable behaviour of backfill/geosynthetic interfaces is one of the key points to achieve a good performance of any geosynthetic reinforced structure. Previous researches have been showing that the interfaces between recycled construction and demolition (C&D) wastes and some geosynthetics have coefficients of interaction in the range of usual values for soil/geosynthetic interfaces. However, most of these studies only evaluated the geosynthetics pullout resistance under monotonic loading conditions (constant displacement or load rates during pullout) and do not consider their long-term behaviour. This paper presents a preliminary laboratory study conducted to investigate the effects of multistage loading on a geogrid pullout behaviour. After reaching a predefined value (40% or 70% of the geogrid pullout resistance) under load-controlled conditions, the pullout force was kept constant for 30 or 120 minutes and then increased until the geogrid pullout failure. The results obtained to date show that sustained loads periods did not reduced the geogrid pullout resistance and thus the usual pullout tests are on the safety side. The duration of the sustained load stage affected mainly the cumulative deformations on the geogrid, which are more significant when the constant load level is closer to the geogrid's pullout resistance.

RÉSUMÉ: Un comportement approprié des interfaces remblai/géosynthétique est un des points essentiels pour assurer une bonne performance de toute les structures renforcée par géosynthétique. Des recherches antérieures ont montré que les interfaces entre les déchets de construction et de démolition recyclés (C&D) et divers géosynthétiques ont des coefficients d'interaction qui se situent dans la gamme des valeurs habituelles pour les interfaces sol/géosynthétique. Cependant, la plupart de ces études n'ont évalué la résistance à l'arrachement des géosynthétiques que dans des conditions de charge monotone (déplacement constant ou taux de charge constant pendant l'arrachement) et n'ont pas considéré leur comportement à long terme. Cet article présente une étude préliminaire conduite en laboratoire pour étudier les effets d'un chargement en plusieurs étapes sur le comportement à l'arrachement d'une géogrille. Après avoir atteint une valeur prédéfinie (40 % ou 70 % de la résistance à l'arrachement de la géogrille) dans des conditions de charge contrôlée, la force d'arrachement a été maintenue constante pendant 30 ou 120 minutes, puis augmentée jusqu'à la rupture de la géogrille. Les résultats obtenus à cette date montrent que les périodes de charges soutenues n'ont pas réduit la résistance à l'arrachement de la géogrille et que les tests d'arrachement habituels sont donc du côté de la sécurité. La duration de la phase de charge soutenue affecte principalement les déformations cumulées sur la géogrille, qui sont plus importantes lorsque le niveau de charge constante est plus proche de la résistance à l'arrachement de la géogrille.

Keywords: Geosynthetics; recycled C&D wastes; pullout behaviour; sustained loads; long-term behaviour.

1 INTRODUCTION

In recent years several studies and applications of recycled Construction and Demolition (C&D) wastes have been carried mainly focused on their use in base and sub-base layers of transportation infrastructures or in concrete production. The valorisation of C&D waste in geosynthetic reinforced structures, such as steep slopes or retaining walls, is also a topic of recent interest (Vieira and Pereira 2018; Santos et al. 2013).

A suitable behaviour of backfill/geosynthetic interfaces is one of the key points to achieve a good performance of any geosynthetic reinforced structure (steep slopes and retaining walls). Previous researches have been showing that C&D waste/geosynthetic interfaces have coefficients of interaction in the range of usual values for soil/geosynthetic interfaces (Santos and Vilar 2008, Arulrajah et al. 2013, Vieira and Pereira 2016, Vieira and Pereira 2022). However, these studies, as most of those found in the literature for soil/geosynthetic interfaces, do not account for the long-term behaviour.

In typical pullout tests, an increasing force is applied to one end of the geosynthetic at a constant displacement rate (displacement-controlled tests) until the geosynthetic failure (pullout). As will be mentioned below, pullout tests can also be carried out with a constant load rate (load-controlled tests). In this paper the effect of applying a constant pullout force (sustained load) at a pre-defined load level and time period before leading the geosynthetic to failure is studied. The influence of this different approach on a geogrid's pullout resistance and on the displacement for which it is mobilised is presented and discussed.

2 MATERIALS AND METHODS

2.1 Materials

The study was carried out with a fine-grained recycled construction and demolition (C&D) material, coming from the recycling process of non-selected C&D wastes (Figure 1a). Thus, it has a very heterogeneous composition (soil, stones, concrete and mortars, ceramics, …).

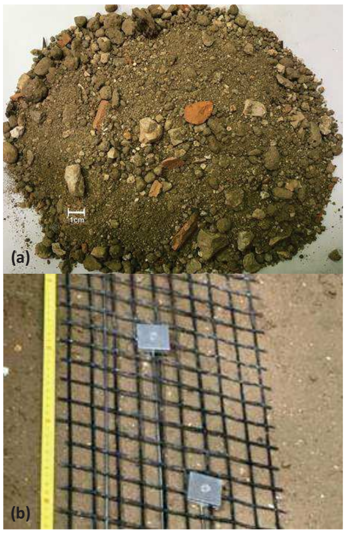

Figure 1. Materials: (a) recycled C&D waste; (b) geogrid.

Their constituents were evaluated following the European Standard EN 933-11:2009 for coarse aggregates. As the particles are sorted by hand, it is not humanly possible to classify particles smaller than 4 mm, so the test specimen according to the standard only includes particles with a higher dimension. Figure 2 shows the relative proportion of the constituents of recycled C&D material, where R_c refers to concrete, concrete products, mortar, concrete masonry units; R_u corresponds to unbound aggregate, natural stone, hydraulically bound aggregate; R_b refers to clay masonry units, calcium silicate masonry units, aerated non-floating concrete; R_a and R_g correspond to bituminous materials and glass, respectively and X is for other materials.

Table 1 summarises some grain size and compaction properties of the recycled C&D waste. Further details can be found in Carneiro et al. 2023).

A polyester geogrid (Figure 1b) with nominal tensile strength of 35 kN/m and corresponding elongation of 10.5% (values provided by the manufacturer) was used in this study.

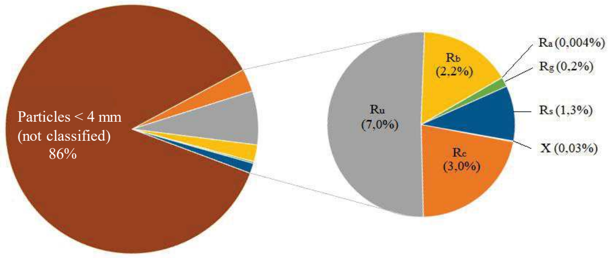

Figure 2. Constituents of the recycled C&D waste.

Table 1. Some properties of the recycled C&D waste.

D_{10} (mm)	D_{50} (mm)	D_{max} (mm)	Proctor compaction test γ_{dmax} (kN/m^3)	Proctor compaction test w_{opt} (%)
0.008	0.39	10	18.8	12

2.2 Laboratory study

The laboratory study comprises benchmark monotonic pullout tests and multistage pullout tests (Figure 3).

Geosynthetics pullout tests (monotonic tests) are usually carried out under displacement-controlled conditions, i.e. imposing a constant frontal displacement rate equal to 2 mm/min (± 10%) - EN 13738: 2004. According to this standard, constant stress loading methods, where the pullout force is applied to the geosynthetic under a uniform loading rate not exceeding 2 kN/m/min can also be used. In this study, benchmark monotonic load-controlled tests under a constant load increment rate of 0.55 kN/m/min were also carried out, since multistage pullout tests must be performed under load-controlled conditions in order to ensure that the pullout force remains constant during a predefined period of time (Figure 3).

Multistage pullout tests consist of an initial monotonic loading (load increment rate equal to 0.55 kN/m/min) to a predefined value of the pullout force (40% or 70% of the pullout resistance, P_{max}), followed by a sustained load stage (during 30 or 120 minutes), and after that, a constant load rate of 0.55 kN/m/min is applied again untile the geogrid pullout failure (Figure 3).

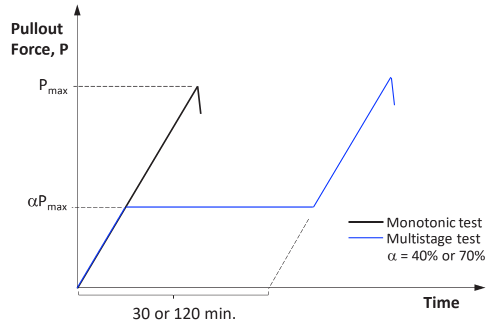

Figure 3. Schematic representation of the different setups of pullout tests carried out.

In all these tests the recycled C&D material was compacted to 90% of its maximum dry density and at the optimum moisture content (standard Proctor test) and the normal stress at the interface level was around 10 kPa. The material was compacted to 90% of its maximum dry density (although higher values are usually used on construction sites), because laboratory compaction above this value, using manual means, revealed to be very difficult.

The geogrid specimens were tested with initial dimensions of 250 mm wide × 750 mm long (inside the pullout box).

3 RESULTS AND DISCUSSION

3.1 Monotonic pullout tests

The displacements throughout the geosynthetic length are usually monitored, during pullout tests, using inextensible wires connected to the geosynthetic specimen (Figure 1b) and to linear potentiometers placed outside the pullout box (Vieira and Pereira 2022). However, the presence of the fixing elements affects the interface conditions and may even have influence on the pull-out resistance, depending on the geosynthetic type and strength (Lopes and Ladeira 1996; Ferreira et al. 2016). Figure 4 illustrates the effects of the displacement recording system (fixing elements, inextensible wires and linear potentiometers) on the geogrid's pulllout behaviour.

Figure 4 shows that the presence of this system leads to an overestimation of around 13% of the geogrid pullout resistance, meaning that the presence of the inextensible wires and corresponding fixing system (Figure 1b) somehow restricts the geogrid from being pulled out. In view of this evidence, the remaining pullout tests were carried out without monitoring of the displacements along the geogrid's length.

As mentioned in 2.2, monotonic pullout tests were carried out under displacement-controlled and load-controlled conditions. Figure 5 compares the geogrid´s pullout behaviour under both scenarios.

The geogrid's pullout resistance was 10 % higher when it was pulled out under a constant load increment rate when compared to its resistance under at a constant displacement increment. Although the load increment rate was selected such that the duration of both tests was similar, it was found that the geogrid was pulled out slightly more slowly under displacement-controlled conditions.

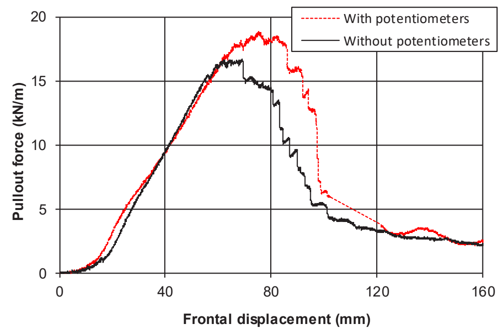

Figure 4. Influence of the presence of displacement recording system.

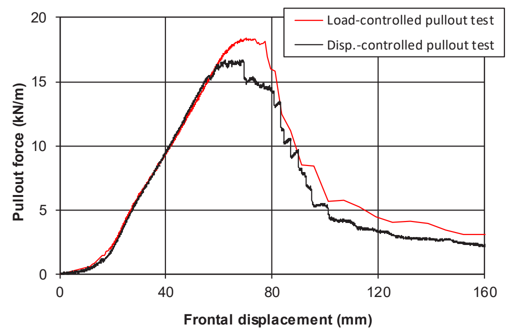

Figure 5. Geogrid pullout behaviour under displacement-controlled and load-controlled conditions.

Previous researches (Lopes and Ladeira 1996; Vieira et al. 2020) have shown that, due to intrinsic viscous response of polymeric geosynthetics, the geosynthetics pullout resistance is affected by the rate of loading and generally increases with an increase of the displacement rate. Thus, the conclusion drawn by the analysis of Figure 5 is consistent with what was expected.

3.2 Multistage pullout tests

3.2.1 Effect of sustained load level

Figure 6 presents the influence of the sustained load on the geogrid's pullout behaviour. It can be inferred from the analysis of Figure 6 that multistage loading led to a slight increase (lower than 10%) in the pullout resistance.

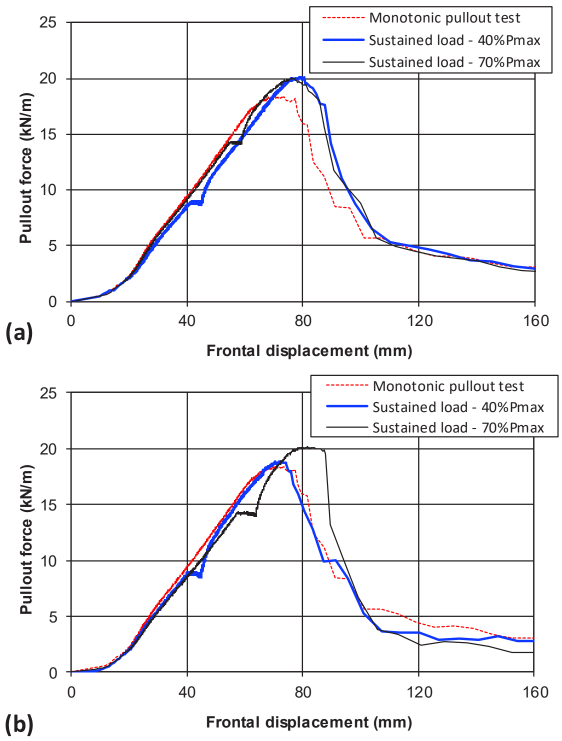

Figure 6. Influence of the sustained load (at 40%Pmax and 70% Pmax) on the geogrid's pullout behaviour: (a) for t = 30 minutes; (a) for t = 120 minutes.

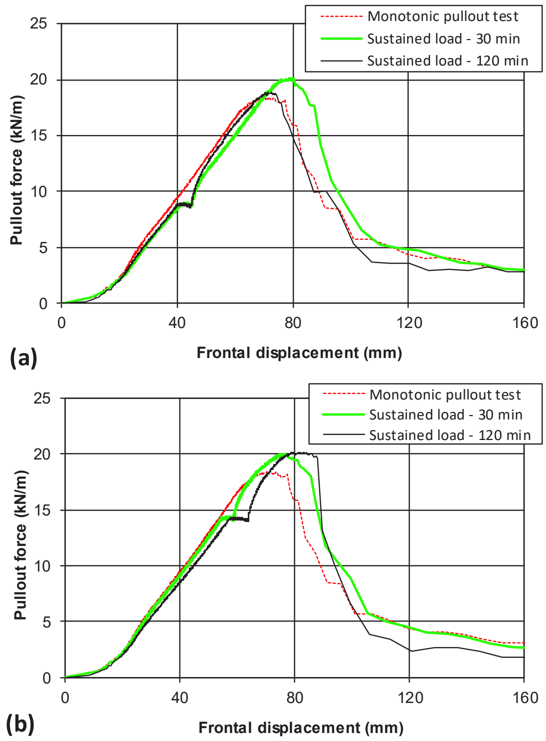

Figure 7. Influence of the time period of the sustained load: (a) at 40%Pmax; (b) at 70%Pmax.

For a sustained load stage of 30 minutes, the behaviour of the geogrid tested with sustained loading at 40%P_{max} and 70%P_{max} was very similar, both in terms of pullout resistance and of the displacement at which the peak resistance was reached. For the higher sustained load period (120 minutes), the behaviour of the geogrid at 40%P_{max} was very similar to that of the monotonic test (an increase in the pullout resistance of only 2.7%), while at 70%P_{max} there was an increase in the peak pullout resistance of around 10% (Figure 6b). The influence of the duration of the sustained load stage will be presented in the next section.

3.2.2 Influence of the duration of sustained load

The effects of the duration of the sustained load stage is shown in Figure 7. For the pullout tests with sustained load at 70%P_{max}, as expected, the longer period of constant load (120 minutes) led to the cumulative deformation on the geogrid and therefore the peak resistance tended to be mobilised for greater deformations. This evidence was not observed in the sustained load tests at 40%P_{max} (Figure 7a). This may be explained by the fact that geogrid´s deformation under constant load is more significant for higher loads, but this point needs to be further explored in future research.

Figure 8 presents the development of geogrid´s frontal displacements during the constant load period. The dashed vertical line marks the beginning of the constant load stage. While the cumulative displacements for 40%P_{max} were 3.8 mm and 4.6 mm, for t = 30 minutes and t = 120 minutes, respectively, the increase is more significant when the sustained load stage occurs at 70%P_{max} (from 4.2 mm to 6.6 mm, for t = 30 minutes and t = 120 minutes, respectively). It is also visible that for 40%P_{max} the displacements tend to stabilise, i.e. small variations after some time (Figure 8a), this is not the case for 70%P_{max} (Figure 8b).

4 CONCLUSIONS

This paper presented a laboratory study to characterize the pullout behaviour of a polyester geogrid embedded in a recycled C&D waste, with emphasis on the effects of sustained loads applied to the geogrid before its pullout failure.

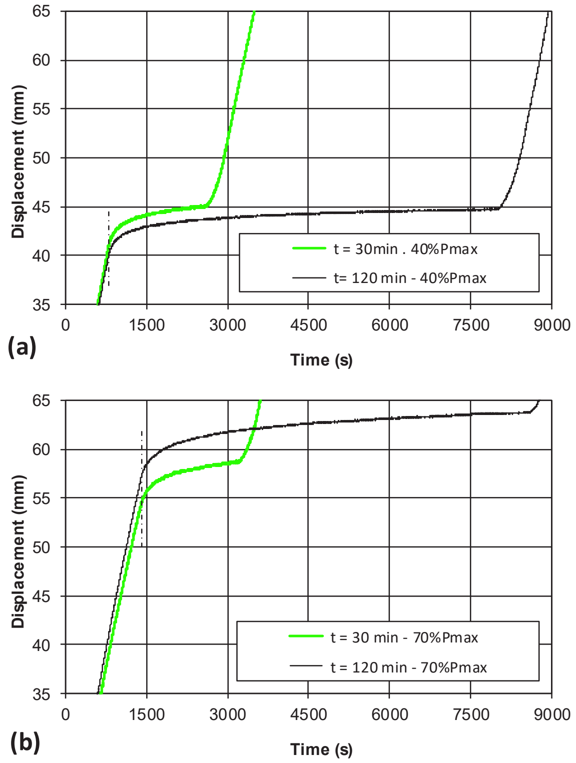

Figure 8. Development of geogrid pullout displacement during the sustained load periods: (a) for 40%Pmax; (b) for 70%Pmax.

The main conclusions of this study are summarized as follows:

- The geogrid's pullout resistance tended to be slightly higher when it was pulled out under a constant load increment rate when compared to its resistance under a constant displacement rate.
- Multistage pullout tests with a constant load stage did not significantly affect the geogrid´s pullout resistance. A slight increase in the pullout resistance was observed.
- The effect of the duration of the sustained load on the geogrid pullout behaviour is mostly seen in the cumulative deformations, which are more significant when the constant load is higher, i.e., is closer to the geogrid's pullout resistance.

It should be highlighted that this is a preliminary study that requires a more comprehensive research programme with other materials, other sustained load levels and longer durations.

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