# Evaluating the interaction between geogrid and recycled aggregate using pullout tests

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**Abstract** The understanding of the fill material-geogrids interface is critical in the design of the reinforced fill structure. Pullout tests are commonly used to characterize the interaction between fill material and geogrids. In recent years, recycled aggregate shows some promising results to be used as an alternative fill material. Nevertheless, the interaction between selected recycled aggregate and geogrids requires further investigation. This paper presents experimental results focusing on the interaction between one type of recycled aggregate and two different geogrids through a series of large-scale pullout tests. The pullout resistance of the geogrid is correlated with the confining stress. When the confining stress increases from 10 to 30 kPa, the peak value of the pullout resistance also increases due to the improved interlocking of recycled aggregate with the geogrid. Tighter interlocking provides greater resistance to the applied pullout force, leading to higher pullout resistance. Increased vertical confining stress enhances contact between the geogrid and recycled aggregate, creating a stronger bond resulting in dilatancy of the aggregates, which in turn results in higher frictional resistance against the pullout force. The results show that the tested recycled aggregate can be used as a fill material in a reinforced fill structure.

## 1 Introduction

In any civil engineering project, geotechnical works usually implemented at the very beginning, can significantly bring sustainable development by reusing construction and demolition materials as an alternative fill and other applications [1-5]. As stated in the Circular Economy Action Plan, the construction industry has been identified as one of the critical sectors for the shift towards a circular and sustainable economy, with the goal of achieving climate neutrality in the EU by 2050 through the European Green Deal. Construction and demolition (C&D) wastes are recognized as a priority waste stream in the EU due to its high resource value and significant potential for recycling and reuse. In 2018, households and other economic activities accumulated 2.317 million tons of waste in the EU, and 36 % of this came from the construction industry (source ICEDD). Recent statistics of

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Buildwise show that Belgium has one of the highest growth rates in C&D waste treatment with a recycling rate over 90%. However, this data does not include backfilling applications.

Geogrids have been extensively used in the last two decades to build or reinforce retaining walls, slopes, and embankments. The interaction between the geogrid and fill material at the interface is crucial for transmitting stresses from the fill material to the geogrid. The resistance between reinforcement and fill material mainly arises from the friction between geogrid and the fill material [6]. Under serviceability conditions, the stresses generated within the reinforced fill structure cause the deformation and the elongation of longitudinal reinforcements towards the face of the reinforced structure [7]. A strong bond between the geogrid and fill material prevents developments of different failure modes within the structure. Hence, these interaction parameters need to be considered in design verifications [8-9].

Vieira and Pereira in 2018 [10], performed direct shear test and found that recycled aggregate has similar shear strength to conventional fill materials in geogrid reinforced fill structure. Tests were conducted on recycled aggregate and demonstrated a drop in shear strength from the air-dried state to the optimum moisture content. The cohesiveness of the recycled aggregate significantly reduced as the moisture content increased. As anticipated, the shear strength of the recycled aggregate increased proportionally with the level of compaction. An increase in the moisture content of recycled aggregate may clearly decrease the shear strength of the interface.

In recent years, recycled aggregate have shown a sustainable alternative to conventional fill materials. However, the interaction between recycled aggregate and geogrids needs to be better understood, as it plays a critical role in determining the overall performance of reinforced fill structures. The present study focuses on the interface behaviour of recycled aggregate used in combination with two types of geogrids, using a series of large-scale pullout tests to assess the interaction properties between these materials. The results of this study aim to evaluate the suitability of the tested recycled aggregate as backfill material in reinforced fill structures. The pullout resistance of the geogrid reinforcement was correlated with confining stress, revealing that as the confining stress increased from 10 to 30 kPa, the peak value of the pullout resistance also increased accordingly. This improvement is attributed to the enhanced interlocking between the recycled aggregate and the geogrid, which offers greater resistance to the applied pullout force. Additionally, the increased vertical confining stress was found to strengthen the bond between the geogrid and aggregates, resulting in higher frictional resistance and improved pullout performance. The findings provide valuable insights into the feasibility of using the tested recycled material in reinforced fill structure.

## 2 Materials

### 2.1 Recycled aggregate

The recycled aggregate used in the present study is provided by Tradecowall. This is a mixed recycled aggregate with particles ranging in size from 0 to 31.5 mm in diameter. It is shown in figure 1. These recycled aggregate come from the recycling of demolition materials from local construction sites. The gradation curve of the recycled aggregate is shown in figure 2. Some relevant geotechnical properties of the recycled aggregate are shown in table 1.

**Fig. 1.** Recycled aggregate used in the present study.

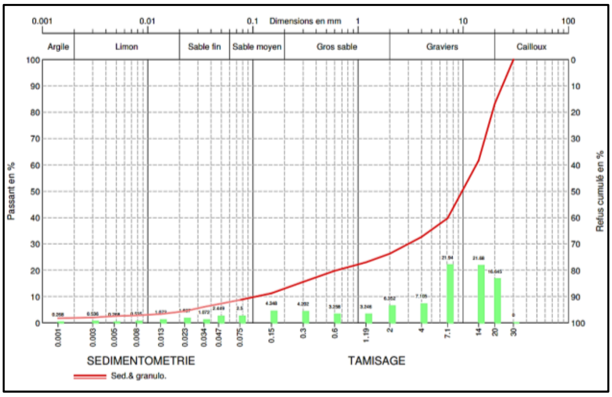

**Fig. 2.** Gradation curve of the tested recycled aggregate.

**Table 1.** Properties of the recycled aggregate.

| | |
|---|---|
| $D_{10}$ | 0.107 mm |
| $D_{30}$ | 3 mm |
| $D_{60}$ | 13.3 mm |
| Coefficient of uniformity $C_u$ | 124.3 |
| Coefficient of curvature $C_c$ | 6.3 |
| Cohesion c (from direct shear test) | 57.6 kPa |
| Angle of internal friction φ (from direct shear test) | $51.5^0$ |
| Sample moisture content | 4 % |
| Max dry unit weight $\gamma_{max}$ | 1623.4 kg/m$^3$ |

## 2.2 Geogrids

As shown in figure 3, the two types of geogrids used in this research work consists of a network of connected strips having an open grid-like structure. The point of intersection between the longitudinal and transverse strips is called the junction and is always critical because they maintain the integrity and shape of the geogrid. As shown in Fig. 4, there is a considerable spacing between transverse strips of both geogrids. They are specifically designed to facilitate the alignment of longitudinal strips on the field. As shown in figure 5a and 5b, two commercially available geogrids were tested. Both are high tenacity geogrids which are planar structures consisting of a monoaxial array of composite geosynthetic strips.

These geogrids are mostly used for reinforcement purposes being their peculiar structure able to provide the necessary strength to reinforce fill material. The strips comprise of a core of high tenacity polyester tendons encased in a polyethylene sheath. The physical and mechanical properties of the geogrids are shown in table 2.

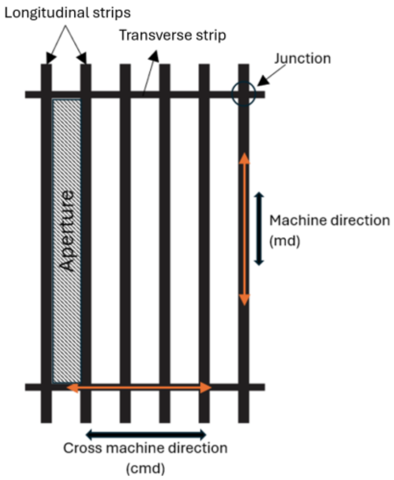

**Fig. 3.** Components of a geogrid.

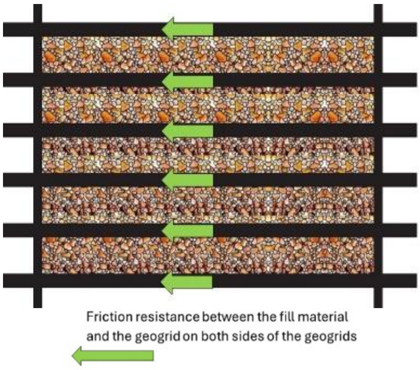

**Fig. 4.** Interaction mechanism between fill material-geogrid (top view).

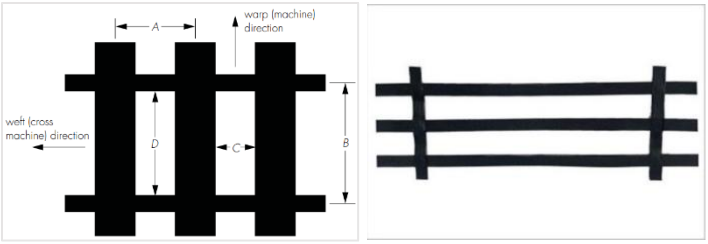

**Fig. 5.** Geogrid sample (a) Geogrid G1 (b) Geogrid G2.

## 3 Methodology

Pullout tests have been widely used to investigate the interaction behaviour between fill material and geogrid. In case of fill material-geotextile interface, the skin friction is the primary mechanism that develops whereas for geogrids, the interaction is more complex as different mechanisms can develop, including the following:

- The bearing resistance offered by the transverse strips (also called passive resistance)
- The friction between the fill material and longitudinal reinforcement surface

In this study, a large pullout test setup is used to determine the fill material-geogrid interface properties (see Figures 6 and 7).

**Table 2.** Physical and Mechanical Properties of the Geogrid G1 and Geogrid G2.

| **Properties** | **Geogrid G1** | **Geogrid G2** |
|---|---|---|
| Short-term tensile strength from short-term test in accordance with EN ISO 10319 | 309 kN/m | 212 kN/m |
| Polymer of the reinforcement strip element | PET | PET |
| Polymer coating of the strips | PE | PE |
| Thickness of the reinforcement strips | 1.8 (mm) | 2.4 (mm) |
| Single strip width | 88 (mm) | 47 (mm) |
| Aperture size warp / weft (C x D) | 92 x 940 (mm) | 133 x 940 (mm) |
| Grid Size warp / weft (A x B) | 180 x 1000 (mm) | 180 x 1000 (mm) |
| Structure | Uniaxial | Biaxial |
| Characteristic strength ($T_{char}$) conform EN 13251 | 301 kN/m | 200 kN/m |

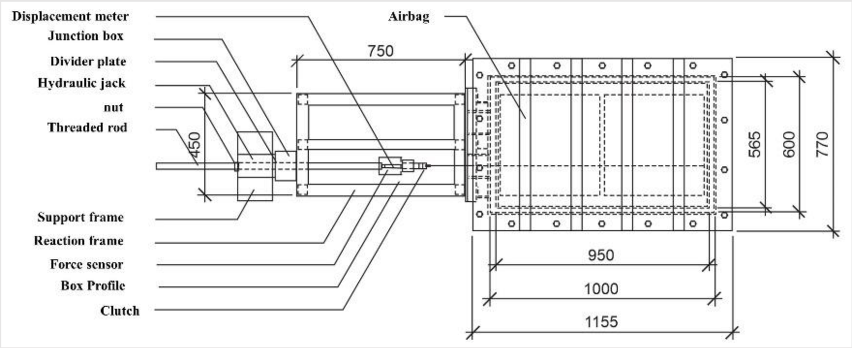

**Fig. 6.** Layout of the experimental setup: top view.

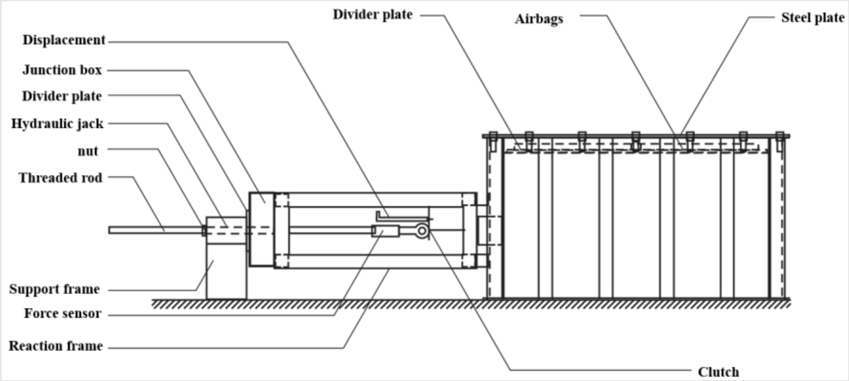

**Fig. 7.** Schematic diagram of the experimental setup.

The test box is constructed with welded steel plates, forming a structure with external dimensions of 61 cm in height, 77 cm in width, and 115.5 cm in length. The internal dimensions are 1 m in length, 0.60 m in width, and 0.605 m in height. The geogrid clamp is placed inside the box and shielded from the fill material to ensure that no additional force is measured due to the clamp's resistance in the fill material. The pullout resistance of geogrids usually comprises of two components i.e. skin friction resistance along the longitudinal strips and passive resistance along the transverse strips. The latter is probably much less significant than the skin friction resistance along the longitudinal strips.

The sample preparation involves the filling of the lower half of the pullout box with the selected fill material. This fill material is then compacted in thin layers, using an electric plate compactor. It is assumed that the density achieved using this method is uniformly distributed across the volume of the fill material.

After reaching the desired compaction level, the geogrid is carefully clamped and placed on the surface of the compacted fill layer. The upper half of the pullout box is then filled with fill material, which is similarly compacted in small layers using the electric plate compactor. Once the fill material is fully placed, a steel plate is positioned on top, followed by the installation of air cushions to apply the confinement (vertical) pressure. The pullout box is sealed using a rigid steel plate.

The air cushions cover the entire surface of the test box (100 x 60 cm) and are regulated by a pressure control unit to ensure accurate pressure application on the fill material in the test box. The geogrids are pulled using a hydraulic jack. The pull-out force and the displacement are recorded during the test. The highlights of the pullout test are shown in figure 8.

**Fig. 8** Illustration of the sample preparation and testing.

It is assumed that the pullout resistance is supplied by the friction along both surfaces of the reinforcement and is given by the following equation:

$$T = 2\,L\,W\,\sigma_n \tan\delta \qquad (1)$$

where T is the maximum pullout force developed, L the length of the tested reinforcement, W the width of the reinforcement, $\sigma_n$ the overburden pressure and δ the friction angle between the fill material and the reinforcement. The interface coefficient between the fill material and the reinforcement is defined as:

$$f = \tan\delta / \tan\varphi \qquad (2)$$

where φ is the internal friction angle between the particles of the fill material (in other words, between the particles of the recycled aggregate).

## 4 Testing Programme

A summary of the testing program is shown in Table 3 for the two tested geogrids (G1 and G2). The impact of vertical confining pressure ($\sigma_v$) on the geogrid's pullout behaviour was assessed by applying vertical stresses of 10 kPa, 17.2 kPa, and 30 kPa. The pullout force per unit width of the geogrid, continuously monitored by the data acquisition system, was evaluated, and plotted against the front displacement of the tested geogrid.

**Table 3.** Testing Program.

| Test # | Geogrid | Characteristic short-term tensile strength of the geogrid (kN/m) | Confining pressure (kPa) |
|---|---|---|---|
| 1 | G1 | 301 | 10 |
| 2 | G1 | 301 | 17.2 |
| 3 | G1 | 301 | 30 |
| 4 | G2 | 200 | 10 |
| 5 | G2 | 200 | 17.2 |
| 6 | G2 | 200 | 30 |

## 5 Results and discussion

This study investigates the effect of normal stress on the characteristics of the fill-geogrid interface during pullout tests. Two geogrids, G1 and G2, were used as reinforcements, and recycled aggregate was selected as the fill material. The primary objective was to assess the geogrid's pullout resistance and the coefficient of interface friction between the recycled aggregate and geogrid under varying normal stresses.

Figures 9 and 10 depict the influence of the vertical confining pressure on the pullout behaviour of both tested geogrids.. The pullout force increases with increasing pullout displacement and the relationship between the pullout force and pullout displacement corresponds to strain hardening. The analysis of normal stress and peak pullout force was carried out by comparing the geogrid force-displacement curves obtained under different vertical loads. At low normal stress, the forces between the particles of the fill material and between the fill and geogrid are relatively low, which facilitates the movement of fill particles and results in minimal friction between the recycled aggregate and geogrid. Conversely, at higher normal stress, the forces transmitted between the particles of the fill material and the geogrid increase, leading to higher friction. The shear dilation effect at the fill-geogrid interface becomes more pronounced, resulting in further compaction of the fill particles. This enhanced embedment between the fill material and geogrid contributes to a continuous increase in pull-out resistance, and the pull-out displacement corresponding to the peak strength increases.

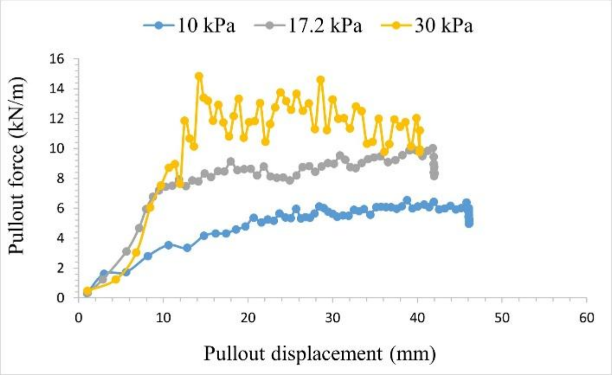

**Fig. 9.** Effect of different vertical confining stresses (kPa) on the pullout behaviour of Geogrid G1.

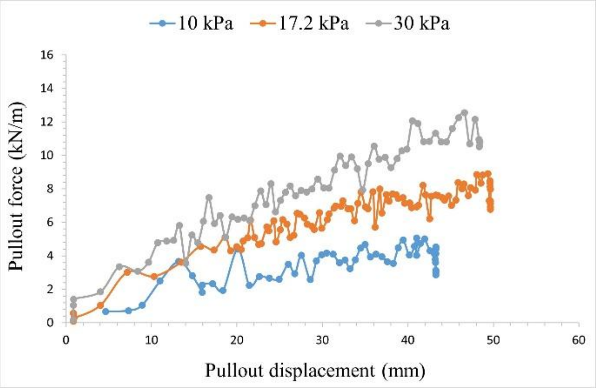

**Fig. 10.** Effect of different vertical confining stresses (kPa) on the pullout behaviour of Geogrid G2.

Figure 11 presents the interface resistance envelopes, and Table 4 summarizes the interface parameters derived from these pullout test envelopes. The results indicate that, for the tested recycled aggregate, geogrid G1 exhibits a higher interface friction value (0.7) compared to geogrid G2 (0.64).

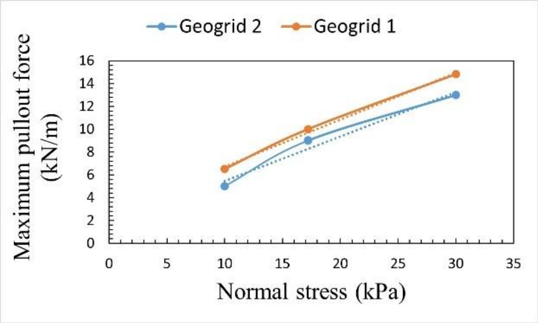

**Fig. 11.** Interface resistance envelopes for the conducted tests.

**Table 4.** Resistance parameters of the recycled aggregate-geogrid interface.

| Type of Geogrid | Confining stress (kPa) | Maximum pullout force (kN/m) | Cohesion ($C_a$) (kN/m$^2$) | Friction angle between fill material and geogrid (δ) (°) | Interface coefficient between the fill material and the geogrid (f) |
|---|---|---|---|---|---|
| Geogrid G1 | 10 | 6.5 | 2.62 | 41 | 0.7 |
| Geogrid G1 | 17.2 | 10 | | | |
| Geogrid G1 | 30 | 14.8 | | | |
| Geogrid G2 | 10 | 5 | 1.6 | 39 | 0.64 |
| Geogrid G2 | 17.2 | 9 | | | |
| Geogrid G2 | 30 | 13 | | | |

After completing the pullout tests, the geogrids were therefore analysed to check for any damage. No rupture of any reinforcement was observed upon completion of the tests. However, for some geogrids, damages were observed at joints between the longitudinal strips and the transverse strips, as shown in figure 12.

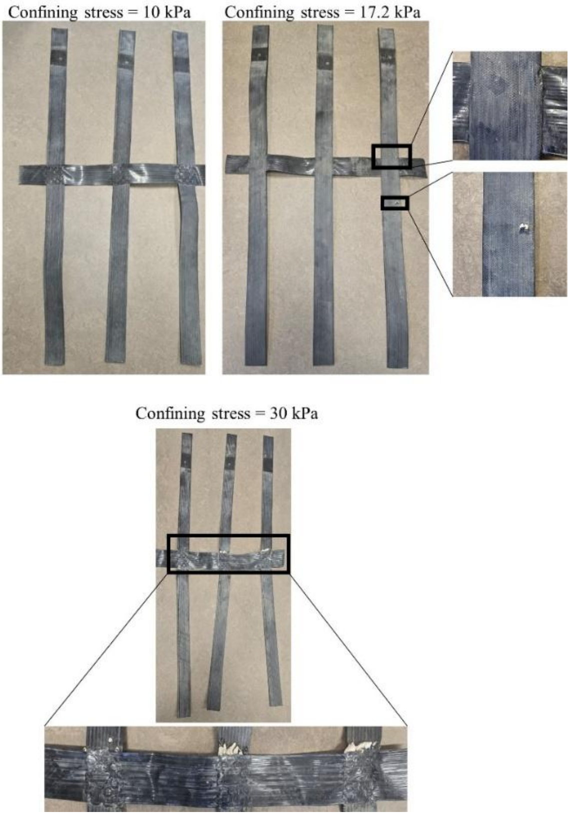

**Fig. 12.** Geogrid G2 after pullout test at different confining stresses.

## 6 Conclusions

The results of this study highlight the significant influence of normal stress on the pullout resistance and interface friction between geogrids and recycled aggregate in reinforced fill structures. The findings demonstrate that increased normal stress leads to higher friction and pullout resistance due to enhanced fill material-geogrid interaction and shear dilation at the interface. Geogrid G1 showed a higher interface friction value compared to G2, indicating that the choice of geogrid material can impact on the overall performance of the structure.

From a design and construction perspective, it is crucial to consider the normal stress conditions in the field, as higher normal stress can improve the pullout resistance and stability of the reinforced fill structure.

Further testing is recommended to facilitate a direct comparison between recycled aggregate and conventional fill material, accompanied by statistical analyses (such as error margins) to provide a more thorough validation of the recycled aggregate performance. Additionally, it is advisable to conduct studies to explore the effect of optimum moisture content on the pullout resistance between geogrids and recycled aggregate.

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