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Pull-Out Resistance of Sand-Geosynthetics Reinforcement

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Abstract: Geosynthetics are widely used in earth retaining structures such as steep slope and earth retaining wall. The stability of the earth retaining structures depends on the interaction between geosynthetics and soil at the reinforced area known as reinforcement mechanism. The reinforcement mechanism of the soil reinforced structure usually difficult to be analysed thoroughly. It is because the preliminary study on the pull-out resistance and durability of the reinforcement material is not taking into account before it has been used to the site location especially in Malaysian practises. Less supervision and the assessment after the installation of the reinforcement materials also contributed to the failure of the soil reinforcement. In this paper, the laboratory model was used to imply the real condition of the soil reinforced structure using pull-out test. A standard pull-out test was carried out by using geotextile and geogrid reinforcing elements embedded into silica sand of size $D_{50}=1.357$ mm and $D_{50}=0.571$ mm subjected to normal pressures of 100 kPa, 150 kPa and 200 kPa. Comparative result and analysis showed that the geotextile reinforcement give more resistance rather than geogrid reinforcement under high normal pressure.

Keywords: Geosynthetics, interaction, reinforcement mechanism, pull-out test

1. Introduction

Geosynthetic is related to many functions and usages. According to Pinto [1] and Ennio et al. [2] geosynthetics such as geotextiles and geogrids are broadly used as reinforcement materials and stabilization. The design of the reinforcement always related to the ultimate tensile strength of the geosynthetics and it depends on the materials itself. Bao [3] mentioned that, the study on the reinforcement mechanism and the relevant design theory are much backward relative to the engineering application. Omer [4] reported that, several failure modes are considered before installation of the geosynthetics in order to suit internal and external stability. External stability refers to the sliding and overturning failures which are determined as one unit rigid during analysis. It is easy to measure the external stability compared to the internal stability using the factor of safety analysis. However, the internal stability refers to the reactions of the geosynthetics with the soil media. This reaction caused by the friction forces between soil particles and tensile strength of the geosynthetics. When tensile force in reinforcement exceeds friction force between the reinforcement and soil, the reinforcement is pulled out of the soil mass, resulting in a pull-out failure. If the tensile force in the reinforcement becomes larger than the geosynthetic, it would lead to rupture failure. It is parallel with Alfaro [5] that found the internal stability of the geosynthetic-reinforced soil is classified for two common failure mode which is rupture due to tensile over stressing in the high-stress condition and pull-out failures. Pull-out failure occurs whenever the slippage of soil-geosynthetics interaction in the low-stress condition within the interface region. Therefore, the difficulty of the internal stability has encouraged many researchers to explore and enhance the behavior of the geosynthetics and its effects to the soil structure.

2. Pull-Out Test

According to ASTM D6706-01 [6] and Yin [7], pull-out test is a method used to identify the interaction of geosynthetics and soil structure induced by surcharge load. The interaction is related to maximum pull-out force (kN) required with respect to displacement (mm) of geosynthetics. The pull-out resistance, Pr also has been identified as shear resistance values of geosynthetics per contact area due to different normal pressure. A pull-out device that has been used for this research is modified by previous study done by [8].

2.1 Model Set-Up

The model set up of pull-out test machine is fabricated and conducted accordance to ASTM D6706-01 [6]. It is made by mild steel and Perspex sheet whereby the size of a box is 400 mm (width) x 550 mm (height) x 700 mm (length). This box is filled up with the soil sample and embedded geosynthetics until reached 400 mm of height. There is a 10 mm thick steel plate at the top of the box used to compress the soil sample with desired pressure [7]. The pressure was generated by a hydraulic power pack attached with S-type load cell. Meanwhile, the horizontal movement was generated with an electric motor that pulled the geosynthetics sample at constant rate of 2 mm/min [6]. Similar to the vertical load, the horizontal force induced by movement of geosynthetics has also been recorded by S-type load cell. Furthermore, the displacement of the geosynthetics leads to pull out being measured using the Linear Variable Differential Transducer (LVDT). All the measured reading of load and displacement were directly recorded and saved in the data logger. Fig. 1 shows the set-up apparatus of geosynthetics pull out test.
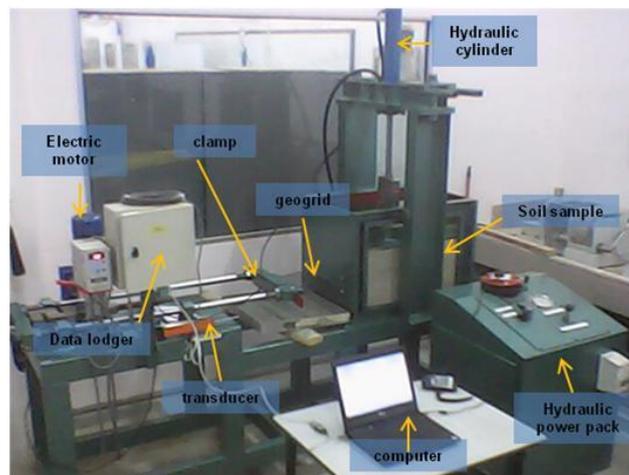

Fig. 1 - Set-up apparatus of geosynthetics pull-out test

2.2 Test Procedure

The test started with sample preparation whereby the geosynthetics were cut into a square size of 860 mm (length) x 280 mm (width). The dry sand sample was poured, 1 reached 200 mm from the bottom of the box. This is to allow the installation of the geosynthetics in the middle of the soil sample. One end of the geosynthetics is clamped, and another one is freely laid on the sand sample. Fig. 2 shows the typical installation method of geosynthetics. All equipment were calibrated before test was conducted. The calibrations were made by an appointed supplier.

| (a) | (b) |

Fig. 2 - (a) installation of geogrid; (b) gluing of the geotextile

The sand was again poured into the pull-out box until achieved 400 mm of height. The sand sample is pre-compacted 100 mm thick for each layer to provide adequate compaction [9]. Next, the top plate is lowered down and the sand is compressed to achieve desired pressure, which are 100 kPa, 150 kPa and 200 kPa. Pull out process was conducted just after compression has achieved the desired value. The geosynthetics is pulled out at rate of 2 mm/min whilst displacement and pull-out force is recorded in a data logger (model: CR 1000). The test was stopped because the geosynthetics has achieved the maximum pull-out force, or it has failed due to rupture. The additional process was made for geotextile-pull-out test. The geotextile was wrapped and glued with the clamp for three rolls. After 30 minutes of being dried, the geotextile was drilled precisely to the bolds' holes. There were six bolds which were used to tie up the clamp. Again, the geotextile was spread with glue in order to give the uniform distribution of load at the clamp [6]. In addition, the glued area may prevent geotextile to fail at the clamp. After geotextile has been tied to pull-out clamp, it was left to dry for 30 minutes to get a strong binding.

2.3 Material and Sample Preparation

Geosynthetics that has been used as reinforcement material is geogrid and geotextile. Previous researchers also used geogrid as a material to define the reaction of reinforcement mechanism. McDowell [10] and Yan [11] has studied on the behavior of soil reinforced-geogrid experimentally and numerically. Meanwhile, geotextile has been installed for separation, reinforcement of soil and also for filtration purposes. The reinforcement materials were cut for 280 mm (width) x 860 mm (length). The dimension of pull out box is just 700 mm in length and 400 mm in width. The extra 160 mm of length is used to tie up the geosynthetics to the clamp. These two reinforcement materials are shown in Fig. 3. The description on the materials properties are explained in Table 1. Soil samples was used is silica sands which is supplied by L&T Mineral Sdn. Bhd, Bestari Jaya, Selangor. Silica sands were classified based on the mean size distribution or D_{50} as shown in Fig. 4. Two different size of D_{50} was highlighted purposely to determine the effect of particles size and friction angle to pull-out resistance. Table 2 describes properties of silica sand.
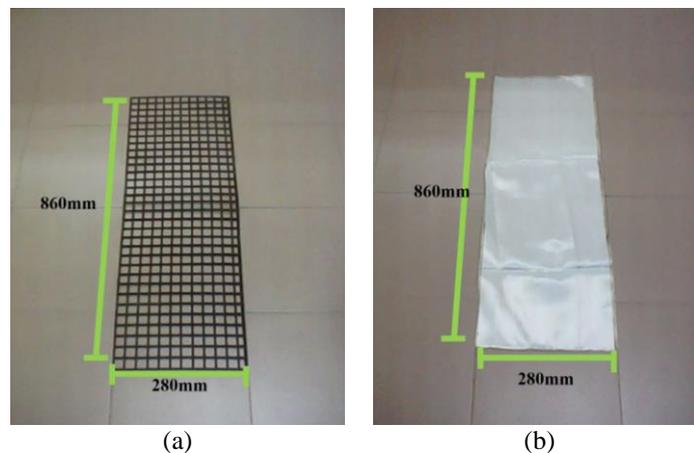

(a)   (b)

Fig. 3 - (a) biaxial geogrid; (b) woven geotextile
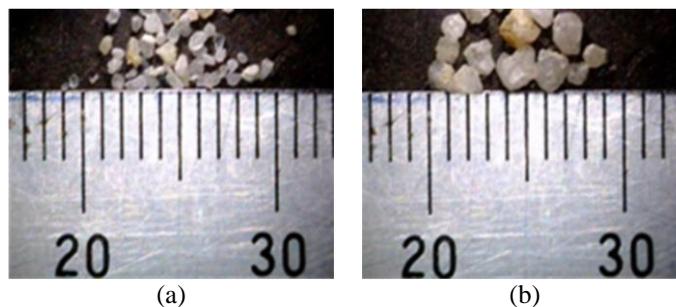

(a)   (b)

Fig. 4 - (a) silica sand, D_{50} = 0.571 mm; (b) silica sand, D_{50} = 1.357 mm

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Table 1 - Description of geosynthetics supplied by Tencate Geosynthetics, Malaysia

Geosynthetics Products	Tensile strength (kN/m)	Type of product	Raw material	Main function
Tencate Miragrid GX (20/20) (Geogrids)	20-21	Biaxial geogrid	Polymeric coated high tenacity PET yarns	Reinforcement
Tencate Polyfelt Geolon PET (100) (Geotextiles)	100-110	Woven	High tenacity PET yarns	Separator and reinforcement

Table 2 - Properties of silica sand

Mean size distribution (D_{50}), mm	Soil classification	Particles density, (ρ_s) kg/m³	Relative density (%)	Friction angle, (degrees)
1.357	Poorly Graded SAND,SP	2.63	60	52.6
0.571	Poorly Graded SAND,SP	2.64	64	46.8

## 2.4 Tensile Strength of Geosynthetics

The tensile strength of the geotextile was conducted according to the [12]. Meanwhile, the tensile strength of the geogrid was conducted according to the [13]. The tensile strength of geosynthetics was calibrated with the manufacturer's standard values as shown in Table 3. There are three samples of geosynthetics were tested for each geogrid and geotextile respectively. The average value of the tensile strength for geotextile is 108.97 kN/m. It has 0.94-8.23% different of tensile strength. The identified tensile strength has located in the range of the manufacturer standard. Meanwhile, the geogrid samples have given an average tensile strength at 22.34 kN/m. It has 3.18-7.79% different of tensile strength. The average tensile strength for geogrid has exceeded the manufacturer's range value.

Table 3 - Tensile strength of geosynthetics

Geosynthetics	Tensile strength, kN/m		Percentage different %
	Manufacturer	Identified	
Woven Geotextile	100-110	108.97	0.94-8.23
Biaxial Geogrid	20-21	21.69	3.18-7.79

3. Result and Discussion

The reinforcement mechanism of sand-geosynthetics interaction due to pull-out is illustrated in Fig. 5. The normal pressure has induced the interlocking effect between sand particles and geosynthetic, and then formed the rigid interaction. The geosynthetic try to resist the pull-out force and shear force is increased significantly with respect to displacement of geosynthetic. The geosynthetics is pulled until it has failed due to pull-out or rupture failure. The cumulative shear force along the interface region called as shear zone. Reference [5] identified this phenomenon as shear band.
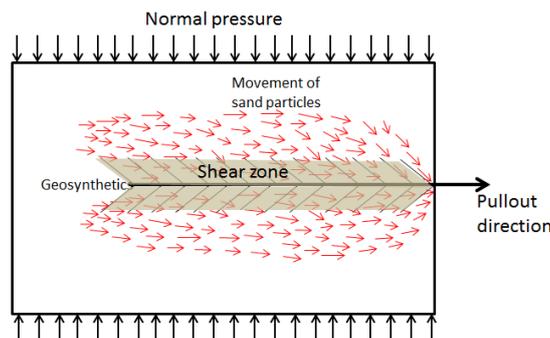
Fig. 5 - Reinforcement mechanism of sand-geosynthetics at interface region

3.1 Sand-Geosynthetics Interaction Behavior

Fig. 6 shows the results of pull-out force versus displacement of geotextiles and geogrids in D_{50}=1.357 mm sand. In additional, the pull-out resistance, Pr was calculated as shear resistance values of geosynthetics per contact area. Pr value also used to define the maximum tensile strength of the geosynthetics. Comparatively, the maximum pull-out force at failure is 39.1 kN which was recorded by sand- geotextile interaction at 200 kPa whereas, the minimum reading pull-out force at failure is 8.67 kN which was recorded by sand-geogrid interaction at 100 kPa of normal pressure. The percentage different is 78% with respect to 35.27 mm and 60.79 mm of displacement respectively. Sand-geogrid interaction has recorded a high value of pull-out force at 11.52 kN under 200 kPa of normal pressure. The effect of this condition has made the geogrid ruptured during the pull-out. This is due to the reaction of transverse ribs that interlocked with the sand particles in dense condition. The passive resistance against transverse ribs encouraged the load transfer mechanism at interface region [14]. Furthermore, it is related to the production of the geogrid, whereby the maximum tensile strength is (20-21 kN/m) only. It is predicted to have a large maximum pull-out force if the geogrid sample has a high value of tensile strength. At 100 kPa and 150 kPa, most of the geogrids samples do not fail by rupture in sand. Its failure was due to poor interaction of geogrid with sand particles at the reinforced zone. Poor interaction relates to the failure of frictional forces between sand-to-sand and also sand-to-geogrid's surface. Furthermore, it also related to the transverse ribs of geogrid. This is caused by the reaction of transverse ribs that pass through the assembled sand particles and encouraged sand particles to slide and rotated accordingly to the mobilized geogrid. It similar with [15] proves that the reaction of interlocking by geogrid's ribs is functioning well whenever geogrid is embedded in denser particles and gaining the shear strength of reinforced soil structure. Similar to geotextile sample, it has failed by rupture at 200 kPa due to a large contact area between sand to geotextile. The large contact area at high densification has increased shear resistance at the reinforced zone. At a dense condition, woven geotextile also allowed the sand particles to penetrate the geotextile's surface and interlocked between the yarns. It is also related to the high tensile strength of the geotextile (100-110 kN/m) which is five times larger than the geogrid has. As a result, the combination of large contact area, interlocking and high tensile strength at constant densification has produced a great interface effect at reinforced zone. Fig. 7 illustrates the rupture failure of geotextile and geogrid at 200 kPa of normal pressure. Fig. 8 illustrates the results of pull-out force versus displacement of geotextiles and geogrid in D_{50}=0.571 mm sand. Geotextile sample has recorded 30.67 kN of peak force failure at 52.21 mm of displacement with respect to 200 kPa of normal stress. Comparatively, pull-out force increased by 13.63% if the normal pressure increased from 100 kPa to 200 kPa, whereas, at 100 kPa to 150 kPa and 150 kPa to 200 kPa of normal stress, pull-out forces differ by 2% and 11.87% respectively. It is parallel with [16] and [17], the pull-out force increases with increasing normal pressure. For geogrid, the maximum pull-out force at failure is stated by 200 kPa of normal stress which is 11 kN at 51.51 mm displacement.
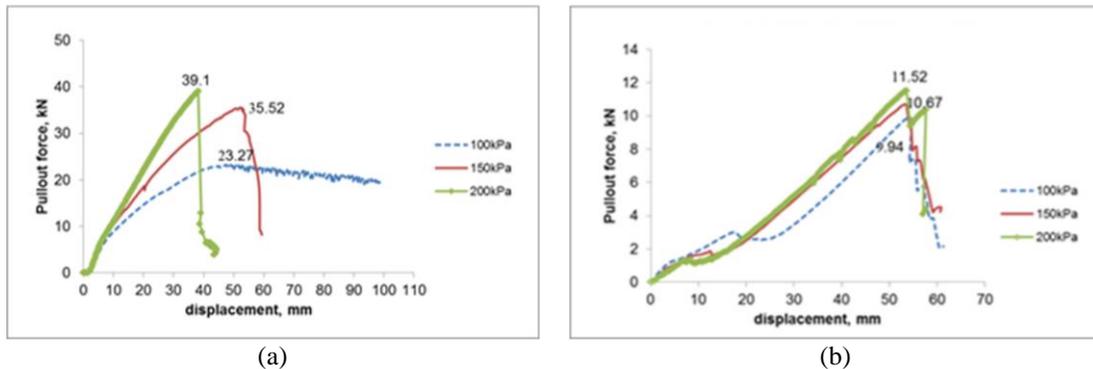

| (a) | (b) |

Fig. 6 - (a) pull-out of geotextile in (D_{50}=1.357 mm); (b) pull-out of geogrid in (D_{50}=1.357 mm)
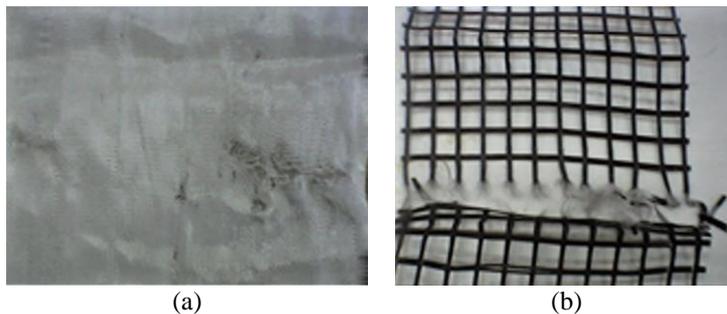

| (a) | (b) |

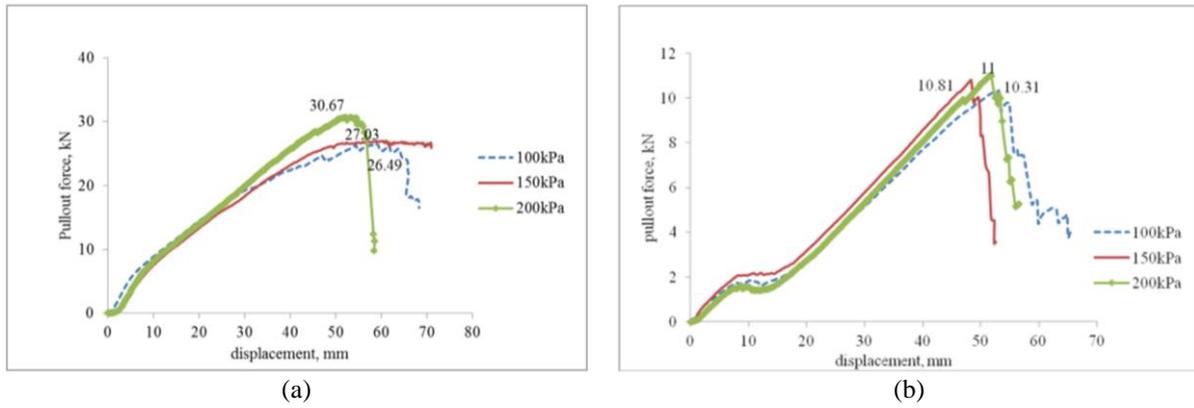**Fig. 7 - (a) rupture failure of geotextile; (b) rupture failure of geogrid**

Fig. 8 - (a) pull-out of geotextile in (D$_{50}$=0.571 mm); (a) pull-out of geogrid in (D$_{50}$=0.571 mm)

Fig. 9 shows the pull-out resistance, Pr of geotextile and geogrid in D$_{50}$=1.357 mm and D$_{50}$=0.571 mm. Pr of geosynthetics was identified according to [4]. For D$_{50}$=1.357 mm, geotextile gave a high value of resistance at 200 kPa pressure at which the resistance is 139.64 kN/m and Pr has exceeded the maximum tensile strength. Meanwhile, for D$_{50}$=0.571 mm, Pr is recorded at 94.61 kN/m at 100 kPa of normal stress. It is followed by 150 kPa and 200 kPa of normal stress whereby Pr has recorded at 96.54 kN/m and 109.54 kN/m respectively. Refer from the result, the resistance values of geotextile in D$_{50}$=0.571 mm for three different normal pressures indicate that geotextile can be loaded with more normal pressure as long as the resistance value does not exceed 110 kN/m of maximum tensile strength. Meanwhile, for geogrids in D$_{50}$=1.357 mm and D$_{50}$=0.571 mm sand. The resistances for three different normal stresses were not too obvious. Pr has produced 19.68 kN/m at 100 kPa of normal stress. It is followed by 150 kPa and 200 kPa which produced 20.67 kN/m and 21 kN/m of Pr respectively. Pr values for 150 kPa and 200 kPa is in range (20-21 kN/m) of tensile strength of geogrid. However, the geogrid samples still in good condition without broken off although the Pr value just attained the ultimate tensile strength. It is predicted that geogrid samples will fail if the normal pressure increase more than 200 kPa.Sand-geotextile interaction has recorded high values of pull-out force at 100 kPa, 150 kPa and 200 kPa compared to sand-geogrid interaction. It can be concluded that, the increment of the pull-out resistance, Pr, is directly proportional to the maximum pull-out force associated with increment of normal pressure.
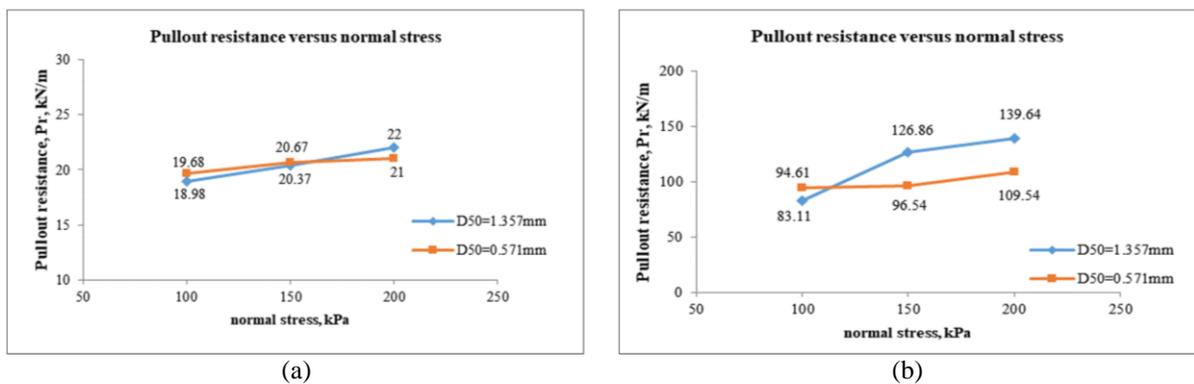

Fig. 9 - (a) Pr of geotextile in silica sand; (b) Pr of geogrid in silica sand

4. Conclusion

In conclusion, the pull-out test of geosynthetics has demonstrated the pull-out resistance of Sand-Geosynthetics reinforcement. Comparatively, in D$_{50}$=1.357 mm, for geotextile, the peak force at failure is 39.1 kN at 38.27 mm displacements, whereas, for geogrid, the peak force at failure is 11.52 kN at 53.55 mm displacement. The percentages differ is 70.54%. Meanwhile, in D$_{50}$=0.571 mm, the pull-out force at failure is recorded at 30.67 kN for geotextile and 11 kN for geogrid due to 200 kPa of normal pressure. The pull-out forces at failure keep reducing with respect to 150 kPa and 100 kPa of normal pressure and caused the geogrid and geotextile just failed due to sliding. The large contact area at high densification has increased shear resistance at the reinforced zone. At a dense condition, woven geotextile allowed the sand particles to penetrate the geotextile's surface and interlocked between the yarns. It is caused by the influenced of normal pressure that provided a different densification of sand structure. The denser sand structure, the higher force required to pull-out the geotextile. Moreover, the different size of the soil media obviously contributed in giving the maximum pull-out resistance. The bigger sizes of sand particles, the higher shear resistance were produced

[15], [18]. It is related to silica sand D_{50}=1.357 mm which has higher friction angle compared to silica sand D_{50}=0.571 mm. The friction angle of D_{50}=1.357 mm has 11% higher than D_{50}=0.571 mm of silica sand. Yet, this laboratory testing is useful to be applied for preliminary study of soil reinforcement characteristics before the installation of the reinforcement on specific area. Through several pull-out tests, the engineer may find the suitable geosynthetics materials and optimize the design of soil reinforcement.

Acknowledgement

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