Measured and Simulated Interactions between Kenaf Geogrid Limited Life Geosynthetics (LLGs) and Silty Sand Backfill

Interactions mesurées et simulées entre kénaf géogrille limitée Géosynthétiques vie (LLGs) et de remblai de sable limoneux

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ABSTRACT: New types of natural fiber reinforcing materials have been introduced recently in geotechnical applications; for example, jute, coir, sugarcane bagasse. Natural fibers can be modified into woven geogrid and used in geotechnical engineering applications and generally classified as Limited Life Geosynthetics (LLGs). The natural fiber used for this study was roselle or Thai Kenaf which was made into geogrid with opening size of 4 mm was investigated. Locally available silty sand was used for compacted backfill material. Large scale pullout and direct shear tests were performed in order to investigate interaction mechanism of kenaf geogrid and compacted sand. Numerical simulation was studied in terms of its reinforcement mechanism on plane strain mode. From the results of sensitivity analyses, the interaction coefficient and axial stiffness of the geogrid were found to be important parameters affecting the efficiency of geogrid. The interaction coefficient R_{inter} is 0.9 for pullout mechanism and 0.6 for direct shear mechanism. The recommended parameters for these reinforced systems have been introduced to use as sustainable geosynthetics. Furthermore, Kenaf geogrid which is LLGs concept can be widely promoted for natural fiber application in many countries.

RÉSUMÉ: De nouveaux types de matériaux en fibres naturelles de renfort ont été introduits récemment dans les applications géotechniques, par exemple, le jute, le coco, la bagasse de canne à sucre. Les fibres naturelles peuvent être modifiés en tissé géogrille et utilisé dans les applications d'ingénierie géotechnique et généralement classés comme Géosynthétiques durée de vie limitée (LLGs). La fibre naturelle utilisée pour cette étude était kénaf oseille ou thaïlandais qui a été faite en géogrille avec l'ouverture de la taille de 4 mm a été étudiée. Sable limoneux disponible localement a été utilisé comme matériau de remblai compacté. Retrait à grande échelle et essais de cisaillement direct ont été réalisées afin d'étudier mécanisme d'interaction de kenaf géogrille et de sable compacté. La simulation numérique a été étudiée en fonction de son mécanisme de renforcement du mode de déformation plane. D'après les résultats des analyses de sensibilité, le coefficient d'interaction et de la rigidité axiale de la géogrille se sont révélés être des paramètres importants qui influent sur l'efficacité de la géogrille. Le Rinter coefficient d'interaction est de 0,9 pour mécanisme de retrait et de 0,6 pour le mécanisme de cisaillement direct. Les paramètres recommandés pour ces systèmes renforcés ont été mis en place pour l'utiliser comme géosynthétiques durables. En outre, le kénaf géogrille qui est le concept LLGs peut être largement promu pour la demande de fibres naturelles dans de nombreux pays.

KEYWORDS: interaction, geogrid, kenaf, simulation.

1 SUSTAINABLE GEOSYNTHETICS

Living sustainably, according to many, requires that we use resources to meet our present needs without compromising the ability of future generations to meet their needs. Living sustainably does not, however, require that we live in thatch huts that periodically biodegrade. According to the free online encyclopedia, the definition of sustainability is simply "the capacity to endure". People, resources, and the environment are all intertwined. We have an impact on the environment when we extract raw materials, manufacture, install, use and dispose of our products. This is why endurance counts. A longer lasting geosynthetic product delays the repeat of the manufacturing cycle, uses fewer resources, costs less money and causes less stress on the environment.

Belton (2008) hit the sustainable issue head-on by illustrating how geotextiles and geogrids save large quantities of natural materials, mainly stone aggregate for highways, railroads, parking lots, and building foundations. They also described the use of on-site soils for use in walls and slopes rather than using imported sands and gravels. In addition they bring into context the carbon footprint of both materials and the processes involved in obtaining these materials, e.g., transportation from quarries to construction sites. Interestingly, the intent of this tax was to increase the use of recycled materials but it appears to more immediately play into the use of geosynthetics, to all of our advantage. Robinson and Quirk (2008) give several tables of aggregate thickness saved using geogrids in highway base courses. They also illustrate aggregate savings when using geodrains, fin drains, and geocomposites in walls and bridge abutments. Lastly, they described the many uses of these drainage geosynthetics in waste containment. Landfills require drainage of leachate at their base, drainage of water at the surface, and sometimes drainage within the waste mass itself.

2 NATURAL FIBERS REINFORCEMENT FOR GREEN TECHNOLOGY

Environment protection is important because construction represents a major contribution to climate change, resource depletion and pollution at a global level. This strategy for more sustainable construction is a significant step towards a more successful, socially and environmental friendly atmosphere making a strong contribution to the better quality of life signaled by our sustainable development strategy (Mwasha, 2009).

The biobased geotextiles research project has been conducted by several Institutions in United Kingdom by Sarsby et., al. (2006), Mwasha (2005), Mwasha and Sarsby (2003). Today most biodegradable geotextiles are used in erosion control where they serve to stabilize the soil surface while natural vegetation is established. There are other numerous ground engineering situations where the critical period for stability is immediately, or very shortly, after construction, e.g. any form of 'foundation loading' of free-draining or slow-draining soils. In such situations it is common practice to incorporate geosynthetic basal reinforcement to provide an additional stabilizing force. The stability of the system will improve in time and so the stabilizing force, which needs to be provided by the geosynthectic, will diminish. After a certain time (typically between a few months and a few years) the whole system will be stable with little or no assistance from the geosynthetic – in many cases the geosynthetic becomes totally redundant. In such a situation, the use of a non-conventional geosynthetic, which has a limited, but predictable working life, is sound engineering practice. This is the concept of limited life geotextiles (LLGs). In this paper, the interactions between Kenaf geogrid which is a kind of Limited Life Geosynthetics (LLGs) have been measured and numerically simulated.

3 INTERACTION BETWEEN BACKFILL SOIL AND REINFORCEMENT BY PULLOUT AND DIRECT SHEAR TEST

In reinforced earth structures, the interaction between grid reinforced (e.g. inextensible and extensible grid reinforcements) and soil can be simplified into two types: a) direct shear resistance and b) pullout resistance. Direct shear resistance can be represented as soil sliding over the reinforcing material, but for pullout resistance, it is the pulling of reinforcements out from the fill material. The dashed line shown in Fig. 1 represents the potential failure of a typical reinforced structure. Such direct shear and pullout resistance can be investigated by conducting direct shear and pullout tests under various soil types and a range of normal stresses, respectively.

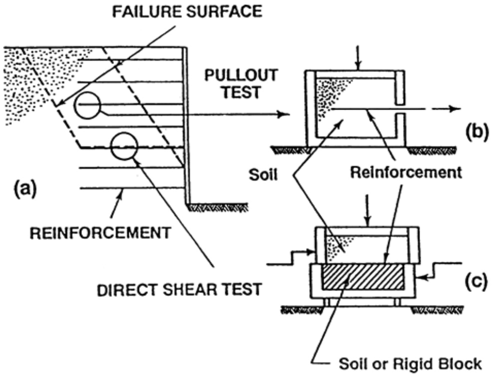


Figure 1. Interactions between soil and reinforcement

3.1. Pullout mechanism

Pullout resistance of grid reinforcements embedded in backfill soils basically consists of two resistance contributions; the former is frictional resistance and the latter is passive or bearing resistance. In case of geogrid reinforcements, the shape of longitudinal and transverse ribs are flat, therefore, the frictional resistance can be mobilized along not only the surface area of the longitudinal ribs, but also the surface area of the transverse ones as shown in Fig. 2.

Pullout test was conducted to determine displacement and structure of LLGs reinforcement layer needed to achieve active limit state in order to exploit reinforcement's load capacity properly (Artidteang et al., 2012). The pullout machine which performed testing is show in Fig. 3. Pullout force was measured by a load cell connected to the data logger. High strength wires were connected to the longitudinal rib and the other ends were connected to the LVDTs to measure the displacement (Fig. 4)

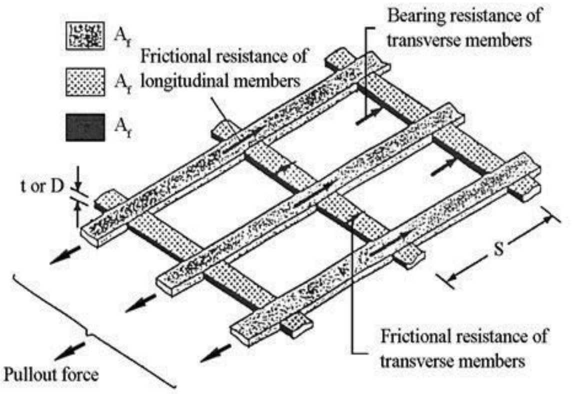


Figure 2. Components of pullout resistance for geogrid reinforcement (Jewell et al., 1984)

Figure 3. Pullout machine (Artidteang et al., 2012)

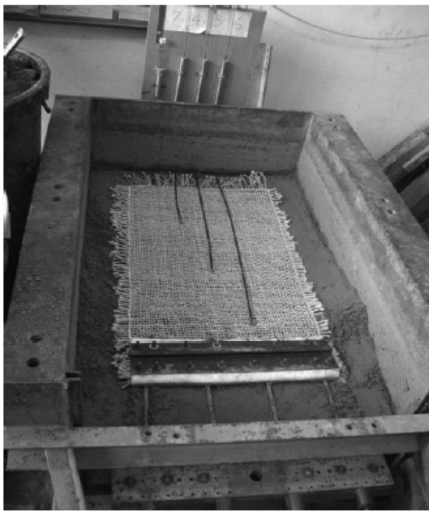
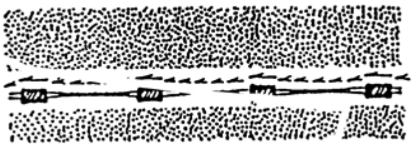


Figure 4. Position of LVDTs attached on the woven kenaf LLGs (Artidteang et al., 2012)

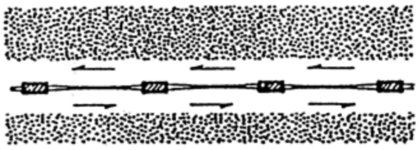
3.2. Direct shear mechanism

Direct shear resistance between soil and grid reinforcement generally consists of three components. The first component is the shearing resistance between the soil and the surface area of grid reinforcement, the second component is the soil-to-soil shearing resistance at the apertures of grid reinforcement, and the last component is the resistances from soil bearing on the bearing surfaces of grid reinforcement (Jewell et al., 1984) see Fig 5.

The large-scale direct shear test conducted for evaluating the friction between backfill soils only and between kenaf LLGs and backfill soil. A photograph of device is shown in Fig. 6 (Artidteang et al., 2012). Kenaf LLGs was prepared by dimension of 300 mm by 500 mm and it was folded at one end and placed between compacted backfill soils which compacted to optimum moisture content in the upper and lower direct shear box



a) Shear resistance between soil and reinforcement plane surface area



b) Soil to soil shear resistance

Figure 5. Components of the direct shear resistance of grid reinforcement (Jewell et al., 1984)

Figure 6. Large scale direct shear apparatus (Artidteang et al., 2012)

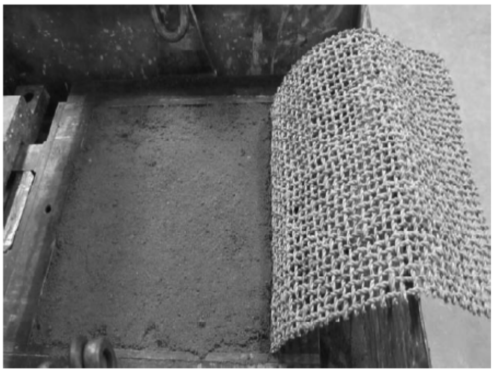


Figure 7. Kenaf LLGs folded with sand backfill (Artidteang et al., 2012)

4 NUMERICAL SIMULATION FOR LABORATORY INVESTIGATION

4.1. Pullout test simulation

The interaction between soil and reinforcement (Kenaf geogrid) can be simulated in term of pullout and direct shear tests of grid and compacted sand by using PLAXIS. Six-node triangular elements were used as soil elements, and geogrid elements were used to simulate the reinforcement. The upper and lower interface elements of the reinforcement were modeled by thin layer elements. The elastic perfectly-plastic model was used to simulate the behaviour of sand-geogrid interfaces. In PLAXIS program, the shear modulus and strength parameters of the interface were automatically calculated from the surrounding soil parameters using the interaction coefficient, R. Air-bag pressure was simulated by vertical loading applied directly to the soil surface, and pullout loading was then given by applying prescribed displacement to the reinforcement at the opening front node of the pullout box to a desired value.

Finite element mesh for pullout box with PLAXIS program is shown in Fig. 8. Table 1 shows the input parameter for pullout test simulation.

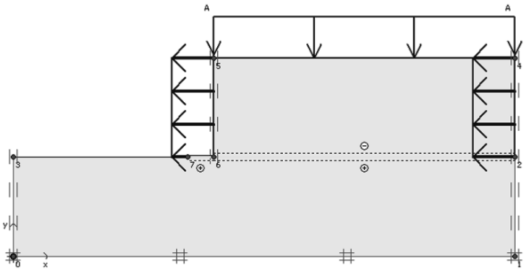


Figure 8. Pullout test simulation

Table 1 Input parameters for pullout test simulation

Compacted Sand	
Normal Stress	20, 40, 60 kPa
Maximum Dry Density, γ_d	18.1 kN/m^3
Cohesion ,c	11.0 kN/m^2
Friction Angle ,ϕ	35^o
Young Modulus, E_{50}	6000 kN/m^2
R_{inter}	0.5, 0.6, 0.7, 0.8, 0.9, 1.0
Kenaf Geogrid	
Modulus of Elasticity, E	50 kN/m^2
Length	0.9 m.

4.2. Direct shear test simulation

The large scale direct shear box was modeled by as shown in Fig. 9. Six-node triangular elements were used as soil elements, and geogrid elements were used simulating the reinforcement. The upper and lower interface elements of the reinforcement were modeled by thin layer elements. The elastic perfectly-plastic model was used to simulate the behaviour of soil-geogrid interfaces. Air-bag pressure was simulated by vertical loading applied directly to the soil surface, and shear loading was then given by applying prescribed displacement to the side nodes of the upper box. Finite element mesh for direct shear test with PLAXIS program is shown in Fig. 5. Table 2 shows the input parameter for direct shear test simulation.

Table 2 Input parameters for direct shear test simulation

Compacted Sand	
Normal Stress	40, 80, 120 kPa
Maximum Dry Density, γ_d	18.1 kN/m^3
Cohesion, c	11.0 kN/m^2
Friction Angle, ϕ	35^o
Young Modulus, E_{50}	6000 kN/m^2
R_{inter}	0.5, 0.6, 0.7, 0.8, 0.9, 1.0
Kenaf Geogrid	
Modulus of Elasticity, E	50 kN/m^2
Length	0.3 m.

5. RESULTS AND DISCUSSIONS

5.1. Pullout mode

In this study, the interaction coefficient (R) between the reinforcement and backfill material was chosen as variable parameter. The numerical simulations were conducted by varying the interaction coefficient until the predicted results coincide with the laboratory results as shown in Fig 10. The comparison between laboratory test and predicted results are made in Fig. 11 for pullout test. The results of simulation captured well with laboratory test results.

After the maximum pullout resistance, the predicted results show constant residual strength as compared to the measured results. The reason might be consideration of PLAXIS to geogrid element as rough sheet which did not show any damages in geogrid as it occurred in laboratory. Average back-calculated interaction factor for Kenaf and compacted sand is 0.9 in pullout mode.

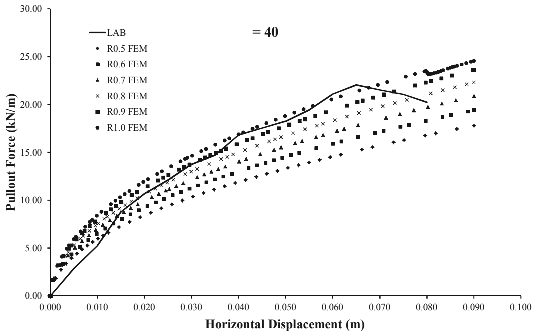


Figure 9. Parametric study of R_{inter} for normal stress of 40 kPa.

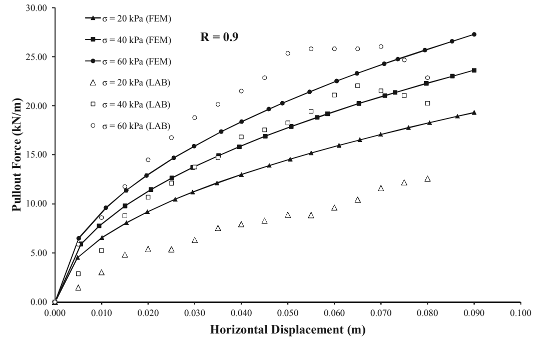


Figure 10. Pullout test between FEM and laboratory test results

5.2. *Direct shear mode*

For direct shear test simulation, the interaction coefficient (R) also varied in order to parametric study for this variable as shown in Fig. 12. The sensitivity analysis show that the interaction coefficient (R) of 0.6 is good fit with laboratory results. The comparison between laboratory test and predicted results are made in Fig. 13 for direct shear test. The results of simulation captured well with laboratory test results.

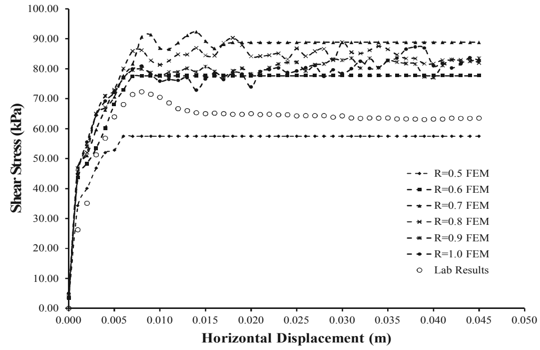


Figure 11. Parametric study of R_{inter} for normal stress of 120 kPa.

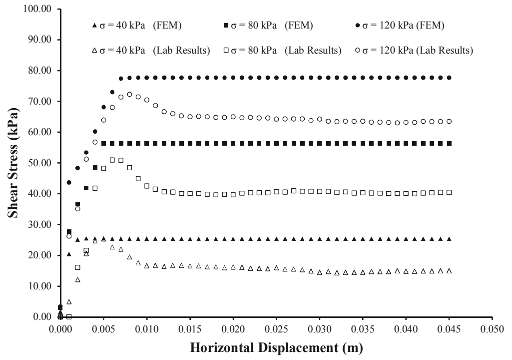


Figure 12. Direct shear test between FEM and laboratory test results

6. CONCLUSIONS

The purposes of this study are to assess the interactions between the Kenaf geogrid and compacted sand as well as perform the numerical simulations by finite element analyses. Sensitivity analyses were also performed for the pullout and direct shear test by varying the interaction coefficient. The back-calculated from numerical simulations average values of interaction coefficients were found to be similar as to the measured results. The interaction coefficient and axial stiffness of the geogrid were found to be important parameters affecting the efficiency of geogrid. The interaction coefficient R_{inter} is 0.9 for pullout mechanism and 0.6 for direct shear mechanism. These parameters are useful for analysis and design of reinforced soil structure using kenaf geogrid and compacted sand. Limited Life Geotextiles (LLGs) from Kenaf geogrid can be used as natural fibers for sustainable geosynthetics.

7. ACKNOWLEDGEMENTS

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