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DIRECT SHEAR TESTS OF SANDY SOILS INTERFACED WITH FRP SHEETS

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Abstract: The interface friction between the soil and the pile is an important design factor in the design of deep foundations. The conventional construction materials (i.e. concrete, steel, wood) were found to have serious major soil-substructure problems with time, especially in terms of durability, deterioration, and corrosion. Fiber-reinforced polymer (FRP) composites are potential alternatives to overcome these problems. FRP composites are corrosion resistant, poses higher strength, lighter in weight, and more durable compared to conventional materials. More records and data are necessary to adopt these new materials in foundation design and geotechnical practice. This paper presents the results of an experimental study of the interface friction behaviour between glass FRP (GFRP) composites and sandy soils. The experimental program consists of GFRP sheets with different surface roughness. Each sheet was fabricated out of two layers of unidirectional fibreglass fabric and epoxy resin. The experimental testing was carried out using direct shear test. The normal stress applied on the specimens through the direct shear test was 50. 100, and 200 kPa. The specimens were sheared with three types of sandy soils (sand, silty sand, and sandy lean clay). The sand and the silty sand was used in the dense state. The experimental results showed that the interface friction of GFRP with sand depends significantly on the surface roughness of FRP.

1 INTRODUCTION

The direct shear test is one of the effective tests to study the interface friction behaviour between sub-structure materials and soils to obtain the interface strength parameters. Many studies have been established on the interface behaviour of conventional construction materials (i.e. concrete, steel, wood). These studies showed that the controlling parameters are the surface roughness, soil composition, magnitude of normal loading, and moisture content (Potyondy 1961).

However, many of these conventional materials used for pile foundations were found to deteriorate with time. Fiber-reinforced polymer (FRP) was found to be a potential alternative compared with steel and concrete pile to overcome these soil-interaction problems with more durability and more corrosion resistance (Iskandar and Hasan 1998). FRP composite piles showed better durability, require less maintenance, and have better corrosion resistance. The lifetime of deep foundation can be increased by using fibre-reinforced polymer self-consolidated concrete piles (FRP-SCC) by increasing the durability and corrosion resistance which will reduce the life cycle cost (Sakr et al. 2004). For FRP piles the two controlling parameters for the pile-soil interface are the soil particle size (Pando 2003), and the surface roughness of the FRP with little influence for the thickness of the specimen, rate of shearing in the direct shear test (Frost and Han 1999). The normal stress affects the interface behaviour of FRP composite materials with sand. Results of direct shear tests showed that as the normal stress on carbon fibre-reinforced polymer (CFRP) with sand increased, the interface friction angle increased (Toufigh et al. 2015). CFRP had higher interface friction angle when it sheared with well graded soil compared to poorly graded soil. Using direct shear tests, the interface friction angle between soil and glass fibre-reinforced polymer (GFRP) increases if the fibre direction is perpendicular to the shear load (Vineetha and Ganesan 2014). FRP interfaces (carbon and glass FRP) with clay were shown to perform same or higher than of traditional steel piling under both drained and undrained conditions in-terms of the interface friction angle (Giraldo and Rayhani 2013).

In the design of pile foundations, many engineers consider that the interface friction angle δ is equal to 2/3 of the internal friction angle of soil Φ in their design (Terzaghi and Peck 1948). However, until today, designers are still using an approximate value of interface friction angle between different pile materials and soil as there is no exact value. A higher δ makes an economical design and decreases the project costs as it affects determining the pile diameter, length and number of piles needed (Aksoy et al. 2016).

A reliable quantitative assessment of the interface friction parameters between the pile's material and the surrounding soil will allow for less conservatism and/or safer design. Hence, more data and records on the interface behaviour of FRP with sandy soils are necessary to promote the use of this new material in pile design and geotechnical practice. This paper was designed to study the effect of the interface on the behaviour of glass fibre-reinforced polymer (GFRP) with sandy soils using direct shear test.

2 EXPERIMENTAL PROGRAM

2.1 Specimen Layout

A total of 6 groups of FRP specimens (99 mm x 99 mm x 2 mm) were prepared. Each specimen was fabricated out of two layers of unidirectional fibreglass fabric and epoxy resin. The test parameters were the surface roughness of the specimen and the normal stress in the direct shear test. The normal stresses applied on the specimens using the direct shear test were 50, 100, and 200 kPa, respectively. Three identical specimens were used for each case as shown in Table 1. The test specimens were identified with the specimen identification (ID) as GX-NY, where G stands for GFRP specimen, X stands for the surface roughness of GFRP, N stands for the applied normal stress on each specimen through the direct shear test, and Y stands for normal stress. For instance, S1-N50 is a GFRP specimen with smooth surface roughness tested under normal stress of 50 kPa in the direct shear test.

Table 1: Specimen layout

Group #	Specimen ID	Surface Roughness	Normal Stress (kPa)
1	G1-N50	Smooth	50
2	G1-N100	Smooth	100
3	G1-N200	Smooth	200
4	G2-N50	Rough	50
5	G2-N100	Rough	100
6	G2-N200	Rough	200

*Footnote~ three identical specimens were prepared and tested for each case

2.2 Material Properties

2.2.1 GFRP

All specimens were prepared with the same unidirectional fibreglass fabric with two layers on the top of each other of unidirectional fibreglass fabric as one laminate. The ratio of the weight per surface area for each layer of dry fabric was 468.34 g/m^2. The laminate was bonded by an epoxy resin (West System 105), and a hardener (West System 206). As reported by the manufacturer (Haining Anjie Composite Material Co., Zhejiang, China) the tensile strength of the Fiberglass fabric (dry fibre) is more than 1500MPa, areal fabric weight 450 g/m^2, elongation is 2.8%, and E-modulus is more than 72GPa. The tensile strength of the GFRP composite was 500 MPa.

2.2.2 Soil

Three types of sandy soils were used in this experimental study. The first type of soil used was sand. The coefficient of uniformity (C_u) for the sand is 3.86, and the coefficient of curvature (c_c) is 0.97. The gradation curve determined (ASTM, C. 1984) in Figure 1a shows that this sand is poorly graded sand (USCS. 2011). The maximum dry density determined (ASTM, D698-07. 2012) of this sand using standard effort was 1717 Kg/m^3 with an optimum water content of 13 % as shown in figure 1b. The second type of soil used was silty sand with a maximum dry density of 1883 Kg/m^3 and optimum water content of 12 %. The coefficient of uniformity (C_u) for the silty sand is 6, and the coefficient of curvature (C_c) is 0.66. The third type of soil used in this study was sandy lean clay with liquid limit (LL) of 25.2 %, plastic limit (PL) of 15.9%, and plasticity index (PI) of 9.3%. The sandy lean clay has a maximum dry density of 1840 kg/m^3 and optimum water content of 14%.

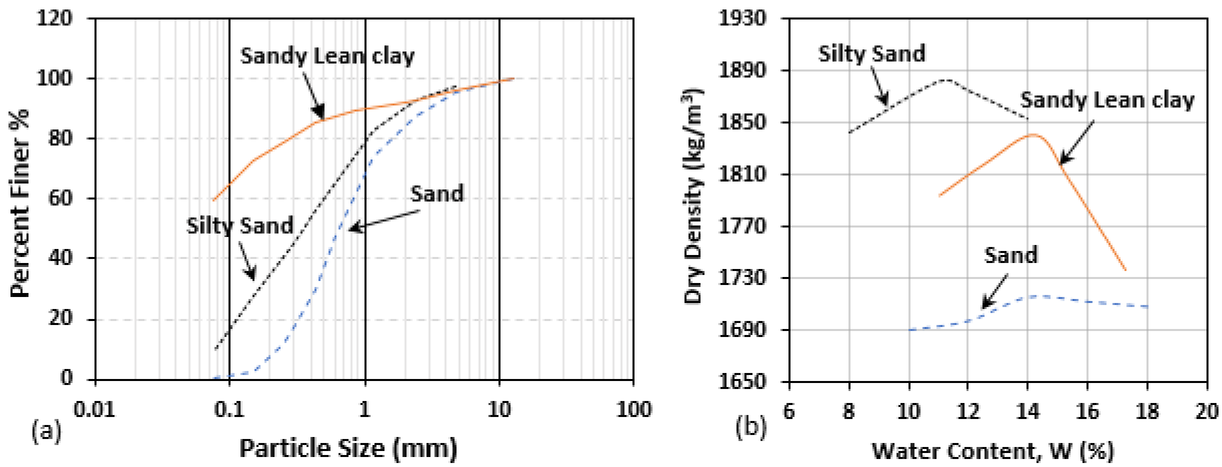

Figure 1: (a) Sieve analysis for soil used; and (b) maximum dry density vs. optimum water content

2.3 Specimen Preparation

A total of 2 FRP sheets (406 mm x 406 mm) were initially fabricated. Each sheet consists of two layers of glass fabrics (936.68 g/m^2 dry fabric). On the surface and the bottom of each glass fabric layer, 68.8 g of epoxy resin plus hardener were applied. Wax paper was used underneath each sheet to avoid sticking the resin with the working space. The surface of one the FRP sheets (G1) was smoothed by a roller on the top of the wax paper to remove the extra resin and air bubbles with a steel roller. After that, a flat board was placed at the top of the wax paper on the surface and six blue steel plates at the top of the board to compress symmetrically. The surface of the other FRP sheet (G2) was exposed to the air without rolling. The weight of each composite sheet G1 and G2 were 1852, and 1902 g/m^2. The two sheets were cured for seven days in total from the date of fabrication at room temperature. After curing were done, the sheets were cut by a diamond blade saw into nine squares (99 mm x 99 mm) specimens for testing.

2.4 Test Setup and Instrumentation

The direct shear test (DST) was used to evaluate the internal friction angles of the considered sandy soil samples and the interface friction angle between FRP and these sandy soils (ASTM, D3080-90. 1994). Direct shear box (99 mm x 99 mm) with a depth of 29.57 mm was used in this study. The lower half of the box was filled with a steel formwork (99 mm x 99 mm) with 12.78 mm in height. On the top of the steel formwork a 2 mm in thickness GFRP specimen (99.mm x 99 mm) was attached by resin epoxy. The top half of the box (99 mm x 99 mm) with 12.78 mm was filled with sand. The GFRP specimen was sheared with the soil from the lower half of the box with shearing rate 0.24 mm/min. The shear box was connected to dial gauges to measure the horizontal and the vertical displacements of the specimen in the box as shown in Figure 3 and Figure 4. For each test set, 3 normal stresses 50, 100, and 200 kPa were applied.

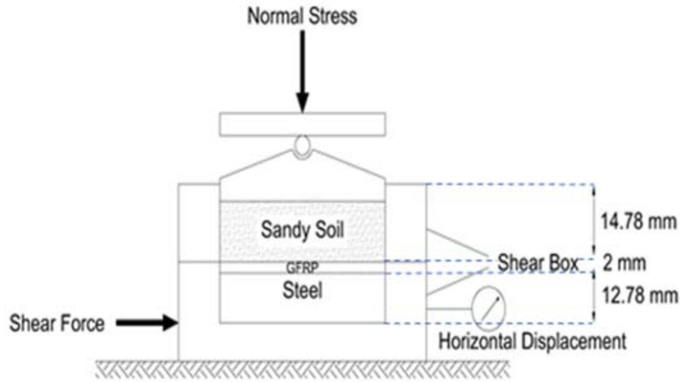

Figure 3: Test set up for interface friction measurement

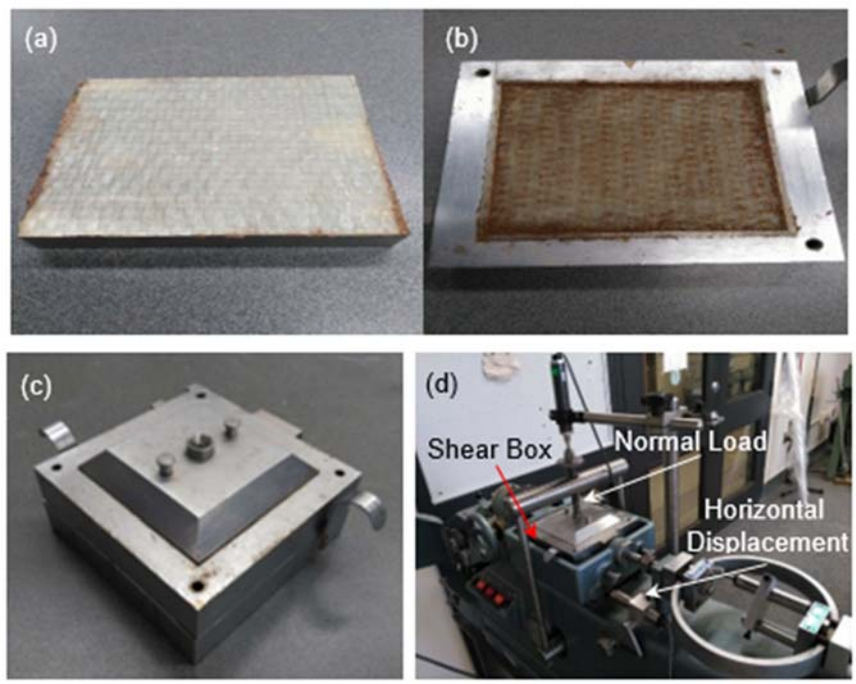

Figure 4: Test set-up: (a) GFRP specimen before the test on the steel formwork; (b) GFRP specimen inside the shear box after the test; (c) direct shear box used; (d) test set-up

3 RESULTS AND DISCUSSION

3.1 Failure Modes of Soil

All three types of sandy soils were sheared alone first with the direct shear box to determine their frictional characterises. The first type of soil which is sand reached its ultimate shear strength in the dense state with 50.13, 94.13, and 194.35 kPa under normal stresses of 50, 100, and 200 kPa, respectively as shown in Figure 5.

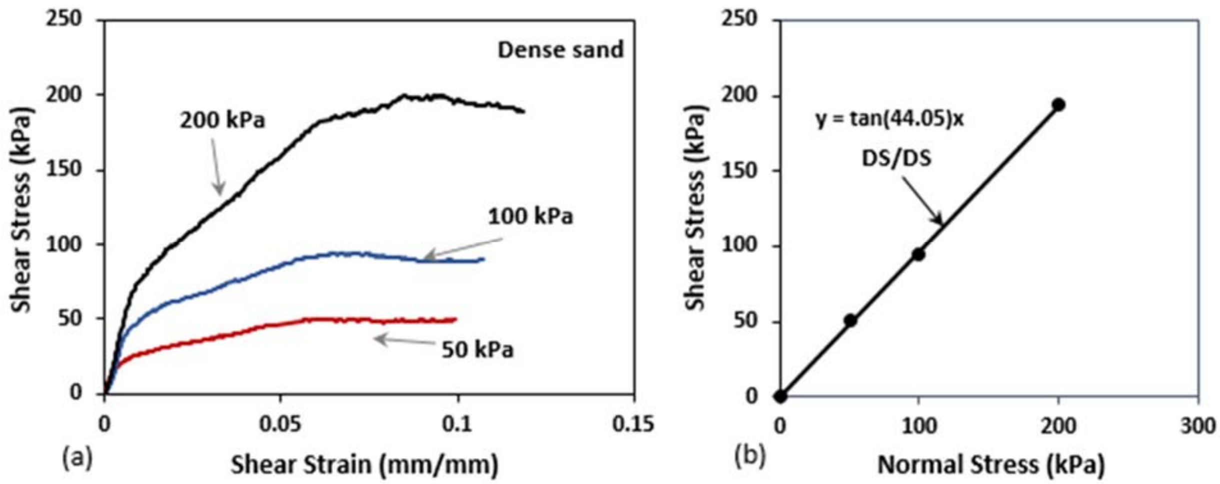

Figure 5: Direct shear test of dense sand (DS): (a) shear stress vs. shear strain; and (b) shear stress vs. normal stress

The second type of soil used was silty sand. It reached its ultimate shear strength in the dense state with 63.08, 114.52, and 202.63 kPa under the normal stresses 50, 100, and 200 kPa respectively as shown in Figure 6.

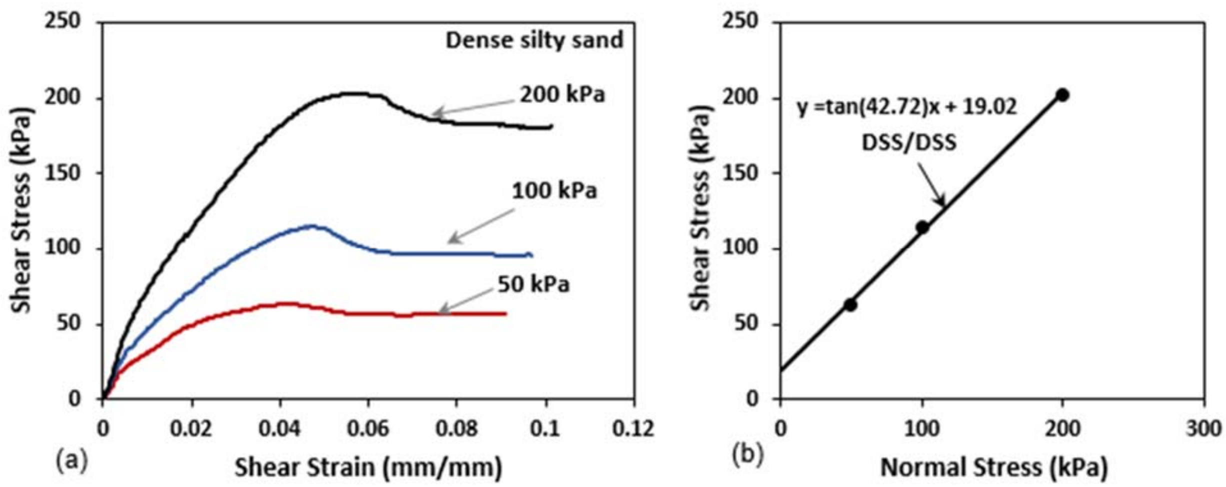

Figure 6: Direct shear test of dense silty sand (DSS): (a) shear stress vs. shear strain; and (b) shear stress vs. normal stress

The third type of sand used sandy lean clay reached its ultimate shear strength with 35.46, 57.06, and 97.84 kPa under the normal pressures 50, 100, and 200 kPa respectively as shown in Figure 7.

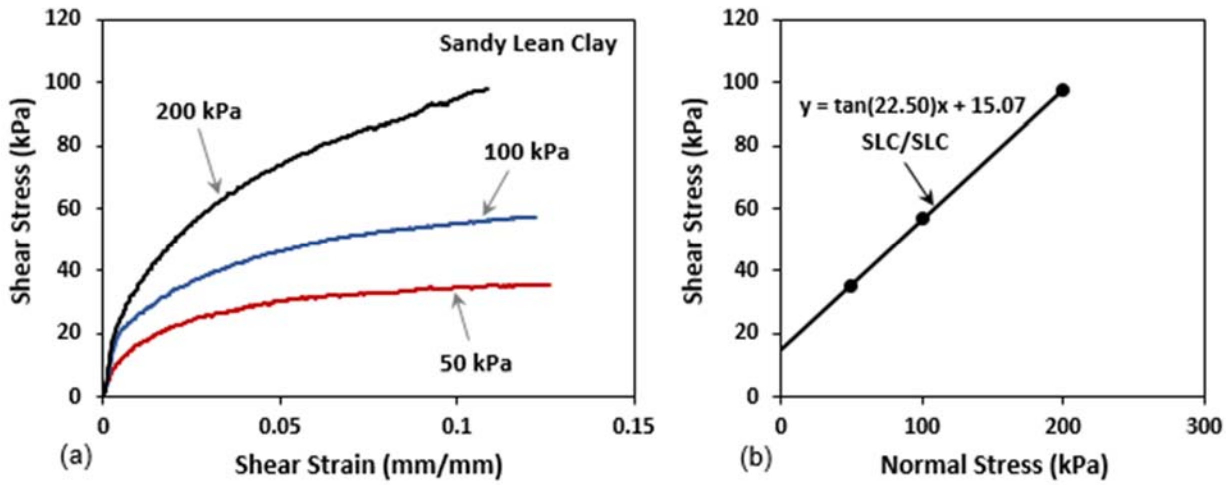

Figure 7: Direct shear test of sandy lean clay (SLC): (a) shear stress vs. shear strain; and (b) shear stress vs. normal stress

3.2 The Interface Behaviour of GFRP Against Sandy Soils

3.2.1 GFRP/Sand

As shown in Figure 5, the sand used had an internal friction angle, Φ, of 44.05 degree in the dense state. As shown in Figure 8, when the GFRP specimen with smooth surface G1 sheared with the dense sand, the interface friction angle, δ, was 32.37 degree.

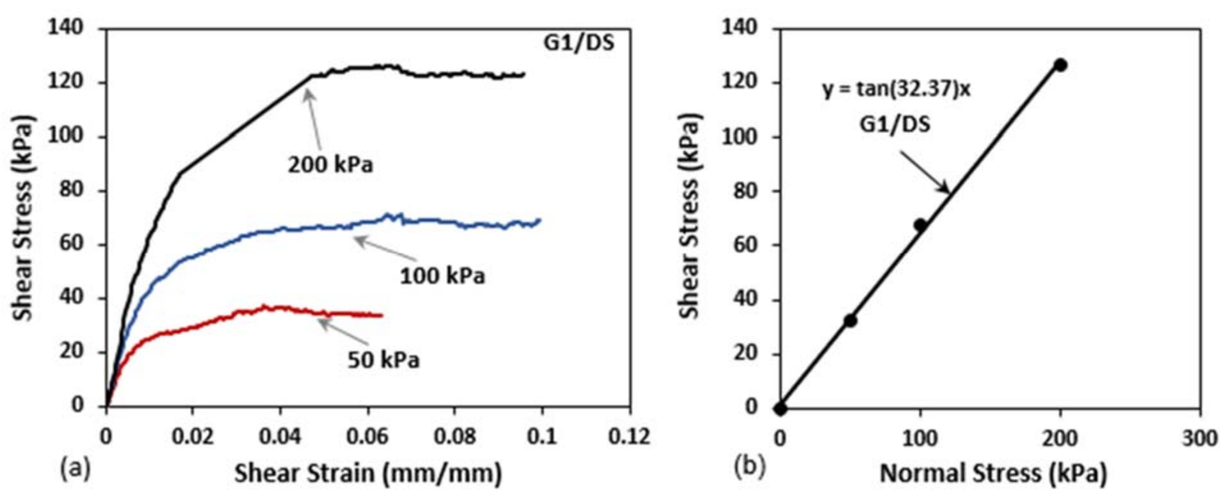

Figure 8: Direct shear test of plain GFRP (G1) with dense sand (DS): (a) shear stress vs. shear strain; and (b) shear stress vs. normal stress

As shown in Figure 9, when the GFRP specimen with rough surface G2 sheared with the dense sand, the interface friction angle δ increased to 36.81 degree (Neglect adhesion). The rough surface of GFRP specimen G2 indicated higher interface friction angle with dense sand compared with the smooth specimen G1.

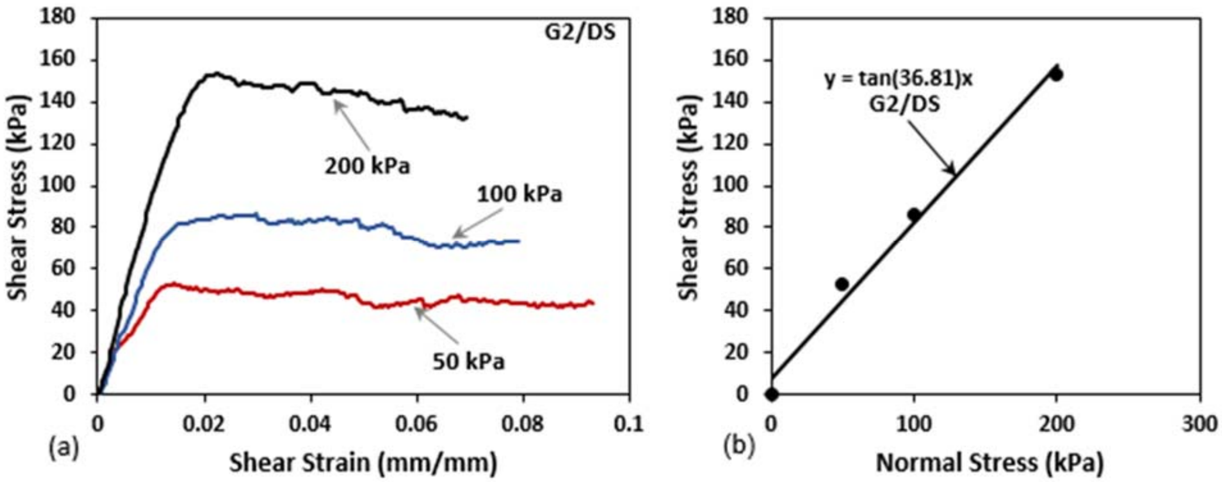

Figure 9: Direct shear test of plain GFRP (G2) with dense sand (DS): (a) shear stress vs. shear strain; and (b) shear stress vs. normal stress

3.2.2 GFRP/Silty Sand

As shown in Figure 6, the silty sand used had an internal friction angle, Φ, of 42.72 degree in the dense state with cohesion value of 19.02 kPa. As shown in Figure 10, when the GFRP specimen with smooth surface G1 sheared with the dense silty sand, the interface friction angle, δ, was 35.96 degree. The adhesion Ca for G1 with the dense silty sand was only 4.60 kPa.

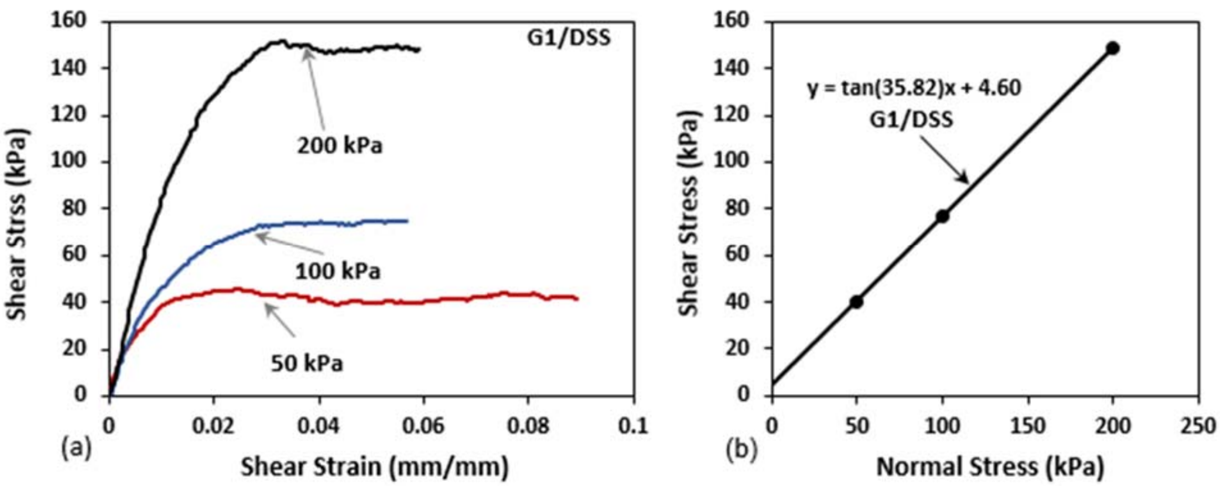

Figure 10: Direct shear test of plain GFRP (G1) with dense silty sand (DSS): (a) shear stress vs. shear strain; and (b) shear stress vs. normal stress

As shown in Figure 11, when the GFRP specimen with rough surface G2 sheared with the dense silty sand perpendicular to the fiber direction, the interface friction angle δ increased to 37.11 degree with adhesion value 13.01 kPa. The interface friction angle and the adhesion were higher for GFRP with rough surface compared to the GFRP specimen with the smooth surface when it was sheared with dense silty sand.

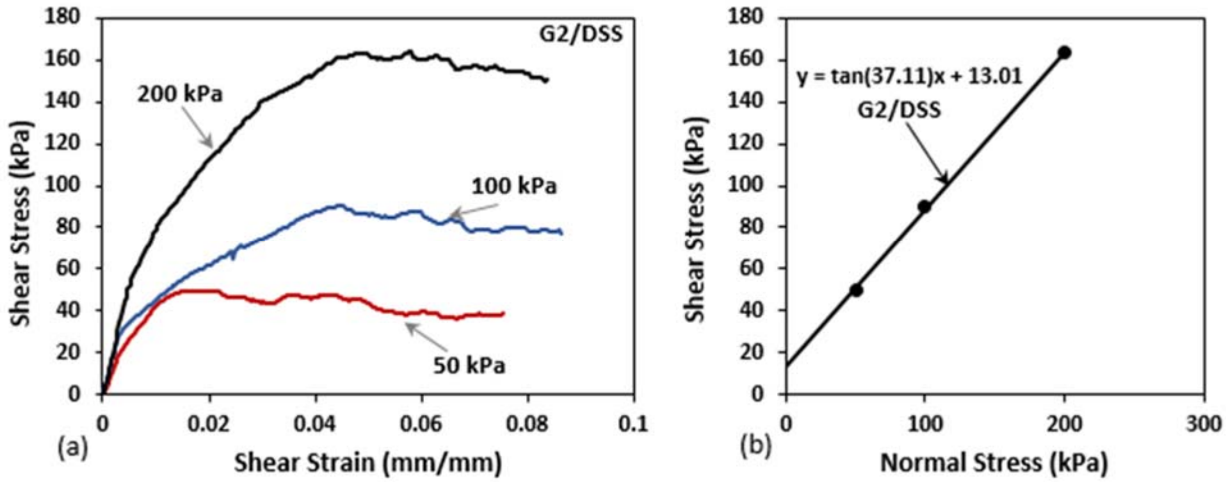

Figure 11: Direct shear test of plain GFRP (G2) with dense silty sand (DSS): (a) shear stress vs. shear strain; and (b) shear stress vs. normal stress

3.2.3 GFRP/Sandy Lean Clay

As shown in Figure 7, the sandy lean clay (SLC) used had an internal friction angle, Φ, of 22.5 degree with cohesion value of 15.07 kPa. As shown in Figure 12, when the GFRP specimen with smooth surface G1 sheared with the sandy lean clay the interface friction angle, δ, was 12.41 degree. The adhesion Ca for G1/SLC was 16.87 kPa.

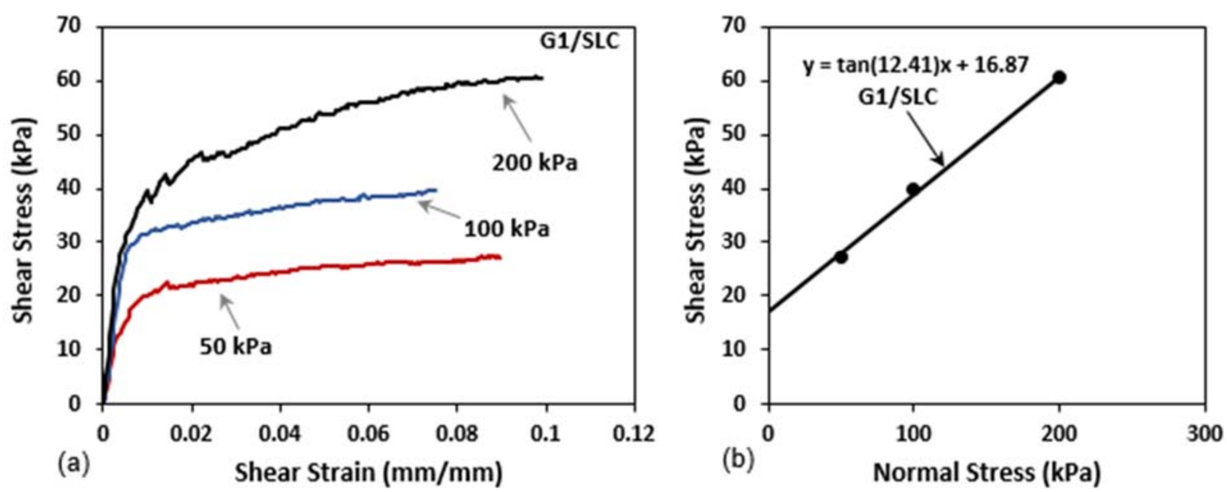

Figure 12: Direct shear test of sand coated GFRP (G1) with sandy lean clay (SLC): (a) shear stress vs. shear strain; and (b) shear stress vs. normal stress

When the GFRP specimen with rough surface G2 sheared with SLC, the interface friction angle δ increased to 15.74 degree with adhesion value Ca 22.15 kPa as shown in figure 13.

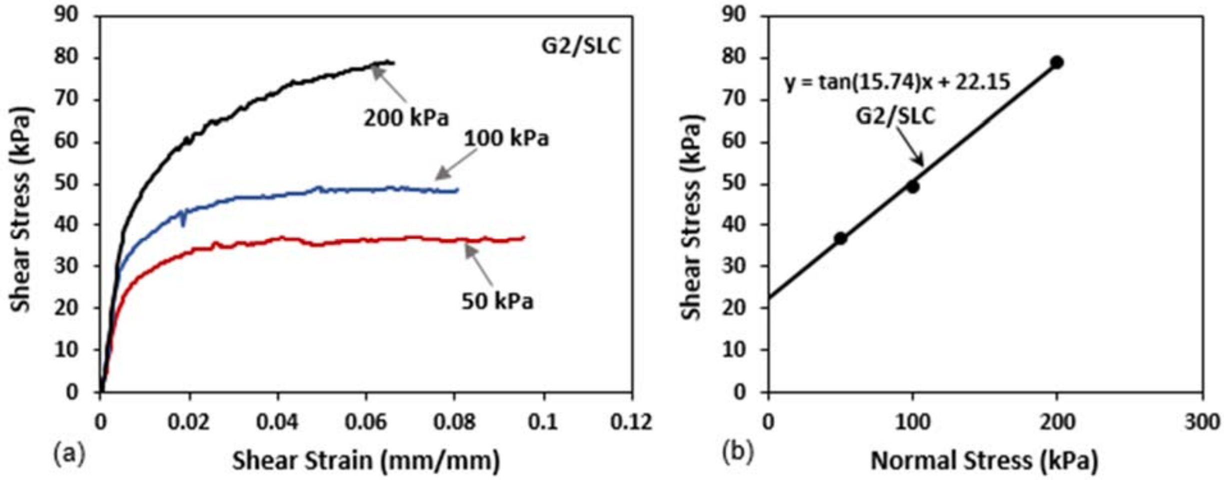

Figure 13: Direct shear test of sand coated GFRP (G2) with sandy lean clay (SLC): (a) shear stress vs. shear strain; and (b) shear stress vs. normal stress

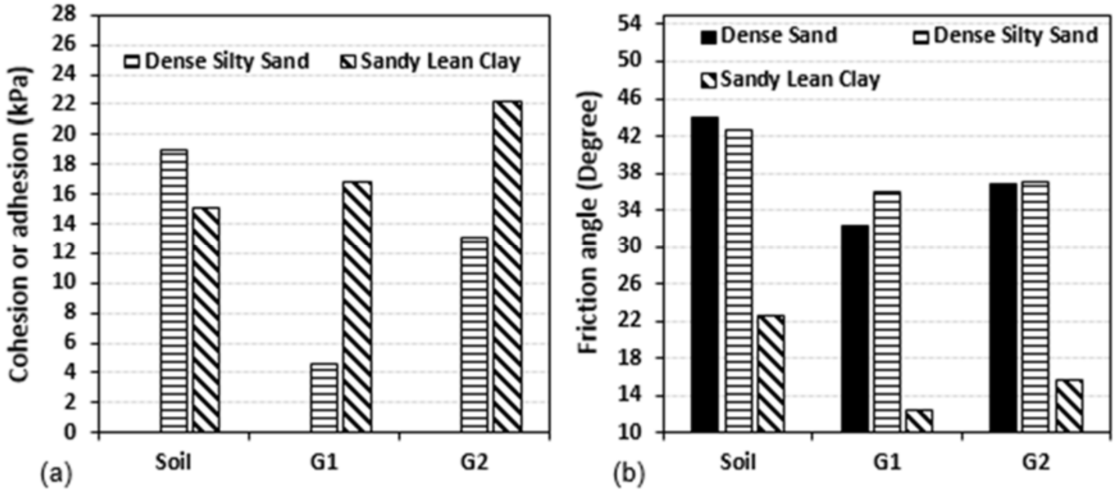

Figure 14: Comparison of test results: (a) cohesion or adhesion with sandy soils; and (b) Friction angle with sandy soils

4 CONCLUSIONS

This experimental study was conducted to investigate the interface properties between sand GFRP sheets and sandy soils using direct shear tests. Two GFRP sheets with different surface roughness (smooth, and rough) were studied. Three types of soil (sand, silty sand, and sandy lean clay) were placed on the top of two GFRP specimens inside a direct shear box under three different normal stresses (50, 100, and 200 kPa). The following conclusions can be drawn from the results of this study:

- The smooth GFRP specimen (G1) when sheared against dense sand and dense silty sand, it indicated interface friction angle ratios with the internal friction angle of the soil (δ/Φ) of 0.73 and 0.83 respectively, with (tanδ/tanΦ) ratios of 0.64, and 0.78.
- The rough GFRP specimen (G2) when sheared against dense sand and dense silty sand, it indicated interface friction angle ratios with the internal friction angle of the soil (δ/Φ) of 0.83 and 0.86 respectively, with (tanδ/tanΦ) ratios 0.77, and 0.81.

- The smooth GFRP specimen (G1) when sheared against sandy lean clay, it indicated interface friction angle ratio with the internal friction angle of the soil (δ/Φ) of only 0.55, with (tanδ/tanΦ) ratio 0.53.
- The rough GFRP specimen (G2) when sheared against sandy lean clay, it indicated interface friction angle ratio with the internal friction angle of the soil (δ/Φ) of 0.7, with (tanδ/tanΦ) ratio 0.68.

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References

Aksoy, H. S. Gör, M. and İnal, E. 2016. A New Design Chart for Estimating Friction Angle Between Soil and Pile Materials. *Journal of Geomechanics and Engineering,* **10**(3): 315-324.

ASTM, C.1984. Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates.

ASTM, D-18 on Soil and Rock. 2011. Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System).

ASTM, D. 3080-90. 1994. Standard Test Method for Direct Shear Test of Soils Under Consolidated Drained Conditions. Annual Book of ASTM Standards, **4**: 290-5.

ASTM, D. 698-07. 2012. Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort.

Frost, J. D. and Han, J. 1999. Behavior of Interfaces Between Fiber-reinforced Polymers and Sands. *Journal of Geotechnical and Geoenvironmental Engineering,* **125**(8): 633-640.

Giraldo, J. and Rayhani, M. T. 2013. Influence of Fiber-reinforced Polymers on Pile–Soil Interface Strength in Clays. *Journal of Advances in Civil Engineering Materials,* **2**(1): 534-550.

Iskander, M. G. and Hassan, M. 1998. State of The Practice Review in FRP Composite Piling. *Journal of Composites for Construction,* **2**(3): 116-120.

Pando, M. A. 2003. A Laboratory and Field Study of Composite Piles for Bridge Substructures. PhD Thesis. Virginia Tech, Virginia Polytechnic Institute and State University, Virginia, VA, USA.

Potyondy, J. G. 1961. Skin Friction Between Various Soils and Construction Materials. *Journal of Geotechnique*, **11**(4): 339-353.

Sakr, M. El Naggar, M. H. and Nehdi, M. 2004. Novel Toe Driving for Thin-Walled Piles and Performance of Fiberglass-reinforced Polymer (FRP) Pile Segments. *Canadian geotechnical journal,* **41**(2): 313-325.

Terzaghi, K. and Peck, R. B. 1948. *Soil mechanics in engineering*. Jhon Whiley & Sons, New York, NY, USA.

Toufigh, V. Ouria, A. Desai, C. S. Javid, N. Toufigh, V. and Saadatmanesh, H. 2015. Interface Behavior Between Carbon-fiber Polymer and Sand. *Journal of Testing and Evaluation,* **44**(1): 385-390.

Vineetha, V. J. and Ganesan, K. 2014. Interface Friction Between Glass Fibre-reinforced Polymer and Gravel Soil. *Journal of Advanced Materials Research*, **984**: 707-710.