1g model tests of vertically loaded GFRP piles

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ABSTRACT
The conventional piling materials (i.e., concrete, steel, wood) are more likely to have durability problems (i.e., corrosion, degradation, deterioration) in harsh environments and offshore construction. Fiber-reinforced polymer (FRP) was found to be a potential alternative to the conventional materials due to its high corrosion resistance which results in higher durability and longer life span. In Geotechnical engineering, more data is required to adopt this new composite material in the piling industry. This paper presents a small-scale experimental study on Glass FRP (GFRP) pile under axial loads and the results were compared to a steel reference pile. The results showed a slightly better performance for GFRP pile under axial loads compared to steel pile due to its higher friction resistance in sand.

RÉSUMÉ
Les matériaux de pieu classiques (béton, acier, bois) sont plus susceptibles de poser des problèmes de durabilité (corrosion, dégradation, détérioration) dans des environnements difficiles et dans la construction en mer. Le polymère renforcé de fibres (PRF) s'est avéré être une alternative potentielle aux matériaux conventionnels en raison de sa résistance élevée à la corrosion qui se traduit par une plus grande durabilité et une plus longue durée de vie. En génie géotechnique, il faut plus de données pour adopter ce nouveau matériau composite dans l'industrie des pieux. Cet article présente une étude expérimentale à petite échelle sur un pieu de verre PRF (VPRF) soumis à des charges axiales. Les résultats ont été comparés à un pieu de référence en acier. Les résultats ont montré une performance légèrement supérieure pour le pieu VPRF sous charges axiales par rapport au pieu acier en raison de sa plus grande résistance au frottement dans le sable.

1 INTRODUCTION

By using conventional materials in pile foundations, it is more likely to have serious durability problems in-terms of corrosion, degradation, and deterioration as some soils are aggressive in nature which affects the life span of piles. FRP as a piling material is a potential alternative to overcome these durability problems in harsh soils and offshore construction (Iskander and Hassan, 1998). Generally, pile driving to moderate depths or in moderate soils such as soft to medium clays and loose to medium sands can become ideal conditions for the use of hollow FRP piles without jeopardizing their structural integrity. FRP composites are corrosion resistant, which increases the life span of the pile foundation. More research and data on the behaviour of FRP as a piling material are required to adopt this new material in foundation design and construction. Many researchers are trying to characterize the interface friction behaviour of GFRP against the soil. The surface roughness of FRP and the magnitude of normal stresses in soil were found to be the controlling parameters in characterizing the interface friction behaviour of FRP against sand (Frost and Han, 1999). The interface friction parameters between FRP and soil can be investigated using the direct shear box. Shearing the soil perpendicularly to the fiber direction results in increasing the interface friction angle between FRP and soil (Vineetha and Ganesan, 2014). The shearing rate has less effect in determining the interface friction parameters between FRP and soil (Toufigh et al., 2015). A higher surface roughness of FRP results in a higher interface friction angle with different types of soil (Almallah et al., 2018).

A trend of using FRP in pile foundations in the past few years was due to its durability and long-life span (Guades et al., 2010). However, more results and data are necessary to understand the behaviour of FRP piles under axial loads. FRP tubes filled with concrete was found to have a similar response to pre-cast concrete piles in axial capacity in compression using pile load test (Pando et al., 2000). The pile load test results may confirm the results of interface shear tests to understand the friction behaviour of FRP piles in sand (Sakr et al., 2005). FRP piles may have suitable characteristics to act as load bearing members under axial loads (Valez and Rayhani, 2014). The lower stiffness of FRP piles leads to increase the pile head displacement under lateral loading, and pile texture and waviness were found to be the controlling parameter under pile axial loading in soft clay (Valez and Rayhani, 2017). Due to the lack of proper design guidelines, FRP piles under axial loads require more experimental results in order to understand its behaviour under axial loads. For that reason, this study was conducted on a small scale GFRP pile subjected to axial loads in dense sand, and the results were compared to the results of steel reference pile under the same experimental conditions.

2 EXPERIMENTAL PROGRAM

2.1 Specimen Layout

GFRP pile with total length (L) 760 mm, and an outer diameter (D) 54 mm was prepared. The GFRP composite pile was fabricated out of four layers of unidirectional fibreglass fabric and epoxy resin. The results of the GFRP pile were compared to a steel reference pile with total length of 760 mm, and an outer pile diameter of 50 mm. Table 1. presents the tested piles identified with the specimen identification.

Table 1. Specimen layout

Pile ID	L (mm)	D (mm)	L/D
GFRP	760	54	14.1
Steel	760	50	15.2

2.2 Material Properties

2.2.1 GFRP

The weight of the GFRP composite was 3438.5 g/m^2. The GFRP pile was bonded by epoxy resin (West System 105), and a hardener (West System 206).

The dry fiber had a tensile strength more than 1500 MPa, areal fabric weight 450 g/m^2, elongation is 2.8%, and E-modulus is more than 72 GPa as reported by the manufacturer (Haining Anjie Composite Material Co., Zhejiang, China).

2.2.2 Sand

The soil used in this study was poorly graded sand according to sieve analysis (ASTM C136-14, 2014) and USCS as shown in Figure 2. This soil had a maximum dry density of 1746 kg/m^3, and optimum water content of 14.5% according to laboratory compaction test (ASTM D698-12, 2012) as shown in Figure 2.

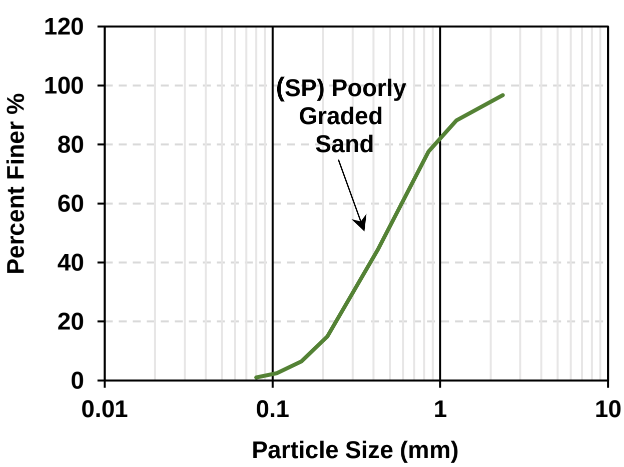

Figure 1. Gradation curve of poorly graded sand

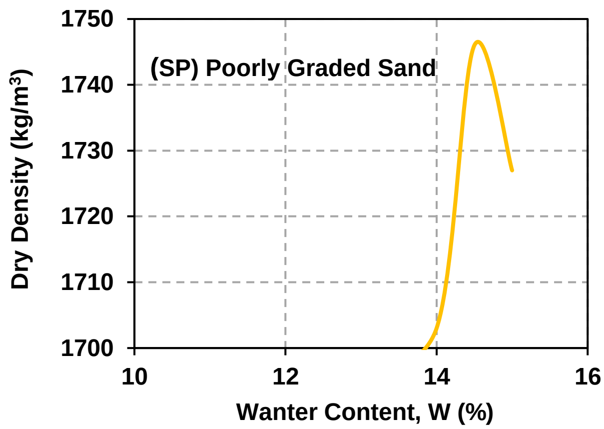

Figure 2. Maximum dry density and optimum water content

2.2.3 Steel

The Steel used in this study had an ultimate tensile strength of 505 MPa, yield tensile strength of 215 MPa, shear modulus of 86 GPa, and modulus of elasticity (E) of 195 GPa.

2.2.4 Aluminum

The Aluminum cone used in this study had an ultimate tensile strength of 290 MPa, yield tensile strength of 240 MPa, shear modulus of 25 GPa, and modulus of elasticity (E) of 69 GPa.

2.3 Specimen Fabrication

A GFRP pile with total length (L) 820 mm, and an outer diameter (D) of 54 mm was initially fabricated. The pile consists of four layers of glass fabrics. The glass fibre layers of GFRP pile were fabricated with the following fibre directions and order [90/0/0/90]. The 90 degrees layers were hoop with 50 mm overlap (820 x 210 mm) each. The 0 degrees layers were axial with no overlap (820 mm x 160 mm) each.

A plastic pipe with total length of 1840 mm and an outer diameter of 45 mm was wrapped with 900 mm length of plastic sheet. The surface of the plastic sheet was brushed gently with epoxy resin plus hardener. The first layer of fibreglass (90 degrees hoop) was wrapped tightly around the plastic pipe. During the process of wrapping, 68.23 g of epoxy resin plus hardener were applied on the glass fibre layer until wrapping is completed, as shown in Figure 3.

Figure 3. Pile fabrication

The next three layers of glass fibres were wrapped with the same method and the same amount of epoxy resin plus hardener added in between. After wrapping four layers of GFRP is done, wax paper was used around the pile for curing. After curing was done, 50 mm at both pile ends were cut by a blade saw to have a pile in total length of 720 mm and an outer diameter of 54 mm.

Moreover, a steel pile was prepared with 720 mm in length, and 50 mm outer diameter to be tested similarly to the GFRP pile. At the end of both piles, a 40 mm in length of the aluminum cone were added to the tip of both piles. Each pile was instrumented with two strain gauges near the pile toe to calculate how much load was mobilized through the bearing tip, and how much load was mobilized along the pile shaft. Figure 4 shows the GFRP pile used, and Figure 5 shows the steel pile investigated in this study.

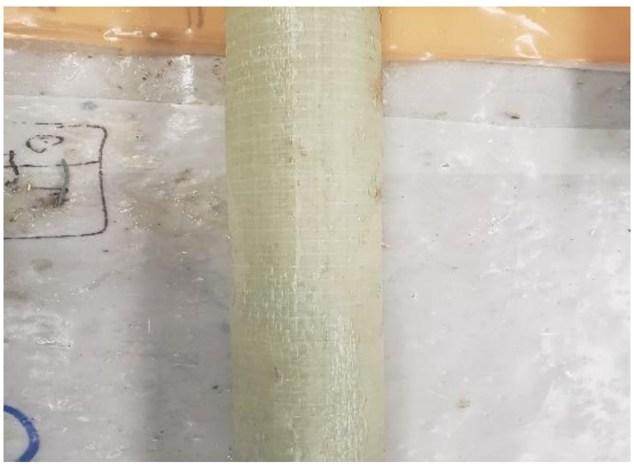

Figure 4. GFRP pile

Figure 5. Steel pile

2.4 Test Procedure

Both prepared piles were tested under axial compression load separately using a small-scale piling system developed at Dalhousie university laboratory. This system contains a soil box filled with around 1m^3 of poorly graded masonry sand with hydraulic jack for axial loading attached to a steel frame, as shown in Figure 6. A pile load test was done to check the pile head settlement of 10% of pile diameter 50 mm (5 mm settlement) as suggested by De Nicola and Randolph (1999) and the ultimate pile capacity under axial loads. The pile load test was done up-to almost 30 mm settlement of pile head then the test was stopped with a loading rate of 0.5 mm/min. After the test is done, load vs settlement curve was plotted with the values of ultimate pile load, friction load, and bearing load for both piles.

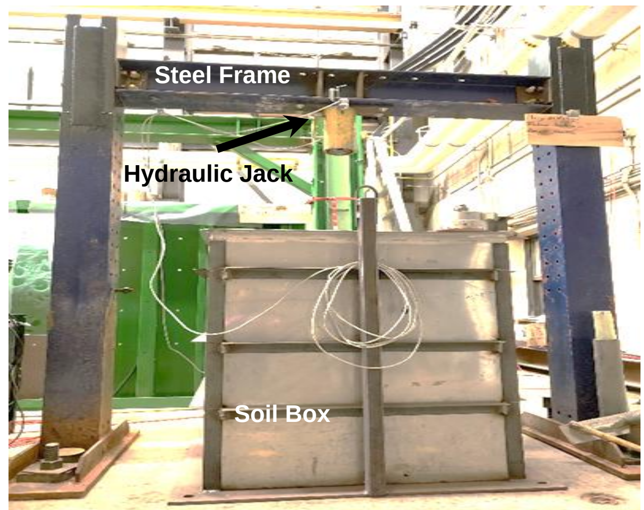

Figure 6. Pile load test set up

3 RESULTS AND DISCUSSION

3.1 Pile Load Test Results

The results of the pile load tests for both GFRP pile and steel pile are shown in Figure 7. The bearing on both piles has almost the same value as they share the same cone tip. The value of the friction load for GFRP pile is slightly higher than that of steel pile due to the rougher surface of GFRP, which resulted in a higher total ultimate load.

In piles literature, various methods are used to estimate the pile friction capacity (ultimate bearing and ultimate friction). One of the common methods used for estimation is Brinch and Hansen method (1963). The following section defines and presents the estimated results of ultimate capacities for both piles according to Brinch and Hansen method.

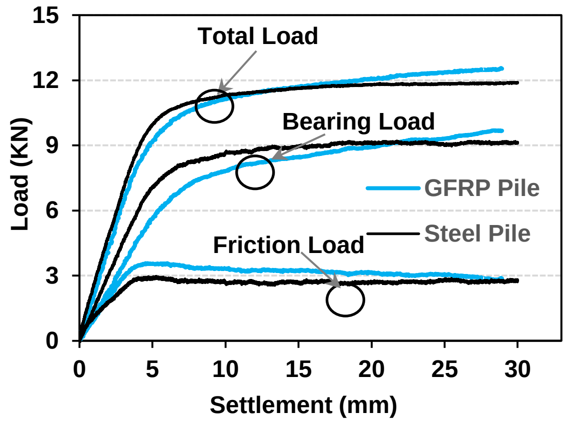

Figure 7. Pile load test results for GFRP and steel pile

3.2 Brinch and Hansen Method (1963)

This method is used to determine the ultimate capacity of a pile (Q_{ult} in KN) from the total load versus settlement graph (i.e. Figure 7) for pile load test by finding a load on the curve which corresponds to a settlement value two times the settlement of $0.9Q_{ult}$. The ultimate bearing capacity and the ultimate friction capacity is taken from the corresponding values of the settlement at Q_{ult}. The values of the ultimate capacities of GFRP and steel piles according to Brinch and Hansen (1963) are presented in Table 2, and Figure 8.

Table 2. Pile ultimate capacities (Brinch and Hansen)

Pile Type	Ultimate capacity Q_{ult} (KN)	Friction capacity Q_s (KN)	Bearing capacity Q_b (KN)
GFRP	11.9	3.2	8.7
Steel	10.7	2.7	8

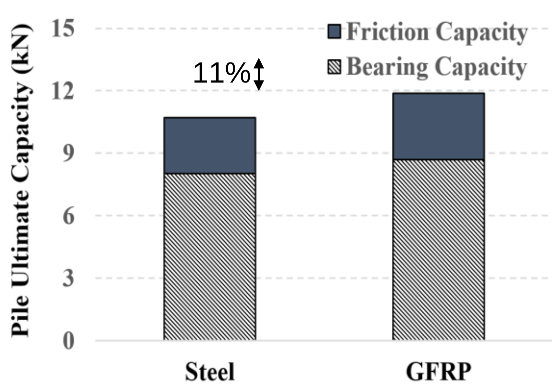

Figure 8. Pile ultimate capacities (Brinch and Hansen)

As per Brinch and Hansen (1963), the GFRP pile has a higher ultimate capacity than that of steel pile with a percentage gain of 11.2%. This is due to the higher value of friction resistance of GFRP surface against sand compared to the steel pile surface with percentage gain 18.5% in the friction component between the two piles.

4 CONCLUSION

Axial Pile Load tests were performed on GFRP and steel piles to compare their ultimate capacities as GFRP composite is a potential alternative to steel piles due to its advantages in overcoming durability problems caused by corrosion and deterioration of steel. The experimental testing was done using a small-scale piling system developed at Dalhousie university consist of steel frame and soil box filled with around 1 m^3 dense sand. The results were analyzed according to Brinch and Hansen method to estimate the ultimate capacities for both piles. The experimental results showed a higher ultimate capacity for GFRP pile compared to steel pile with a percentage gain of 11% due to the higher friction resistance between GFRP surface and sand. These results confirm the findings in the literature, which makes the usages of GFRP composite in pile industry favourable in comparison with conventional steel pile due to its higher durability and longer life span.

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