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Experimental Study on Interface Behaviour between Soil and FRP Composite

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Abstract:- Piles are generally used to transmit vertical loads to the ground. A new trend in foundation is to use a fiber reinforced polymer composite materials as a substitute in piling system. This experimental study presents the performance of FRP wrapping and unconfined piles subjected to vertical loads. Three RC piles with various surfaces were cast with the same reinforcement details to study the behavior of RC piles with fiber reinforced polymers under vertical loading conditions. The parameters that are varied in this investigation are wrapping materials (which include Glass, carbon, Aramid, basalt, polypropylene fiber reinforced polymers) and orientation of fiber (along the length and circumference).

***Keywords**:- Fiber Reinforced polymer, warping material, soil characteristic, direct shear test, pile load test.*

I. INTRODUCTION

In structure, foundation is important role in safety and satisfactory performance of the structure as it transmits the loads from structure to ground. The foundation in various type of soils have to be designed to suit the soil conditions of particular type. Piles are structural element in a foundation which have the function of transferring load from the superstructure through weak compressible strata or through water on to stiffer and less compressible soils or on to rock. Pile foundation are often necessary to support the structure with shallow foundations. A vertical load in designing pile and are often more complicated. Concrete, steel, and timber are the traditional materials for pilling that exhibit many problems when used in corrosive soils and harsh environments. Performance disadvantages of these materials are deterioration of timber, corrosion of steel and degradation of concrete.

Piles subjected to horizontal load due to wind pressure, water pressure, earth pressure, earth quakes, and wave and current forces on off shore structures are termed as vertically loaded piles. The performance of pile foundations subjected to vertical load is of considerable importance in geotechnical practice. Vertical loads are in the order of 10-15% of the vertical loads in the case of onshore structures and in the case of coastal and offshore structures, these lateral loads can exceed 30% of the vertical loads.

II. FIBER REINFORCED POLYMER

Nowadays Fibre Reinforced polymer (FRP) jacketing has become popular to strengthening and retrofit of existing piles. The lightweight, high strength and corrosion resistance of FRP's made them particularly suitable for repair. A considerable amount of research has been directed recently towards understanding and promoting the use of externally applied FRP for the retrofit of pile foundation.

The two major components of an FRP composite material are resin and reinforcement. A cured thermosetting resin without any reinforcement is glass like in nature and appearance, but often very brittle.by adding a reinforcing fiber such as carbon fiber, glass fiber. Aluminum, steel and other metals have isotropic material. Fiber reinforced polymer is an extremely versatile material.

- Applications of FRP Composites

In new construction, repair and rehabilitation applications are done with the help of composites. FRPs have been used in the field of civil engineering for the design of new construction. Bridges and columns are built completely by FRP composites have demonstrated exceptional durability and effective resistance to the effects of environmental exposure.

III. INTERFACE BEHAVIOR BETWEEN SOIL AND FRP COMPOSITES

The interface strength between frp wrapped concrete specimens and soil is discussed since load transfer between sub-structures and soils takes place at their interfaces. Friction between soil and foundation materials is major significance to make a good estimation of frictional resistance between soil and substructures. Soil-structure interaction studies have proven to be an effective tool for the analysis and design of geotechnical structures.

The behavior of the FRP-soil interfaces was also compared with the concrete-soil interfaces. The parameters varied in this investigation were wrapping materials (which includes Glass, carbon, Aramid, basalt and polypropylene fiber reinforced polymers), orientation of fiber (parallel and perpendicular to shear), surface roughness (smooth, medium and rough).

➢ Soil Characteristics

Index and engineering properties of soil were determined by experiment to the interface frictional resistance between FRP wrapped steel and soil. Two different soils were selected.

Soil property	Poorly Graded Sandy Soil
Effective size, D_{10} (mm)	0.27
Coefficient of uniformity, C_u	3.87
Coefficient of curvature, C_c	1.19
Classification	SP
Specific gravity, G_s	2.65
Maximum γ_d (kN/m^3)	17.12
Minimum γ_d (kN/m^3)	15.31
Test γ_d (kN/m^3)	16.43

Table 1:- properties of sandy soil

% Passing	Atterberg Limits			Dry unit weight (kN/m^3)				
4.75 mm	425 µm	75 µm	LL (%)	PL (%)	Ip (%)	γ_d (max)	γ_d (min)	γ_d (test)
98.4	60.2	27.4	34	23	11	17.8	17.2	16.2

Table 2:- Index and Engineering properties of Sandy Clay

➢ Testing Methodology

In this study, the shear test apparatus with shear box size of 6 cm x 6 cm x 6 cm and the concrete specimens of size 6 cm x 6 cm x 1.4 cm. The concrete specimens were prepared by sand, cement, and water mixing gradually and subsequently filling the prepared boxes with concrete. The cube was cured in water. After curing some specimens were tested. Without any FRP wrapping and remaining specimens were wrapped with CFRP, GFRP, PFRP, AFRP and BFRP sheets.

Direct shear test was conducted. The specimens were placed in the lower half of the direct shear box and the upper half of the shear box was filled with soils. Shear force is applied to the lower box through the geared jack, the movement of the lower part of the box is transmitted through the specimen to the upper part of the box. The deformation in proving ring indicates the shear force.

Normal stress(N/mm^2)	Shear stress (N/mm^2)	
	Sandy soil	Sandy clay
0	0	0.061
0.05	0.03	0.1
0.10	0.065	0.145
0.15	0.95	0.185
0.20	0.125	0.225

Table 3:- Effect of shear stress against normal stress Normal stress(N/mm²)

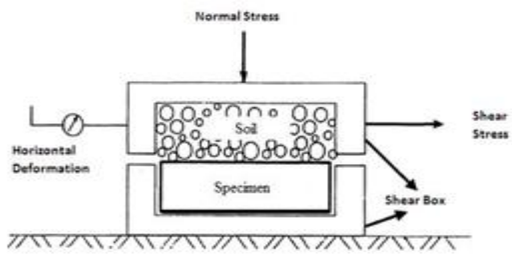

Fig 1:- Effect of shear stress against normal stress

IV. MATERIAL PROPERTIES

➢ *Concrete*

Characteristic compressive vertical load carrying capacity of concrete was 30Mpa.

➢ *Fiber Reinforced Polymer (FRP)*

Glass, carbon, Aramid, basalt, polypropylene fiber reinforced polymers were used in the study.

Properties	Carbon Fiber	Glass fiber	Basalt fiber	Aramid fiber	Polypropylene fiber
Mass of fiber (g/m^2)	200	920	330	227.5	910
Fiber thickness (mm)	0.3	0.90	0.6	0.33	0.30
Nominal thickness(mm)	0.5	1.2	0.85.	0.55	0.5
Fiber tensile vertical load	3500	3400	4840	3900	3200
Tensile modulu N/mm2	285000	73000	86000	131000	100000

Table 4:- Properties of FRP Materials

Density	1.14 g/cc
Pot life	25 minutes @ 27^0 C
Curing	7 days

Table 5:- Properties of Nitowrap 30 primer

➢ *Saturant Coating*

The Nitowrap 410 saturant used in this work was made of two parts, resin and hardener. The components were thoroughly hand mixed for 3 minutes before applied

Color	Pale yellow to amber
Application temperature	15^0C - 40^0C
Viscosity	Thixotropic
Density	1.25 – 1.28 g/cc
Pot life	2 hours @ 30^0 C
Curing	5 days @ 30^0 C

Table 6:- Properties of Nitowrap 410 saturant

➢ *Experimental Set Up*

Piles are commonly driven by a hammer supported by a crane known as pile driver. During pile driving, caps are placed on the top of the pile to receive the blows of the hammer and to prevent damage to the head of the pile.

Types of Confinement	Load corresponding to 5 mm settlement at GL (N)	Load corresponding to 12mm settlement at GL (N)	Safe load (N)
Unidirectional CFRP confinedpile (UniCFRP-L)	360.6256	677.9691	338.9845
Unidirectional CFRP confinedpile (Uni-CFR-C)	362.1852	679.2444	339.6222
Unidirectional BFRP confinedpile (UniBFRP-L)	374.9382	708.6744	354.3372
Unidirectional BFRP confinedpile (Uni-BFRP-C)	377.4888	709.8516	354.9280
Unidirectional GFRP confined (UniGFRP-L)	388.5741	765.2781	382.6390
Unidirectional GFRP confined (Uni-GFRP-C)	391.5147	744.8733	384.4366
Unconfined pile-Medium	403.4853	761.8446	380.9223
confined with bidirectional AFRP mat (Bi-AFRP)	407.4093	771.6546	385.8273
confined with bidirectional PFRP mat (Bi-PFRP)	469.2132	889.3746	444.6873
Unconfined pile-Rough	546.2208	1053.202	527.6010

Table 7:- Safe load based on Settlement criteria (sandy soil)

Pile are driven to a resistance measured by the number of blows required for the last 1 cm of penetration. Resistance of 3 to 5 blows per cm are specified for concrete pile. Finally set penetration per blow taken as average penetration per blow for the last 5 blows of a drop hammer, or 20 blows of a steam hammer.

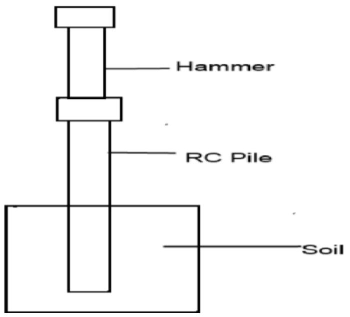

Fig 2:- Schematic diagram

➢ *PILE LOAD TEST*

The pile load test is carried out in sandy soil and sandy clay soil with different pile surface roughness. The roughness is introduced by pasting FRP wrapping .The uniform density of tank (tank size 0.5m x0.5m x1m) is maintained by using sandy soil. The density was varied by the free fall of sand particles. The pile test can be performed on a working pile which forms the foundations of the structure. Test load is applied with the help of place over rigid over circular or square plate which the helps of calibrated of pile projecting above ground level. The load is applied equally in one –fifth of the specimen.

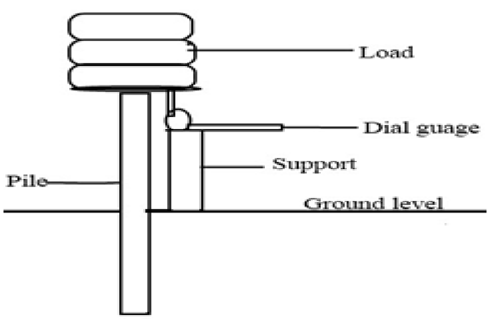

Fig 3:- PILE LOAD TEST

V. RESULTS AND DISCUSSION

➢ *Results*

Surface roughness is the factors that influence the shear strength parameters. Absolute roughness (Ra) is referred as interface friction between two different materials. It calculate the surface roughness of a material. This roughness is expressed in the terms of length as the absolute roughness of the material. The surface roughness of the specimens was determined.

Type of interaction	Angle of internal /interface friction (degree)	
	sandy clay	Sandy soil
Soil-Soil	32.12	39.68
Soil – Smooth surface concrete	32.9	40.25
Soil – Medium surface concrete	33.57	41.09
Soil – Rough surface concrete	42.08	49.23
Soil – Bi- AFRP wrapped specimen	33.57	49.11
Soil – Bi- PFRP wrapped specimen	36.69	44.05
Soil – 0° CFRP wrapped specimen	31.71	39.21
Soil – 90° CFRP wrapped specimen	31.79	39.32
Soil – 0° BFRP wrapped specimen	32.33	39.73
Soil – 90° BFRP wrapped specimen	32.45	39.86
Soil – 0° GFRP wrapped specimen	32.58	39.99

Table 8:- Interface friction angle between soil and FRP composite

The results obtained for the sandy clay soil and sandy soil against FRP composites under different normal stresses were analyzed to obtain the interface friction angle. Interface friction angle between FRP wrapped concrete specimens with two types of soils (sandy clay soil and sandy soil) was determined by conducting direct shear test. The behavior of FRP-soil interface was also compared with concrete-soil interface.

➢ *Discussion*

• *Direct shear test*

The experimental results show that soil gradation, surface roughness of specimens and normal stress significantly changes the interface friction angle. The maximum shear resistance was obtained for fibres with perpendicular (90o) orientation against shear loading.

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Types of Confinement	Load corresponding to 5 mm	Load corresponding to 12 mm	Safe load (N)
Unidirectional CFRP confined (Uni-CFRP-L)	1374.381	2709.522	1354.761
Unidirectional CFRP confined (UniCFRP-C)	1378.894	2718.547	1359.2734
Unidirectional BFRP confined (Uni-BFRP-L)	1387.723	2736.205	1368.1025
Unidirectional BFRP confined (UniBFRP-C)	1396.159	2751.018	1375.5090
Unidirectional GFRP confined (Uni-GFRP-L)	1398.121	2757.002	1378.5010
Unidirectional GFRP confined (UniGFRP-C)	1403.713	2764.262	1382.1310
Unconfined pile-Medium	1423.235	2794.420	1397.2100
Pile confined with bidirectional AFRP mat (Bi-AFRP)	1431.82	2816.647	1408.3235
Pile confined with bidirectional PFRP mat (Bi-PFRP)	1480.82	2912.589	1456.2945
Unconfined pile-Rough	1552.334	3047.771	1523.8855

Table 9:- Safe load based on Settlement criteria (sandy clay)

Normal stress(N/mm^2)	Shear stress (N/mm^2)	
	Sandy soil	Sandy clay
0	0	0.061
0.05	0.03	0.1
0.10	0.065	0.145
0.15	0.95	0.185
0.20	0.125	0.225

Table 10:- Effect of shear stress against normal stress

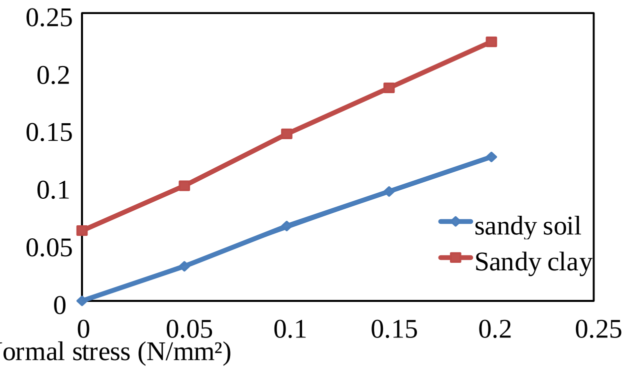

Fig 4:- Effect of shear stress against normal stress

Direct shear tests were conducted to investigate the interface friction angle between FRP wrapped and various surface roughness of concrete specimens with two types of soils.

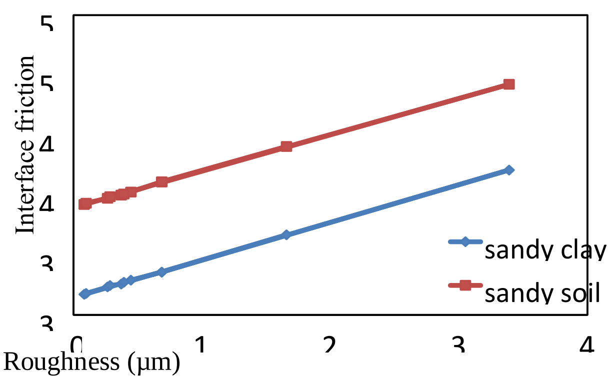

Fig 5:- Effect of roughness on interface friction Confined and unconfined RC piles subjected to vertical loads (sandy soil)

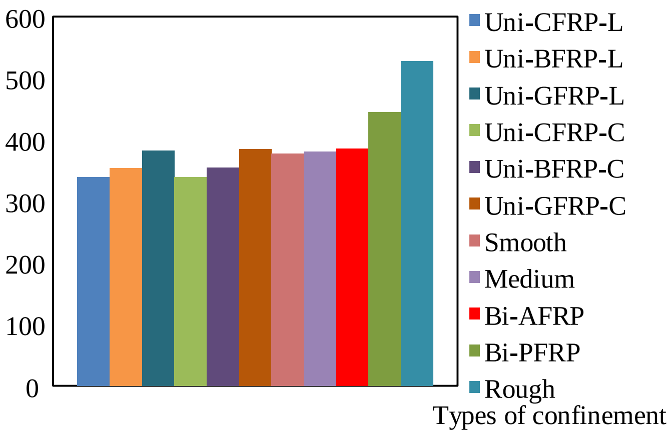

Fig 6:- Safe load based on Settlement criteria (sandy soil)

Confined and unconfined RC piles subjected to vertical loads (sandy clay)

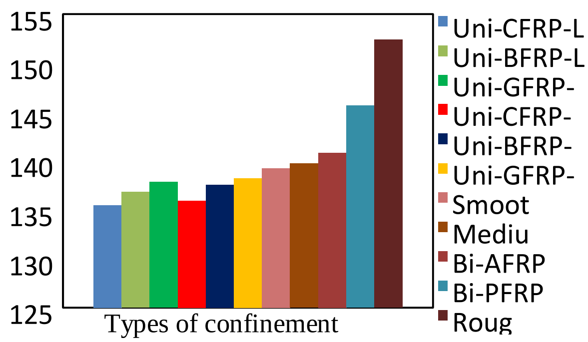

Fig 7:- Safe load based on Settlement criteria (sandy clay)

VI. CONCLUSION

- Examining the data obtained from direct shear test, it could be seen that in general, there was an increase in the angle of interface friction with rough surface concrete specimen. Whereas, there was a decrease in the case of other surface concrete specimens and different FRP wrapping specimen.
- Angle of interface friction is slightly higher when the direction of shear force is perpendicular to the direction of fibers.
- The results show the soil gradation and surface roughness of specimens significantly changes the interface friction angle.
- Experimental results indicate that Rough surface confined pile with more load carrying capacity and confined piles shows less.
- FRP confined piles with fibers along the circumference of the piles have 1% more vertical load carrying capacity than the fibers along the length.

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