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Behaviour of Basalt Fibre Reinforced Polymer (BFRP) Composites Confined RCC Piles Skin Friction in Cohesion less Soil

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Abstract: This article focuses on skin friction developed in Basalt Fibre Reinforced Polymer (BFRP) composites confined RCC piles in cohesion less soil. In cohesion less soil 98% of the total load is carried by the friction developed between the soil and pile wall. An attempt is made to find the enhancement in skin friction in BFRP confined RCC piles in this experiment. 12 nos. of RCC piles of size 150 mm diameter and 2250 mm height are cast and skin friction behaviour of conventional, BFRP double wrapped pile elements are found. Conventional and BFRP confined in 0°, 45° and 90° orientation pile elements are tested with constant embedment ratio. It is observed that piles with horizontal confinement showed good resistance against tension than conventional, BFRP 45° and 90° confined elements. The increase in resistance is due to increase in surface roughness in the direction perpendicular to the direction of pull. Thus BFRP confined in 0° may be used effectively in tension piles.

Keywords: *angle friction, BFRP, cohesion less soil, double wrapped piles*

1. Introduction

The skin friction is very important one for pile foundations and geotechnical structures designing. Normally, skin friction is not consider for end bearing piles designing but the end bearing piles sometimes failure and affected due to uplift pressures, tension under overturning moments, wind & flood pressure, expansion of soils etc.,. In these conditions, skin friction is essential for end bearing RCC piles to resist the uplift pressure damage. Generally, the friction is based on the roughness of the construction materials, size and shape of the structures; soil types, compactions, consolidation, grains, density, porosity, moisture content, particles size, bearing capacity, rate of shearing etc. In this experiment the end bearing RCC piles 12 nos. were cast, tested and investigated the interface friction between BFRP wrapping (double) and cohesion less soil like sand.

Found the interface behaviour between soil and FRP composites. Studied the friction behaviour on smooth, medium & rough surface concrete specimens and wrapped by GFRP and CFRP composites with 0°, 45° and 90° orientations wrapped specimens. Rough surface concrete specimens were attained more strength than others [1]. Explained in postdoctoral thesis, compressive ultimate pile resistance of the model FRP piles was up to 40% higher than the control steel pile. Similarly skin frictional resistance of the FRP piles was measured to be up to 30% higher with both CFRP and GFRP. Compressive ultimate pile resistance of the model FRP piles was up to 40% higher than the control steel pile [2]. M/S Evercomp – Fibre Reinforced Plastic Pile Company noticed that tapering the pile results in greater passive earth pressures and skin friction [3]. Explained, the GFRP tube could be produced with roughened external surface to increase the skin friction for additional load capacity or uplift resistance [4]. Clear up the series of direct shear tests were carried out in various pile materials including steel, concrete, and grout and to investigate the influence of FRP materials on the pile–soil interface strength in soft clay. The FRP materials presented between 105 % and 119 % of the interface friction angle of steel and between 77 % and 88 % that of concrete. In addition, FRP interface adhesion was observed between 86 % and 135 % of the interface adhesion of steel and between 65 % and 75 % of the interface adhesion of concrete. Investigation into the effect of the epoxy surface finish was carried out and indicated lower frictional performance relative to the epoxy-cast specimen [5]. Noticed in his paper, Compressive ultimate pile resistance of the model FRP piles was up to 40% higher than the control steel pile. Similarly skin frictional resistance of the FRP piles was measured to be up to 30% higher with both CFRP and GFRP [6]. Evaluated the skin friction between sand and FRP materials experimentally using the interface shear test (IST). Outcome of the results indicated that the interface friction angles of the FRP composite piles depend on the values of the relative roughness parameters, such as the relative height and the relative spacing. Interface friction angles tend to increase as the relative height increases, and they tend to decrease as the relative spacing increases. Surface hardness and angularity of soil grains were also found to have important influences on the values of the interface friction angle for a relatively smooth FRP surface [7]. Explained the effect of pile embedment ratio (L/d), roughness of piles and batter angle on the pull out capacity of batter piles in sand increase in pile embedment ratio (L/d) and roughness increase the pull out capacity significantly comparing vertical pile about 10-23% of more pull out capacity was observed when the batter angle is approximately 20°. However, increment in batter angle increases the capacity of dense sand medium dense sand whereas it decreases in case of loose sand. It was also observed that circular piles offered high resistance to pull out forces than square and rectangular pile [8].

2. Materials and Methods

For this experiment, 12 nos. of piles made of M_{30} grade concrete of size 150 mm diameter and 2250 mm height with reinforcement as shown in Figure 2 were cast after analyzing the ingredient tests and cube, cylinder and prism tests results [9], [10], [11] and [12]. The pile properties were tabulated in Table 1. 3 sets with 3 pile elements each for conventional & unidirectional Basalt Fibre Reinforcement polymer composite (BFRP) confinement with 0°, 45° and 90° orientation were tested. Conventional and BFRP confined pile elements embedded 1500mm in the test tank of size 1.0m x 1.0m x 1.5m filled with sand. Size of tank was taken as 5 times diameter of pile so that stress distribution is well within the sand. As sand is cohesion less it is suitable for the study of skin friction. Comparison between conventional and BFRP double confined piles were made. Sand properties were tested as IS 2720- Part 3, 13 & 14 and tabulated in Table 2.

Table 1: *Properties of pile elements*

Description	Property
Diameter of pile	150 mm
Height of pile	2250 mm
Embedment Length	1500 mm
Embedment ratio	10
Main reinforcement vertically	8mm ϕ RTS rod-6nos.
Shear reinforcement	6mm ϕ RTS rod-120mm c/c spacing
% of reinforcement	1.706
Grade of concrete	M30
BFRP wrapping thickness in two layers	2.04 mm
Basalt fibre orientation – each 3 element	Warp comes along the circumference 0°Direction
	Warp comes inclined 45° direction
	Warp comes along the vertical direction

Table 2: *Engineering properties of cohesion less soil (sand)*

Description of non-cohesive soil (sand)		Sand Property
Grain size and analysis	Effective size, D_{10} (mm)	0.25
	D_{30} (mm)	0.38
	D_{60} (mm)	0.62
	Co-efficient of uniformity, C_u	2.48
	Co-efficient of curvature, C_c	0.93
	Classification	SP
Dry unit weight, γ_d in kN/m^3	Maximum unit wt.	16.86
	Minimum unit wt.	15.23
	Test unit wt.	16.05
Specific gravity, G_s		2.65
Angle of internal friction ϕ		31°

Pile elements were embedded to a length of 1500mm as shown in Figure 3. On exposed surface of the elements the mechanical strain gauge pallets were fixed to measure the deformation due to tension or pulling and deflection gauges were fixed at top to measure the upward displacements. Piles were subjected to upward pull or tension upto failure. For every 2 kN load series increment, upward displacements were observed and recorded by using strain gauges and deflection gauges.

Observed readings were analyzed, tabulated, plotted and comparison between the conventional and BFRP confined elements were made. In Table 3 the minimum value of tensile force of the three trials were given.

Table 3: *Ultimate pull out capacity*

Element name	Strength due to friction in kN
Conventional Pile elements (Medium smooth surface)	2.5 kN
BFRP double confined in 0^{o} orientation pile elements	3.05 kN
BFRP double confined in 45^{o} orientation pile elements	2.80 kN
BFRP double confined in 90^{o} orientation pile elements	2.60 kN

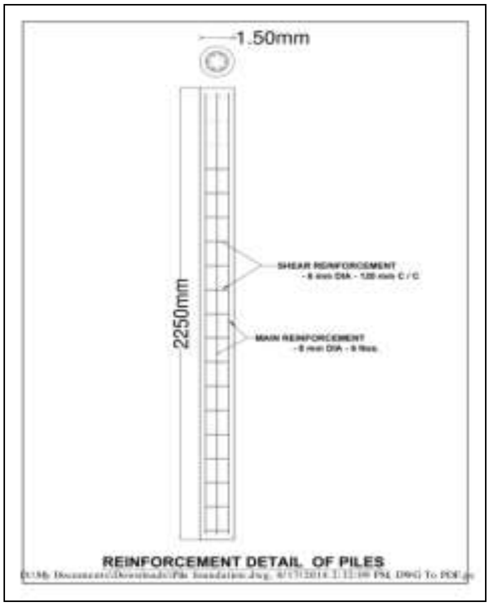

Figure 2 *Reinforcement details of pile elements*

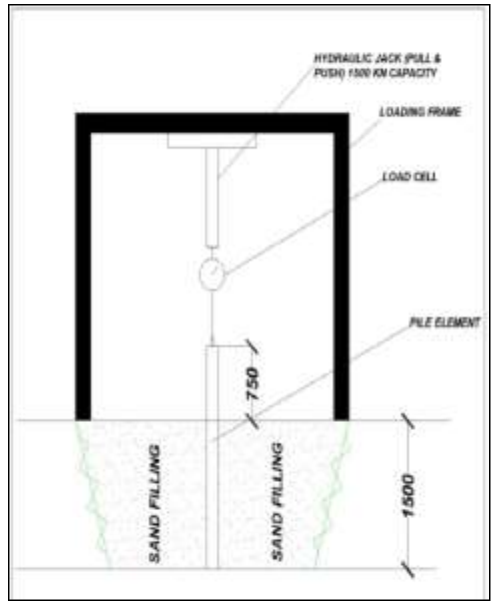

Figure 3 *Pullout test by using loading frame setups*

Table 4: *Conventional elements pull out test performance*

Load in kN	Stress in N/mm^2	Deformation reading in mm		Strain	Displacement readings in mm	
		Initial length	Change in length		Initial depth	Final depth
0.000	0.000	4.722	0.000	0.00000000	0.000	0.000
0.250	0.011	4.723	0.001	0.00000047	0.000	0.000
0.500	0.022	4.724	0.002	0.00000095	0.000	0.000
0.750	0.033	4.725	0.003	0.00000142	0.000	0.000
1.000	0.044	4.726	0.004	0.00000189	0.000	0.000
1.250	0.056	4.727	0.005	0.00000237	0.000	0.000
1.500	0.067	4.728	0.006	0.00000284	0.000	1.000
1.750	0.078	4.729	0.007	0.00000331	0.000	1.000
2.000	0.089	4.731	0.009	0.00000379	3.000	4.000
2.250	0.100	4.732	0.010	0.00000426	6.500	10.500
2.500	0.111	4.733	0.011	0.00000474	9.500	20.000

Table 5: *BFRP wrapped 0^o (Hoop) directional elements pull out test performance*

Load in kN	Stress in N/mm^2	Deformation reading in mm		Strain	Displacement readings in mm	
		Initial length	Change in length		Initial depth	Final depth
0.000	0.000	4.000	0.000	0.00000000	0.000	0.000
0.250	0.011	4.001	0.001	0.00000035	0.000	0.000
0.500	0.022	4.002	0.002	0.00000070	0.000	0.000
0.750	0.033	4.002	0.002	0.00000105	0.000	0.000
1.000	0.044	4.003	0.003	0.00000140	0.000	0.000
1.250	0.056	4.004	0.004	0.00000176	0.000	0.000
1.500	0.067	4.005	0.005	0.00000211	0.000	0.000
1.750	0.078	4.006	0.006	0.00000246	0.000	0.000
2.000	0.089	4.006	0.006	0.00000281	0.000	0.000
2.250	0.100	4.007	0.007	0.00000316	0.000	0.000
2.500	0.111	4.008	0.008	0.00000351	0.000	0.000
2.750	0.122	4.009	0.009	0.00000386	1.000	1.000
3.000	0.133	4.009	0.009	0.00000421	2.500	3.500
3.050	0.136	4.011	0.011	0.00000491	9.500	19.500

Table 6: *BFRP wrapped 45^o (Inclined) directional elements pull out test performance*

Load in kN	Stress in N/mm^2	Deformation reading in mm		Strain	Displacement readings in mm	
		Initial length	Change in length		Initial depth	Final depth
0.000	0.000	4.020	0.000	0.00000000	0.000	0.000
0.250	0.011	4.021	0.001	0.00000037	0.000	0.000
0.500	0.022	4.022	0.002	0.00000073	0.000	0.000
0.750	0.033	4.022	0.002	0.00000110	0.000	0.000
1.000	0.044	4.023	0.003	0.00000146	0.000	0.000
1.250	0.056	4.024	0.004	0.00000183	0.000	0.000
1.500	0.067	4.025	0.005	0.00000219	0.000	0.000
1.750	0.078	4.026	0.006	0.00000256	0.000	0.000
2.000	0.089	4.027	0.007	0.00000292	0.000	0.000
2.250	0.100	4.027	0.007	0.00000329	1.000	1.000
2.500	0.111	4.028	0.008	0.00000366	2.000	3.000
2.750	0.122	4.029	0.009	0.00000402	2.000	5.500
2.800	0.124	4.029	0.009	0.00000409	11.000	20.000

Table 7: *BFRP wrapped 90^o (Vertical) directional elements pull out test performance*

Load in kN	Stress in N/mm^2	Deformation reading in mm		Strain	Displacement readings in mm	
		Initial length	Change in length		Initial depth	Final depth
0.000	0.000	4.122	0.000	0.00000000	0.000	0.000
0.250	0.011	4.128	0.006	0.00000267	0.000	0.000
0.500	0.022	4.136	0.014	0.00000622	0.000	0.000
0.750	0.033	4.142	0.020	0.00000889	0.000	0.000
1.000	0.044	4.150	0.028	0.00001244	0.000	0.000
1.250	0.056	4.158	0.036	0.00001600	0.000	0.000
1.500	0.067	4.164	0.042	0.00001867	0.000	0.000
1.750	0.078	4.170	0.048	0.00002133	0.500	0.500
2.000	0.089	4.170	0.048	0.00002133	1.500	2.000
2.250	0.100	4.170	0.048	0.00002133	4.000	6.000
2.500	0.111	4.170	0.048	0.00002133	6.000	12.000
2.600	0.116	4.172	0.050	0.00002222	8.000	20.000

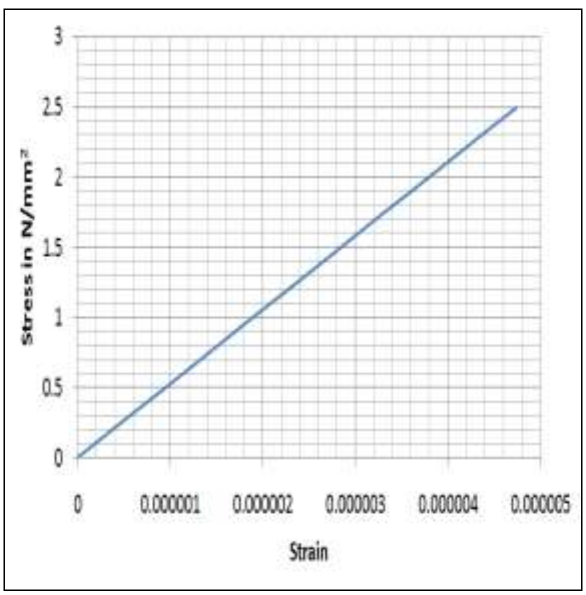

Figure 4 *Stress vs. Strain curve for pull out tested conventional elements*

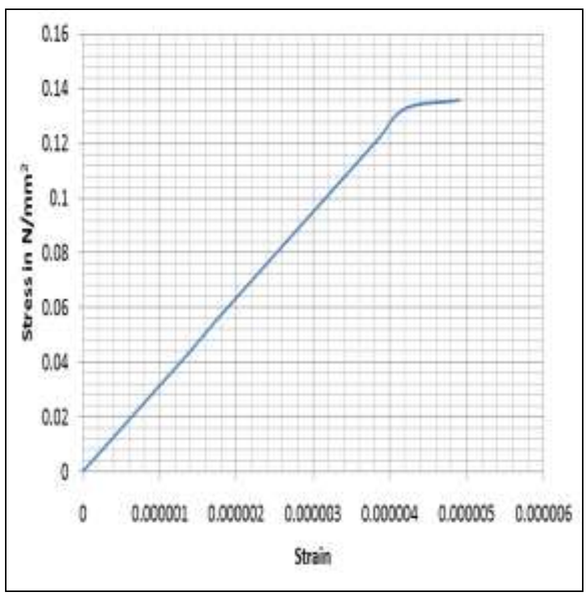

Figure 5 *Stress vs. Strain curve for pull out tested BFRP wrapped in Hoop directional elements*

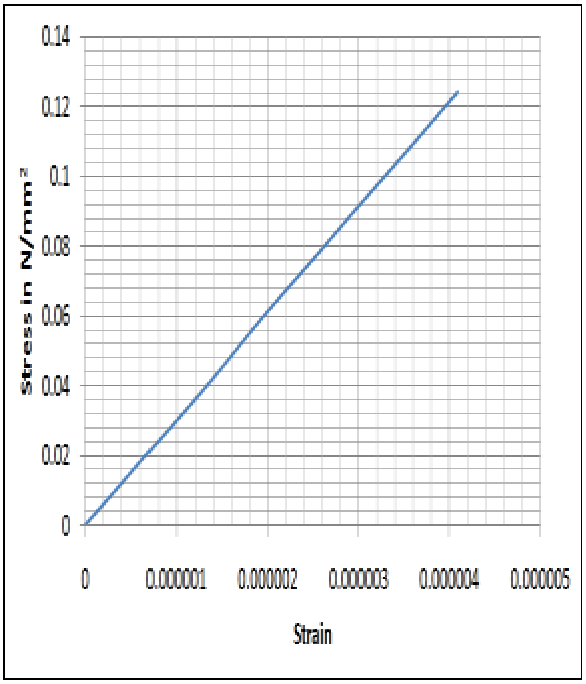

Figure 6 *Stress vs. Strain curve for pull out tested BFRP wrapped in inclined 45° elements*

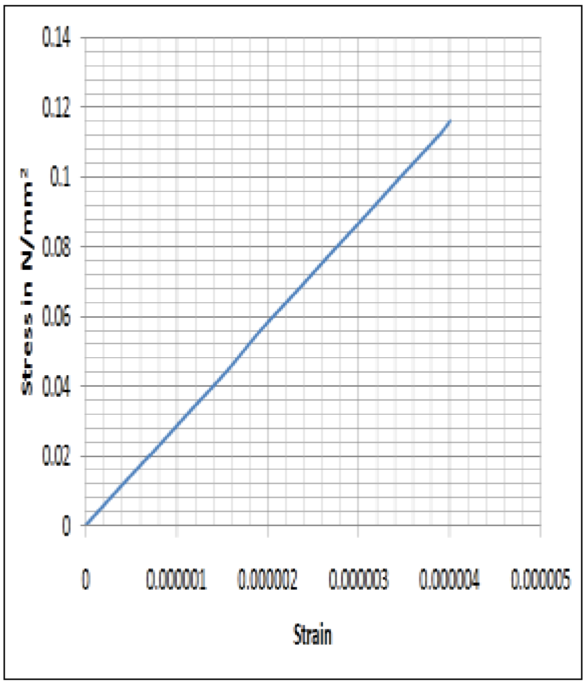

Figure 7 *Stress vs. Strain curve for pull out tested BFRP wrapped vertically elements*

3. Result and Discussion

Table 3 shows minimum value of the three trials of pullout test results. The medium smooth surfaced conventional RCC pile elements pulled out at 2.50 kN. The complete pull out occurred at 3.05 kN, 2.80 kN and 2.60 kN in case of elements wrapped with BFRP in hoop direction (0° orientation of warp), warp 45° inclined direction and warp vertical direction respectively.

The BFRP double wrapped in hoop directional elements showed high friction between soil and pile surface than conventional, inclined and vertically wrapped pile elements. Since the fibres are in hoop direction, the pile tends to behave as a screw pile with small threads. The fibre warp when observed in micro level are placed in wave form with edges curved internally, improving grip between the fibre and soil.

BFRP warp 45° inclined and vertically wrapped elements friction performance is lower than the hoop directional elements as it results loss in friction between fibre and soil due to fibre orientation.

Table 4 to 7 tabulated the parameters such as stress, strain, deformations and upward displacements corresponding to every load increment of 2 kN (upto ultimate load) for conventional and BFRP wrapped pile elements during pull out test. Strain was slightly high in conventional elements than BFRP wrapped elements. This is due to the inducement of tensile strength of piles by BFRP wrapping. Increased friction of BFRP wrapped elements tends to reduce the initial speed of upward displacement from the soil. But during ultimate pulling stage, both conventional and BFRP wrapped elements displaced suddenly from the soil.

Figure 4 to 7 shows the Stress vs. Strain curves for tensile strength of the four varying elements. Load-Displacement performances of Hoop directional BFRP wrapped elements were more effective than conventional, 45° inclined wrapped and vertically wrapped elements. The increase in Young's modulus due to wrapping in hoop direction makes this better Load-Displacement performance viable. Vertically wrapped pile elements withstand the more tensile strength than other three elements.

The tensile strength of pile elements having BFRP wrapped hoop directionally was found to be 21% more than the conventional elements. Whereas, the 45° inclined and vertically wrapped elements possesses 11% and 4% more tensile strength than the conventional elements.

Analyzed and determined the mean value of angle of friction 'δ' between soil and conventional element, BFRP wrapped hoop orientation element, BFRP wrap in 45° inclined orientation element, BFRP wrap in 90° vertical orientation element is 0.75ϕ, 0.90ϕ, 0.87ϕ and 0.82ϕ respectively based on the pull out test results, it is noticed in Table 3.

During the pull out test no cracks were formed in all type of pile elements.

4. Conclusion

This research study was mainly carried out for piles retrofitting purposes. Experimental results shows the BFRP wrapping piles were attained more pull out carrying capacity than conventional piles. BFRP wrapping is giving additional strength and protection to the pile elements based on the fibre orientation; it is concluded from this research. Hoop orientation of BFRP wrap is effective than BFRP wrap in 45° and vertical wrap. Hoop directionally BFRP wrapped pile elements are advised to be used in cohesion less soil as it increases the friction between sand and BFRP wrap effectively. From this research, hoop (Fibre warp) direction is more effectively for withstand the uplift pressure; which can used for strengthening of existing piles. This study can be fulfilled by conducting friction test on different type of fibres in different soils.

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