Visakhapatnam Chapter

Proceedings of Indian Geotechnical Conference 2020
December 17-19, 2020, Andhra University, Visakhapatnam

Analytical Study of Load Carrying Capacity of Fibre Reinforced Polymer Piles

A. I. Dhatrak[1], Swetha N. Bhadke[2], and S. W. Thakare[3]

.

[1]Dean Academics, Government College of Engineering, Amravati, Maharashtra
[2]MTech Geotechnical Engineering, Civil Department Government College of Engineering, Amravati, Maharashtra
[3]Associate Professor, Civil Engineering Department, Government College of Engineering, Amravati, Maharashtra

Abstract. Composite piles have been used generally for waterfront barriers, fender piles and bearing piles for light structures. Fibre-reinforced polymer (FRP) composite as a pile material can eliminate deterioration problems of conventional piling materials when exposed to harsh or marine aggressive environments. FRP composite piles are composed of a hollow FRP pipe that is filled before installation with an expanding concrete and is coated with a durable corrosion-resistant coating layer. However, researchers studies related to the use of FRP materials as pile are very limited. This paper presents the results of study related with the performance of fibre reinforced polymer pile foundation resting in marine layered soil of Chennai port trust (India), with respect to its various parameters. For this purpose, analytical model of FRP pile was developed in MIDAS GTS NX software to simulate the pile foundation with different parameters studied. A defined soil model represents marine layered bed and pile embedded within it with varying slenderness ratio and subjected to vertical, uplift and lateral loading. Performance of pile group, with different number of piles in the group, was also analysed. FRP pile materials investigated were glass fibre reinforced polymer (GFRP) and carbon fibre reinforced polymer (CFRP) and the results were compared to the conventional concrete pile. The results show that the ultimate load capacity of FRP pile is higher than that of conventional concrete pile. Also, increasing the slenderness ratio increases the ultimate load capacity of pile.

Keywords: Fibre reinforced polymer (FRP), marine layered soil, MIDAS GTS NX.

1 Introduction

Fibre Reinforced Polymer (FRP) is a composite material which contains fibre and resin that provide high tensile strength. This material is also known as fibre-reinforced plastics or advanced composite materials (ACMs). Fibre-reinforced materials are lightweight, have high specific strength, durability and are resistance to chemicals and corrosive environments. FRP is well known for its high ratio of strength to weight, high ratio of longitudinal/transversal shear modulus. It can be categorized into Aramid-FRP (AFRP), Basalt-FRP (BFRP), Carbon-FRP (CFRP) and Glass-FRP (GFRP) depending on the materials of fibre.

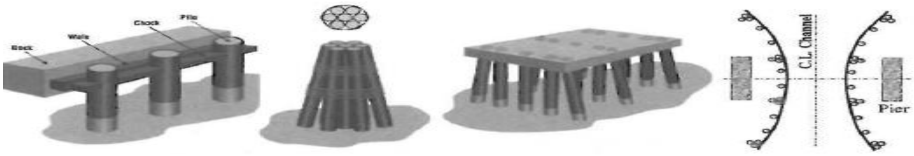
There are wide utilisations of piles whereby some issues occur when piles are located in harsh environments especially in marine or coastal conditions. The piles with traditional materials could be destroyed due to corrosion of steel, deterioration of timber and degradation of concrete as shown in Fig. 1. FRP piles can be used as an alternative construction material to these piles which gets damaged in the aggressive environment. FRP composite piles are composed of a hollow FRP pipe that is filled before installation with an expanding concrete as shown in Fig. 2 and is coated with a durable corrosion-resistant coating layer. The hollow pipe is produced from unsaturated polyester or epoxy resins with reinforcement rovings (E-glass) and appropriate filler material to form a rigid material. E-glass is incorporated as continuous rovings and is set in resin under pressure during the fabrication process. The FRP composite pile can be used in marine environments in a variety of applications viz. fender piling, dauphins, light structural piling and bridge pier protection (Fig. 3). FRP piles can also be used as deep foundations in marine front structures such as jetties, boardwalks, seaside buildings etc. The load bearing capacity of FRP piles is governed by combination of end bearing and friction resistance.

(a) (b) (c)

Fig. 1. Traditional piles in aggressive environment (a) Corrosion of Steel, (b) Deterioration of Timber and (c) Degradation of Concrete [14]

(a) (b)

Fig. 2. FRP composite pile (a) Hollow FRP pipe, (b) Concrete filled FRP pile [14]



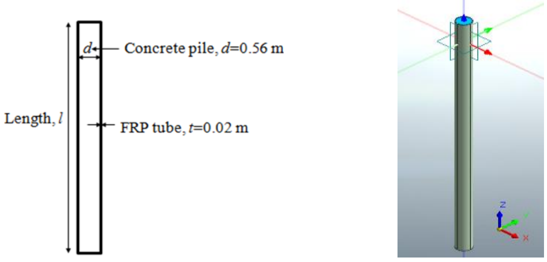
(a) (b) (c) (d)

Fig. 3. Different Applications of FRP composite piles (a) Fender pile, (b) Dauphin, (c) Light Structural piles, (d) Bridge Pier Protection [6]

Shaia *et al*. (2013) carried experimental test on CFRP and GFRP piles subjected to the axial and lateral load. A long-term study was undertaken to assess the effect of FRP degradation on the pile capacity where the piles were exposed to acidic and alkaline soil environments for 180 days. Numerical analysis was carried out using ABAQUS software to simulate and validate the experimental results of FRP pile model [1]. Valez (2013) conducted laboratory investigation on small-scale hollow FRP piles in undisturbed clay samples and compared results with the steel piles. Their findings showed that the FRP piles in soft clays can be used as an alternative solution to traditional steel piles [2]. Nemr *et al*. (2016) investigated the FRP pile behaviour in sandy soil using finite element modeling under static loading condition. Their findings show that as the stiffness of the pile increases the settlement decreases [3]. Giraldo *et al*. (2016) conducted small scale field test on hollow fibre reinforced polymer (FRP) piles in the 'Canadian Geotechnical Research Site' located at Gloucester, Ontario. The load transfer behaviour of FRP piles manufactured using glass and carbon fibres was studied and compared to that of traditional steel piles. Fibre orientation had major role in determining the pile capacity [4].

2 Methodology

In the present study, FRP pile behaviour was investigated using finite element modeling under static loading condition using the MIDAS GTS NX software. Fig. 4 shows the typical FRP pile used in analysis and pile model developed in MIDAS GTS NX. The numerical model represents the cylindrical tube pile filled with concrete embedded in marine layered soil bed of width 40d, where d is the diameter of pile with water table at the ground level. The tubes were modeled as orthotropic unidirectional laminates in three direction (direction 1 being the fibre direction and direction 2; 3 being the perpendicular to the fibre). Table 1 provides the mechanical properties of CFRP and GFRP laminates in the hoop and longitudinal direction. For both CFRP and GFRP type the layer of composite tubes were modeled using unidirectional mechanical properties in longitudinal orientation (0°). The concrete pile was modeled as a linearly elastic perfectly plastic model. Table 2 shows the properties assigned to concrete pile for analysis. The characteristics and thickness of various layers had been selected from the Chennai port trust (India) with the actual soil profile of the marine environment. The soil layers were modeled as elastic perfectly plastic model based on the Mohr Coulomb failure criterion. Table 3 shows the properties assigned to soil layers for analysis. The results of CFRP and GFRP piles tube filled with concrete were compared to that of conventional concrete piles and conclusions were drawn.



(a) (b)

Fig. 4. FRP pile used in analysis (a) Schematic diagram of FRP piles (b) FRP Pile model developed in MIDAS GTS NX

Table 1. Properties assigned to FRP pile for analysis [1]

Property	Symbol	Unit	CFRP	GFRP
Density	ρ	g/cm^3	1.6	2.0
Longitudinal Modulus*	E_{11}	MPa	135000	50000
Transverse in-Plane Modulus*	E_{22}	MPa	10000	40000
Transverse out-Plane Modulus*	E_{33}	MPa	10000	8500
In-plane Shear Modulus**	G_{12}	MPa	5000	4300
Out-of-Plane Shear Modulus**	G_{23}	MPa	1900	3500
Out-of-Plane Shear Modulus**	G_{13}	MPa	5000	4300
Major in-Plane Poisson's ratio**	υ_{12}	-	0.3	0.27
Poisons ratio**	υ_{23}	-	0.3	0.27

Where, CFRP: Carbon fibre reinforced polymer, GFRP: Glass fibre reinforced polymer, *: provided by manufacture, **: provided by Wu, 2011 [9]

Table 2. Properties assigned to concrete pile for analysis [1]

Material	Model	Young modulus, E (Mpa)	Poisons ratio, υ	Unit weight, γ (kN/m^3)
Concrete Pile	Elastic	28000	0.22	25

Table 3. Properties assigned to soil for analysis [10]

Depth, m	Unit weight, γ (kN/m^3)	Poisons ratio, υ	Effective cohesion, c (kN/m^2)	ϕ^0	Modulus of elasticity, E (MPa)
0-14 (loose silty sand)	12	0.25	-	28	8000
14-20 (Medium dense silty sand)	15	0.3	-	30	17000
20-33 (Dense silty sand)	19	0.35	-	38	50000
33-35 (Slightly weathered to fresh clay)	21	0.4	10	-	52500
35-40 (Highly to moderately weathered granite)	22	0.4	33.3	-	120000

3 Numerical Analysis

The model developed was auto-connected by using boolean operation. Separate meshing was provided for pile and soil model. Mesh was generated by using tetrahedron elements produced by the auto-mesh generation function. Fig. 5 shows geometry of FRP pile embedded in soil after mesh generation. Boundary condition for geometry was defined by restraining the sides of soil model in the x and y-directions and the bottom boundary in all directions. An interface element was generated around the FRP pile to account the soil-pile interaction. The analysis was then carried out by selecting the Non-Linear analysis case.

Thus the analysis carried out aims to investigate the load settlement response of FRP pile and conventional concrete pile embedded in marine layered soil bed. The various parameters considered for the study were type of FRP pile material, type of loadings, number of piles in the group and slenderness ratio. The parameters of pile which were kept constant are given in Table 4. Table 5 shows various parameters varied during analysis.

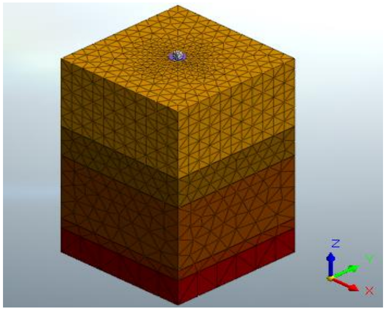


Fig. 5. Geometry of FRP pile embedded in soil after Mesh Generation in MIDAS GTS NX.

Table 4. Constant dimensions of FRP pile

Sr. no.	Parameter	Values
1	Dimensions for pile	Diameter of pile = 0.6 m Thickness of FRP tube, t = 0.02 m

Table 5. Details of parametric study for FRP pile

Sr. no.	Parameter	Values
1	Slenderness ratio (l/d) (d constant)	11/0.6, 16/0.6, 21/0.6, 26/0.6, 31/0.6
2	Type of FRP pile material	GFRP (glass fibre reinforced polymer piles) CFRP (carbon fibre reinforced polymer piles)
3	Type of loadings	Axial Loading Lateral Loading Uplift Loading
4	Number of piles (N)	i) Single pile ii) Pile group with 5 and 7
5	Spacing between piles	3d

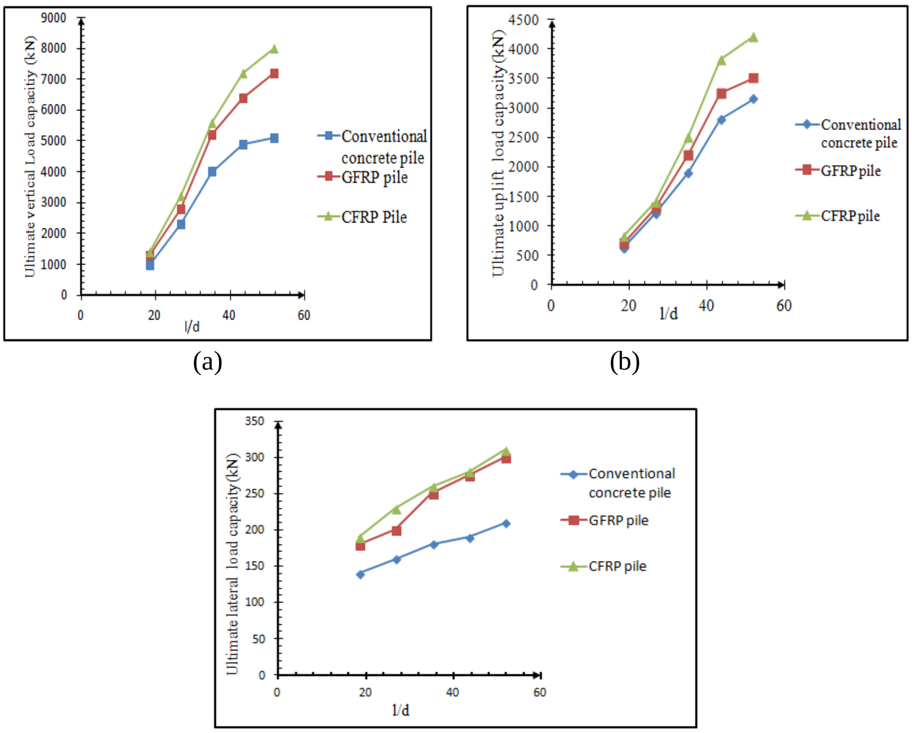
4 Results and Discussions

4.1 Performance of single FRP pile

Initially the analysis was conducted on single conventional circular pile and FRP pile subjected to vertical load, uplift load and lateral load in marine layered soil bed. The ultimate load capacity for conventional pile and FRP pile were considered as per the provision of IS: 2911 (Part -4) 1985. The ultimate capacities as determined from the load settlement curves are presented in the Table 6. The results obtained from the analysis were discussed and the effect of l/d ratio on performance of single GFRP and CFRP pile was studied. Fig. 6 shows the variation in ultimate load capacity, ultimate uplift capacity and ultimate lateral load capacity for conventional, GFRP and CFRP pile with respect to the l/d ratios.

Table 6. Ultimate Load Capacities of Conventional and FRP pile with different slenderness ratio

Loading Condition	Type of pile	Ultimate Load Capacities (kN)				
		Slenderness ratio (l/d)				
		l/d =18.33	l/d = 26.66	l/d= 35	l/d = 43.33	l/d = 51.66
Vertical	Conventional concrete pile	990	2300	4000	4900	5100
	GFRP	1300	2800	5200	6400	7600
	CFRP	1600	3200	5600	7200	8000
Uplift	Conventional concrete pile	625	1200	1900	2800	3150
	GFRP	700	1300	2195	3250	3500
	CFRP	820	1410	2500	3820	4200
Lateral	Conventional concrete pile	140	160	180	190	210
	GFRP	180	200	250	275	300
	CFRP	190	230	260	280	310



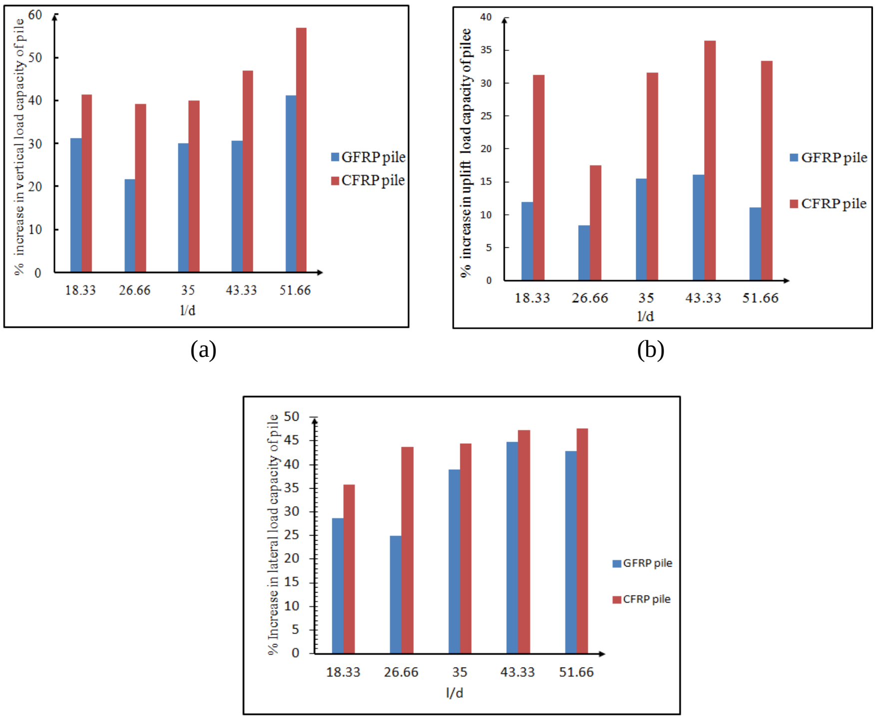
(a) (b) (c)

Fig.6. Variation in Ultimate Load Capacities of piles with respect to l/d ratio (a) Vertical, (b) Uplift and (c) lateral Loading condition

The percentage increase in ultimate vertical load, uplift load and lateral load compared with conventional circular pile is given in Table 7. The percentage increase in ultimate vertical, uplift and lateral load capacities of single GFRP and CFRP pile with slenderness ratio is shown in Fig. 7 in the form of bar charts.

Table 7. Percentage increase in Ultimate Load Capacities of FRP pile with different slenderness ratio.

Loading condition	Type of pile	Percentage increase in pile capacity (%)				
		Slenderness ratio (l/d)				
		l/d=18.33	l/d=26.66	l/d=35	l/d=43.33	l/d=51.66
Vertical	GFRP	31	22	30	31	41
	CFRP	41	39	40	47	57
Uplift	GFRP	12	8	16	16	11
	CFRP	31	18	32	36	33
Lateral	GFRP	29	25	39	45	43
	CFRP	36	44	44	47	48



(a) (b) (c)

Fig.7. Percentage increase in Ultimate Load Capacity with respect to l/d ratio Variation (a) Vertical, (b) Uplift and (c) lateral Loading condition

From the above results, it is observed that the ultimate vertical, uplift and lateral load capacities of single GFRP as well as CFRP pile is higher than that of conventional concrete pile. Ultimate vertical, uplift and lateral capacities of GFRP and CFRP pile increase rapidly with increase in l/d ratio up to 43.33; with further increase in l/d ratio, there is no significant increase in these capacities. Therefore, analysis of group of FRP piles for ultimate load capacities were carried out by keeping l/d ratio of 43.33 as constant parameter. Also, the percentage increase in ultimate load capacities of single CFRP pile is higher as compared to GFRP pile. The percentage increase in vertical load capacities of single FRP piles is higher as compared to uplift and lateral load capacities.

4.2 Performance of Pile Groups

The analyses were conducted on pile groups consisting of conventional as well as FRP piles subjected to vertical, uplift and lateral load. The analyses were performed consisting of group of five piles in square arrangement with pile at centre and seven piles in hexagonal arrangement with pile at centre for conventional, GFRP and CFRP pile and their ultimate load capacities were determined. The ultimate capacities for the pile group as determined from the load settlement curves are presented in the Table 8.

Table 8. Ultimate Load Capacities of Conventional, GFRP and CFRP pile group for Vertical, Uplift and Lateral loading.

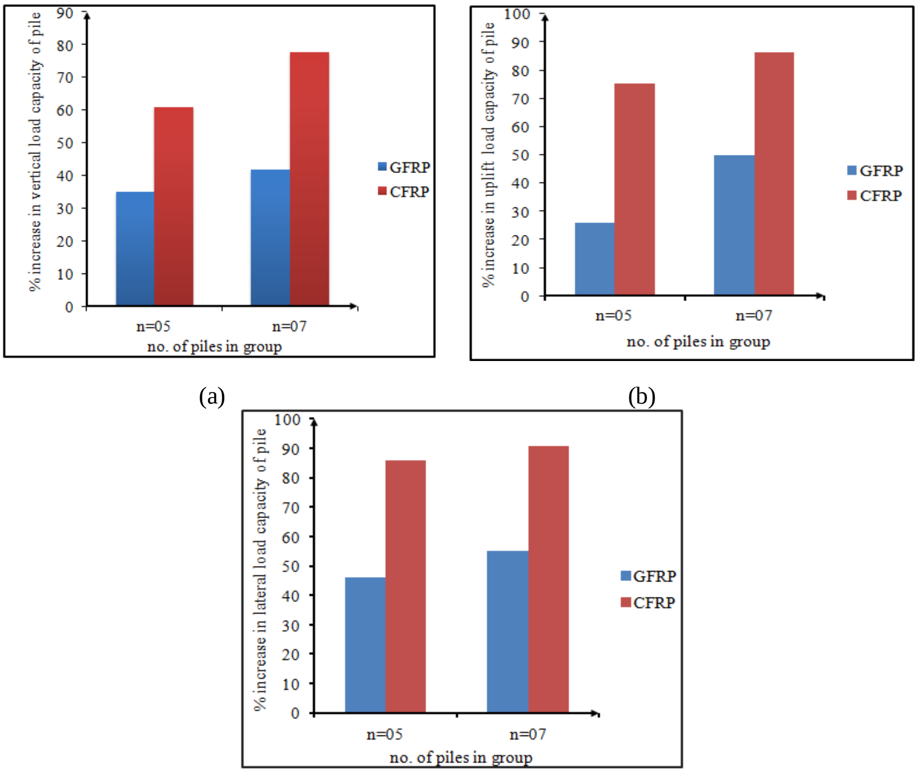
Loading conditions	Type of pile	Ultimate load capacities (kN)	
		No. of piles in group	
		5 (square arrangement with pile at centre)	7 (hexagonal arrangement with pile at centre)
Vertical	Conventional concrete pile	29000	36000
	GFRP	39150	51000
	CFRP	46666	64000
Uplift	Conventional concrete pile	7988	11000
	GFRP	10050	16500
	CFRP	14000	20500
Lateral	Conventional concrete pile	700	1100
	GFRP	1022	1705
	CFRP	1302	2100

The percentage increase in ultimate vertical load, uplift load and lateral load compared with conventional circular pile group is given in Table 9.

Table 9. Percentage increase in Ultimate Load Capacities of FRP Pile Groups compared with Conventional circular pile group

Loading condition	Type of pile	Percentage increase in pile capacities (%)	
		No. of piles in group	
		5 (square arrangement with pile at centre)	7 (hexagonal arrangement with pile at centre)
Vertical	GFRP	35	42
	CFRP	61	78
Uplift	GFRP	26	50
	CFRP	75	86
Lateral	GFRP	46	55
	CFRP	86	91

The percentage increase in ultimate vertical, uplift and lateral load capacities of group of piles with respect to number of piles in group is shown in Fig.8 respectively in the form of bar chart.



(a) (b)

(c)

Fig.8. Percentage increase in Ultimate Load Capacities of FRP Pile Groups (a) Vertical, (b) Uplift and (c) lateral Loading condition

From the above results, it is observed that the ultimate vertical, uplift and lateral load capacity of FRP pile group is higher than that of conventional concrete pile. Also, the ultimate vertical, uplift and lateral load capacity of CFRP pile group is higher than GFRP pile group. The ultimate vertical, uplift and lateral load capacities of group of seven piles in hexagonal arrangement with pile at centre is higher as compared to group of five piles in square arrangement with pile at centre. The percentage increase in ultimate load capacities of CFRP pile group is higher as compared to GFRP pile group. The percentage increase in lateral load capacities of FRP pile group is higher as compared to vertical and uplift load capacities.

5 Conclusions

In present study, FRP pile foundation has been analysed in marine layered soil of Chennai port trust (India) using MIDAS GTS NX software. From the present study, following broad conclusions are drawn.

1. The ultimate vertical, uplift and lateral load capacity of single FRP pile is higher than that of conventional concrete pile. The percentage increase in ultimate load capacities of single CFRP pile is higher as compared to GFRP pile. Also, the percentage increase in vertical load capacities of single FRP piles is higher as compared to uplift and lateral load capacities.
2. Ultimate vertical, uplift and lateral capacities of GFRP and CFRP pile increase with the l/d ratio up to 45. With further increase in l/d ratio, there is no further significant increase in these capacities.
3. The ultimate vertical, uplift and lateral load capacity of FRP pile group are higher than that of conventional concrete pile group. The capacities of CFRP pile group are higher than GFRP pile group.
4. The percentage increase in ultimate load capacities of CFRP pile group is higher as compared to GFRP pile group.
5. The percentage increase in ultimate load capacities of group of seven piles is higher as compared to group of five piles.
6. The percentage increase in lateral load capacities of FRP pile group is higher as compared to vertical and uplift load capacities.

References

1. Shaia, H., Abuel-Naga, H.: Behaviour of Fibre Reinforced Polymer Composite Piles: Experimental and Numerical Study. Ph.D. Thesis, Department of Civil Engineering, Manchester University (2013).
2. Valez, J.: Experimental study of Hollow Fibre Reinforced Polymer Piles in soft clay. Thesis, Department of Civil Engineering, Carleton University (2013).
3. Nemr, M., Hekal, G.: Finite Element modeling of confined concrete piles with FRP tubes in sandy soil under static loading. The sixth international conference on SEMC, 2122-2127 (2016).
4. Giraldo, J., Rayhani, T.: Axial and Lateral Load Transfer of Fibre Reinforced Polymer (FRP) Piles in soft clay. International Journal of Geotechnical Engineering, 11(2) (2016).
5. Zacharia, C., Philip, J. G.: Comparative study on settlement behaviour of FRP composite piles in sand. International Research Journal of Engineering and Technology, 05 (04) (2018).
6. Zhou, J., Erwin, Oh.: A Review of Geotechnical Application of Fibre Reinforced Polymer Materials. Eighth International Conference on Fibre Reinforced Polymer (FRP) Composites in Civil Engineering, 856-861 (2016).
7. Zhou, J., Erwin, Oh.: Deflection Behaviour of GFRP Bar Reinforced Concrete Passive Bored Pile in Deep Excavation Construction. Geotechnical Engineering Journal of the SEAGS and AGSSEA, 48 (3) (2017).
8. IS 2911-Part 4: Indian Standard Code of Practice for Design and Construction of Pile Foundation (1985).
9. Wu, S.: Finite Element Analysis and Theoretical Study on FRP Wrap Concrete Cylinders. Masters, Department of Civil Engineering, Manchester University (2011).
10. Premalatha, P. V., Kumar, S., Baskar, K.: Influence of change in pile diameter at various locations of a pile group in a Berthing Structure. Indian Journal of geo marine sciences (2017).

11. Karthigeyan, S., Ramakrishna, T., Rajagopal, K.: Numerical Investigation of the Effect of Vertical Load on the Lateral Response of Piles. Journal of Geotechnical and Geoenvironmental Engineering, 133 (05) 512-521 (2007).
12. Dhatrak, A. I., Ghawde, M., Thakare, S.W.: Experimental study on Belled Wedge Pile for different loadings in cohesionless soil. Indian Geotechnical Conference, Indian Institute of Science Bengaluru, 1-7 (2018).
13. Dhatrak, A. I., Yaldarkar P. S., Thakare, S.W.: Analyses of shell footing in layered sandy soil. Indian Geotechnical Conference, Indian Institute of Science Bengaluru, 1-8 (2018).
14. Juran, I., Komornik U.: Behavior of Fiber-Reinforced Polymer (FRP) Composite Piles Under Vertical Loads, FHWA-HRT-04-107 (2006).