International Journal of Technical Innovation in Modern Engineering & Science (IJTIMES)
Impact Factor: 5.22 (SJIF-2017), e-ISSN: 2455-2585
Volume 5, Issue 05, May-2019

Numerical Analysis of Spin Fin Pile under Different Loading Conditions

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Abstract*— A Spin Fin pile is a modified pile that has four plates welded along the length of traditional monopile at 90° to each other. In this paper, a 3D analysis of conventional circular and Spin Fin Pile foundation with an elastic plastic soil model (Mohr-Coulomb), an elastic pile material (steel) interface elements are used to model the pile–soil interaction using MIDAS GTS 3D finite element software. The defined soil model represented loose, medium dense and dense sand, and hollow steel pile embedded in sand was subjected to lateral, uplift and vertical loading with fins at top, middle and bottom of pile. Analysis shows that Spin Fin pile with fins at bottom provides higher vertical and uplift capacity compared to that of conventional circular pile. Spin Fin Pile with fins at top provides higher lateral load capacity compared to conventional pile.

***Keywords-* Spin Fin Pile, Ultimate load capacity, Lateral load capacity, Uplift load capacity, MIDAS GTS 3D software.**

I. Introduction

Piles are usually adopted as supporting structures for large structures like very tall buildings, framed buildings, transmission towers, offshore structures etc. Monopiles are widely used to support offshore and onshore wind turbines. Large diameter of piles is required due to presence of weak soil and less over burden soil pressure near the pile top portion. Improvement in the pile capacity can be achieved by providing fins near the top or bottom portion of the monopiles, this new modified pile is Spin Fin pile. Spin fin piles are often used in docks, dolphins, retaining wall tiebacks, wave barriers, seismic anchors and other pile foundations where anticipated uplift or impact load may cause failure. It is an emerging form of pile foundation that is capable of resisting large lateral and uplift displacement. Spin finned piles are driven piles with welded fin attachments that modify pile behavior under tension. The attachment of fins on to the surface of the monopiles has been found to be a good measure to improve the lateral load and uplift load capacity of piles. Spin fin piles are a cost saving alternative for many pile foundation applications. The spin fin tip generates significantly more resistance to tensile loads than that of a conventional pile.

II. LITERATURE REVIEW

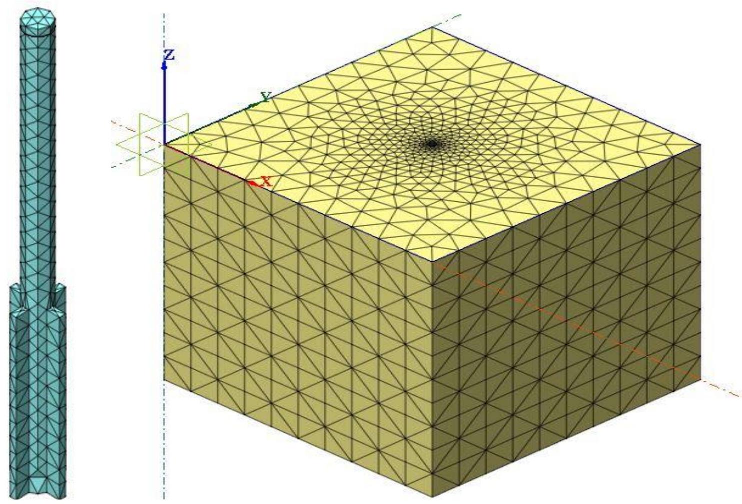
K.V. Babu *et al.* (2018)[1] carried out analysis on Lateral Load Response of Fin Piles. They carried out numerical model studies on the lateral load response of regular piles (pile without fins) and fin piles in sand. Three dimensional finite element analyses were performed on regular piles as well as fin piles. Analyses were performed in sand with different relative densities, viz., 40%, 55% and 85%. Regular and fin piles having four and eight fins were considered during the analyses. The behaviour of regular pile and fin piles with different sand relative densities, fin orientations, fin numbers and position were investigated in sand. They concluded that, at higher fin length, star fin piles carried more lateral load followed by straight and diagonal fin piles. Fins placed near the pile top provided more resistance than those placed near the pile bottom.

J. R. Peng *et al.* (2010)[2] carried out analysis on laterally loaded fin piles. A 3D computer simulation of laterally loaded fin piles was presented to explore the effect of fin dimensions on their load bearing capacity in sand. The behaviour of fin piles was compared with the monopile using PLAXIS-3D software to generate the pile head P–Y curves. They concluded that lateral resistance increased with the increase in length of the fins. A fin pile had the optimum fin efficiency when the fin length is half the pile length. Fins placed near the pile top provided more resistance as compared to fins provided near the pile bottom.

Ahmed M. A. Nasr[4] *et al.* (2013) carried out experimental investigation on laterally loaded finned piles in sand. In their study, they evaluated the improvement in lateral capacity of a pile with fins mounted close to the pile head. Model tests as well as numerical study were performed on regular piles without fins and piles with fins. The piles were installed in sand of different relative densities (D_r = 35% and 78%). The tests and analysis were carried out by varying the length, width, shape of the fins and type of pile. A comparison between the model results and the prototype-scale results were studied. They concluded that piles with fins provided considerably higher ultimate lateral loads and lateral resistance compared with a regular reference pile. Ultimate lateral load improvement depended greatly on length of the fins and increased significantly to the value of $L_F/L_P = 0.4$. When a pile is finned with triangular and rectangular fins, the ultimate lateral load of the pile increased by about 64% and 86%, respectively, than that of a regular pile. At the same time, the lateral head deflection decreased by about 37% and 70%, respectively. Hence, Pile with rectangular fins was more effective in improving the lateral behaviour of piles.

III. METHODOLOGY

A three-dimensional finite element model was established in order to analyse the behaviour of conventional and Spin fin pile. The computations were carried out using MIDAS GTS 3D finite element software. The sand was assumed to be a linear elastic perfectly plastic material. A non-associated Mohr–Coulomb constitutive model was assumed to govern the soil behaviour for which the material parameters are well established in geotechnical engineering practice. The boundary is a cube with sides of 100 m x 100 m x 100 m. The geometry of a three-dimensional model of a Spin fin pile and pile embedded in soil is shown in Fig.1. The bottom boundary was fixed against movements in all directions, whereas the 'ground surface' was free to move in all directions. The properties assigned to soil and the properties of pile are as shown in Table I and II respectively.



(a) (b)

Fig. 1: a) Three Dimensional View of Spin Fin Pile and b) Sand Block

Table I :Properties assigned to soil

Properties	Unit weight	Young's modulus	Poisson's ratio	Angle of internal friction	cohesion
Symbols	**γ**	**E**	**υ**	**Ø**	**c**
Unit	**kN/m^3**	**kPa**		**degree**	**kPa**
Loose Sand	15	20000	0.3	30°	1
Medium dense sand	17	40000	0.3	35°	1
Dense Sand	20	80000	0.3	40°	1

Table II :Properties of pile

Sr. No.	Properties	Symbol	Values	Units
1	Young's modulus	E	2.0×10^8	kN/m^2
2	Density	ρ	78	kN/m^3
3	Poisson's ratio	υ	0.2	

Numerical Analysis

Analysis was carried out to evaluate the performance of Spin Fin Pile and conventional circular pile embedded in sand.The analysis were conducted on model pile foundation and the parameters varied were type of loading, type of soil and position of fins. The parameters viz., pile diameter and length of pile were kept constant. Details of parameters selected for analysis is given in Table III.

Table III: Details of constant and varying parameters

Sr. No	Details of Parameter	Constant Parameter	Varying Parameter
1	Length of Pile	30 m	-
2	Diameter of Pile	2 m	-
3	Slenderness ratio (L/D)	15	-
4	b/D	0.5	-
5	L_F/L_P	0.4	-
6	Type of soil	Sand	-
7	Density of Sand	-	1) Loose sand 2) Medium dense sand 3) Dense sand
8	Type of Loading	-	1) Vertical Loading 2) Lateral Loading 3) Uplift Loading
9	Position of Fin	-	Bottom , Top and Middle

IV. RESULTS AND DISCUSSION

The analysis was conducted on single conventional circular pile and Spin Fin Pile with different fin position. The load settlement curves for these pile subjected to vertical load in loose, medium dense and dense sand are as shown in Fig. 2 (a-d). The ultimate load capacity taken as the load corresonding to the settlement equal to 10 percent of the diameter of pile base as per provisions of IS: 2911 (Part-4) 1985. It is observed that vertical load capacity of Spin Fin Pile with fins at bottom is much higher as compared to Spin Fin Pile with fins at middle and top and that of conventional circular pile.

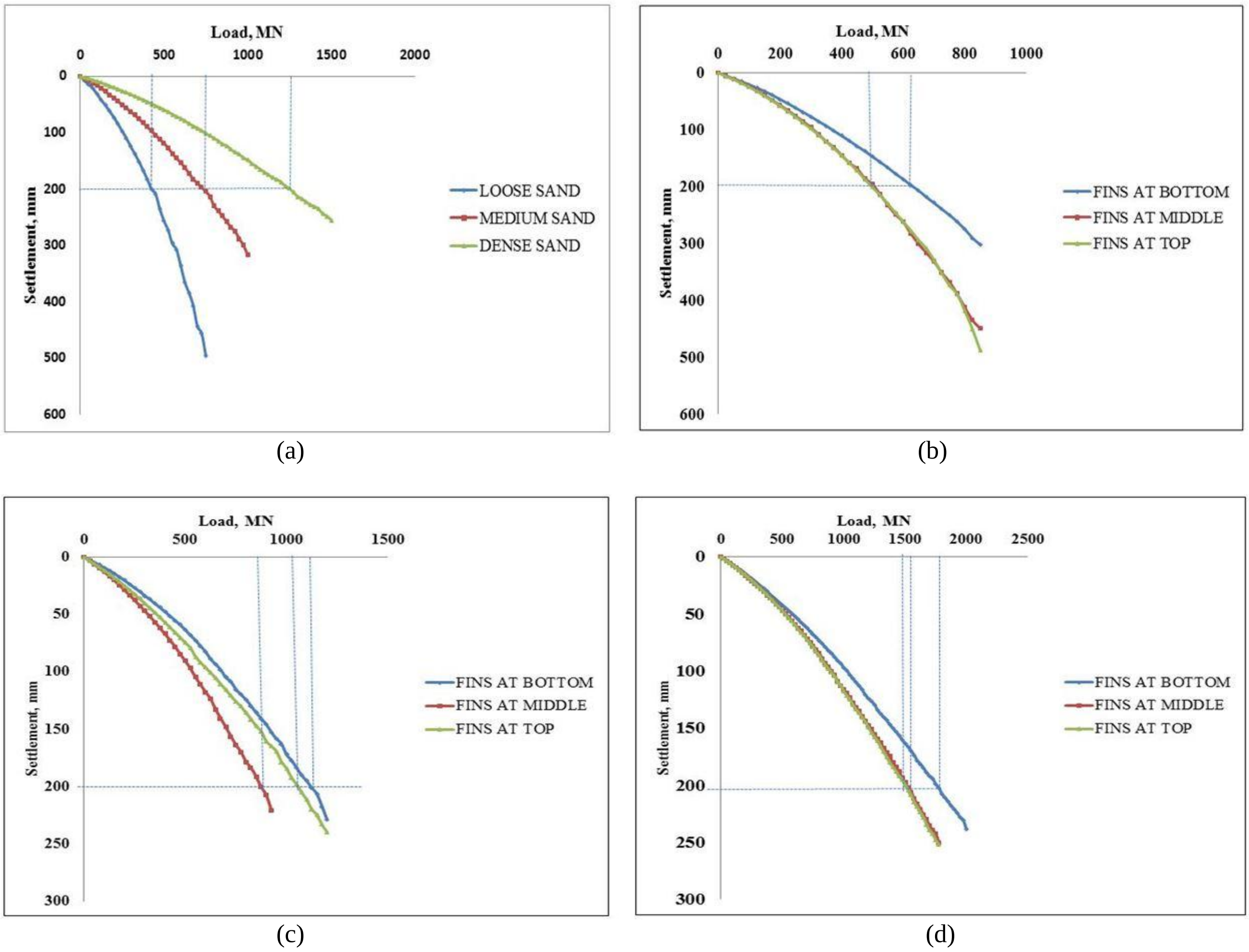


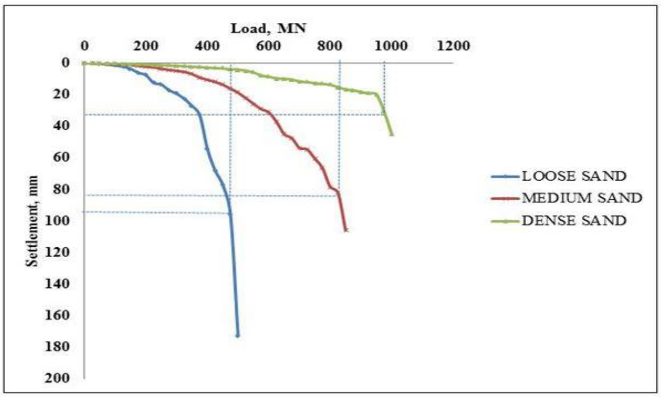
Fig.2. Load Settlement Curves for (a) conventional circular pile, (b) spin fin pile with different fins position in loose sand, (c) medium dense sand, (d) dense sand

The ultimate load capacities of the piles are given in Table IV.

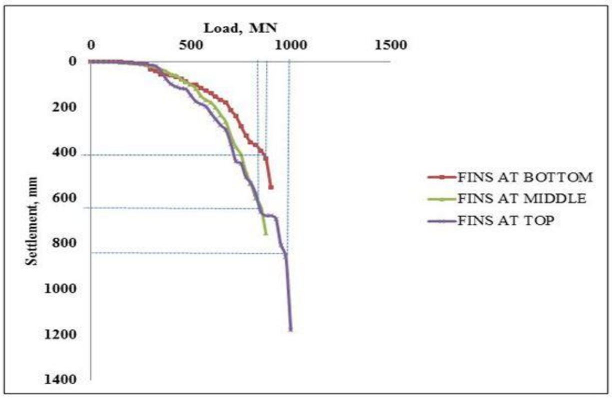
Table IV: Ultimate Load Capacities (Vertical) of conventional circular pile and spin fin pile

Type of pile	Ultimate load capacity (MN)			% increase in pile capacity compared with conventional circular pile		
	Loose sand	Medium dense sand	Dense sand	Loose sand	Medium dense sand	Dense sand
Conventional Circular Pile	450	650	1250	-	-	-
Spin fin pile (Fins at bottom)	630	1125	1775	40	73.08	42
Spin fin pile (Fins at middle)	500	875	1525	11.11	34.62	22
Spin fin pile (Fins at top)	500	1050	1500	11.11	61.53	20

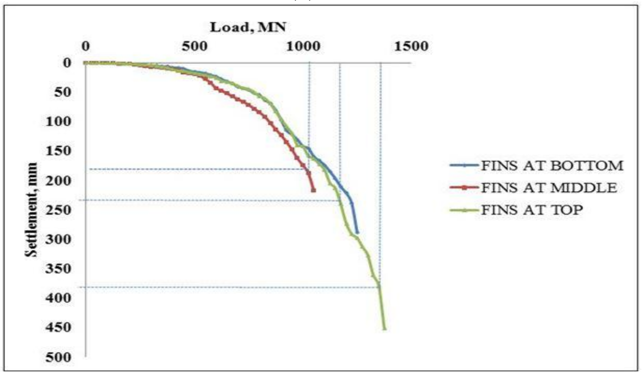
The load settlement curves for conventional circular pile and Spin Fin Pile with different fins position subjected to lateral load are shown in Fig 3. It is observed that lateral load capacity of Spin Fin Pile with fins at top is much higher as compared to Spin Fin Pile with fins at middle and bottom and that of conventional circular pile.



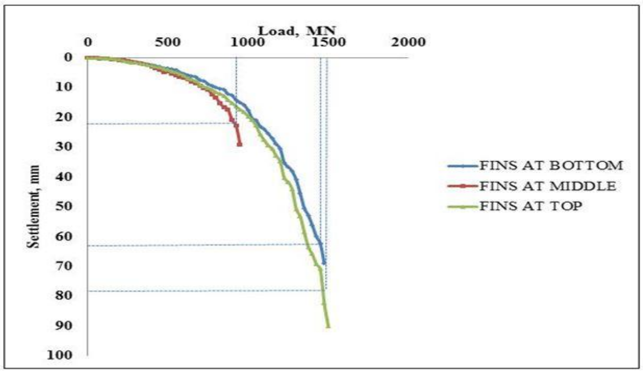
(a)



(b)



(c)



(d)

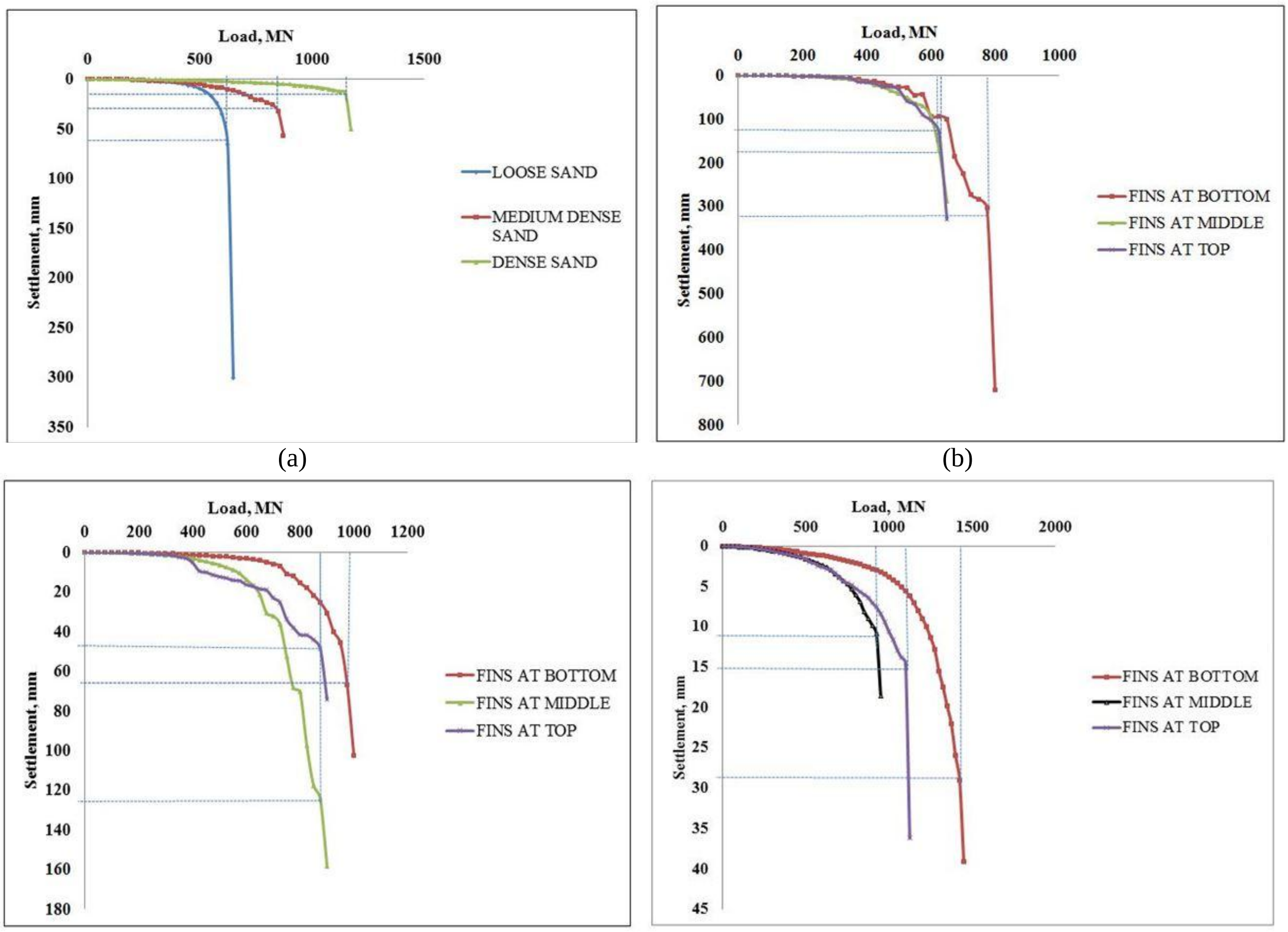
Fig. 3: Lateral Load Settlement Curves for (a) conventional circular pile, (b) spin fin pile with different fins position in loose sand, (c) medium dense sand, (d) dense sand

The ultimate lateral load capacities of the piles are given in Table V.

Table V: Ultimate Lateral Load Capacities of conventional circular pile and spin fin pile

Type of pile	Ultimate load capacity (MN)			% increase in pile capacity compared with conventional circular pile		
	Loose sand	Medium dense sand	Dense sand	Loose sand	Medium dense sand	Dense sand
Conventional Circular Pile	500	850	975	-	-	-
Spin fin pile (Fins at bottom)	900	1250	1475	80	47.06	51.28
Spin fin pile (Fins at middle)	875	1050	950	75	23.53	-2.56
Spin fin pile (Fins at top)	1000	1375	1500	100	61.76	53.85

The load settlement curves for conventional circular pile and Spin Fin Pile with different fins position subjected to Uplift load are shown in Fig 4. It is observed that Uplift load capacity of Spin Fin Pile with fins at bottom is much higher as compared to Spin Fin Pile with fins at middle and top and that of conventional circular pile.



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

Fig. 4: Uplift Load Settlement Curves for (a) conventional circular pile, (b) spin fin pile with different fins position in loose sand, (c) medium dense sand, (d) dense sand

The ultimate Uplift load capacities of the piles are given in Table VI.

Table VI: Ultimate Pull-Out Load Capacities of conventional circular pile and spin fin pile

Type of pile	Ultimate load capacity (MN)			% increase in pile capacity compared with conventional circular pile		
	Loose sand	Medium dense sand	Dense sand	Loose sand	Medium dense sand	Dense sand
Conventional Circular Pile	650	875	1175	-	-	-
Spin fin pile (Fins at bottom)	800	1000	1450	23.08	14.30	23.40
Spin fin pile (Fins at middle)	650	900	950	0	2.85	-19.15
Spin fin pile (Fins at top)	650	900	1125	0	2.85	-4.25

V. CONCLUSIONS

In this paper a comparative analysis of Conventional circular pile and Spin fin pile has been carried out in order to determine the increase in resistance of pile foundation against lateral, uplift and vertical loading. Based on the results of the present study, the following conclusions are drawn:

1. The ultimate vertical load capacity and uplift capacity of Spin Fin Pile with fins at bottom are much higher as compared to that of Spin fin pile with fins at middle and top.
2. The lateral load capacity of Spin Fin Pile with fins provided at top is much higher as compared to that of Spin fin pile with fins at bottom and middle.
3. The vertical load capacity of single Spin Fin Pile with fins at bottom is much higher than that of conventional circular pile i.e. 40 % in loose sand, 73 % in medium dense sand and 42 % in dense sand.

4. Lateral load capacity of single Spin Fin Pile with fins at top is higher than that of conventional circular pile i.e. 100 % in loose sand, 62 % in medium dense sand and 54 % in dense sand.
5. Uplift load capacity of single Spin Fin Pile with fins at bottom is much higher than that of conventional circular pile i.e. 23 % in loose sand, 14 % in medium dense sand and 23% in dense sand.

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