Numerical Analysis of Triangular Spin Fin Pile Subjected to Lateral Loading

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Abstract - *Spin fin piles are circular piles fitted with flat, steel plates ("fins") attached at a slight angle to the periphery of the pile. A triangular spin fin pile is a modification in conventional pile where triangular shaped fins are welded to the periphery of the monopile. Spin finned pile is used as foundation for offshore structures. The behavior of spin fin piles is difficult to explain using simple pile–soil theories or two-dimensional numerical analyses because of the complicated geometry of the piles. When driven, these piles rotate into the ground and achieve pile capacities far in excess of conventional piles. In this paper the study of the performance of triangular shaped spin fin pile foundation resting in sandy soil with respect to its various parameters is carried out. For this purpose, analytical model of spin fin pile is developed in MIDAS GTS NX software to simulate the pile foundation with different parameters proposed. A define soil model represent loose sand and medium dense sand with hollow steel triangular spin fin pile embedded within sand subjected to lateral loading. The fins increase the gross bearing area at the top of the pile and improve the lateral load carrying capacity. As a result, lateral load carrying capacity for spin fin piles can be usually achieved at shallow depths compared to similar sized straight pipe piles.*

Keywords: Fins, Lateral loading, MIDAS GTS NX, Numerical analysis, Triangular spin fin pile

1. 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. A Spin Fin pile is described as a pile that has four plates welded along the length of monopile at 90° to each other. Spin fin piles are most commonly used to provide geotechnical resistance for large tensile and compressive forces. The geometry of the fins is such that when viewed from but to tip, the top of one fin meets the bottom of the adjacent fin, thus providing 360^0 coverage. The angled "fins" cause the pile to rotate slightly as it is driven into the soil profile.

2. 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 behavior 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 behavior 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.

Mohamed A. Sakr et al. (2019)[8] carried out analysis on single pile with triangular shaped wings in sand for uplift loading condition. A nonlinear 3D analysis with an elastic plastic soil model, an elastic pile material and interface elements were used to model the modified pile–soil interaction. A numerical study using finite element analysis PLAXIS- 3D was run on piles without/with wings. Studies were done by changing the wing-width ratio (D_w/d_p = 2, 3, 4 and 5), number of wings (n_w = 0, 2 and 4). The effects of sand relative densities were also considered. Results indicated that the adopted wings at the pile end have a considerable effect in increasing the uplift capacity with lesser deformation. It has been found that, for the same wing-width ratio (D_w/d_p), the wing efficiency for uplift capacity increases as the sand relative densities increase. For the wing width ratio (D_w/d_p of = 5) and number of wings of (n_w =4) the improvement in the uplift capacity are found to be (2.2, 2.33 and 2.45) times of normal pile without wings for sand density of (30%, 50% and 80%) respectively. The existence of such wings at the lower part of the piles was provided an ideal anchorage system because of the significant locking-up effect of the soils within the wings, resulting in increased uplift capacity.

Table-1: Properties Assigned to Soil

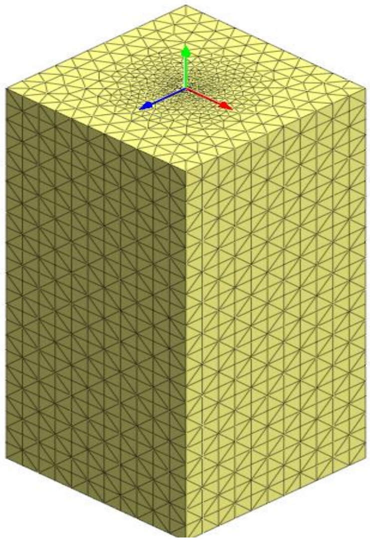
Properties	Unit weight	Relative Density	Young's modulus	Poisson's ratio	Angle of internal friction	cohesion
Symbols	γ	D_r	E	υ	Ø	c
Unit	kN/m³	%	MPa		degree	kPa
Loose Sand	16.33	40	20	0.3	34	2
Medium Dense Sand	16.5	55	27	0.3	37.88	1

3. METHODOLOGY

A three-dimensional finite element model was established in order to analyze the behavior of conventional circular pile and Spin fin pile with triangular shaped fins subjected to lateral loading. The computations were carried out using MIDAS GTS NX 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 behavior for which the material parameters are well established in geotechnical engineering practice. Soil block dimensions are taken as 22.5 times diameter of pile and 2.5 times length of pile. 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 and pile cap are as shown in Table 1, 2 and 3 respectively.

(a)

(b)



(c)

Fig-1: Three-Dimensional View of Triangular Spin Fin Pile with (a) Inclined fins (b) Straight fins and (c) Sand Block

Table-2: Properties Assigned to Pile

Sr. No.	Properties	Symbol	Values	Units
1	Young's modulus	E	2.0 x 10^8	kN/m²
2	Density	ρ	78	kN/m³
3	Poisson's ratio	υ	0.3	

Table-3: Properties Assigned to Pile Cap

Sr. No.	Properties	Symbol	Values	Units
1	Young's modulus	E	2.0 x 10^7	kN/m²
2	Density	ρ	24	kN/m³
3	Poisson's ratio	υ	0.15	

4. NUMERICAL ANALYSIS

Analysis was carried out to evaluate the performance of triangular spin Fin Pile with inclined and straight fins and conventional circular pile embedded in sand. The analyses were conducted on model pile foundation and the parameters varied were type of soil, slenderness ratio and inclination angle of fins. The parameters viz., pile diameter and length of pile were kept constant. Details of parameters selected for analysis is given in Table 4.

Table-4: Details of parameters selected for analysis

Sr. no.	Parameter	Constant parameters	Varying parameters
1	Diameter of pile	1.2 m	-
2	Dimensions for Fins	$L_f/L = 0.5$ $B_f/D = 0.5$	-
3	Thickness of Pile and Fin	0.075 m	-
4	Position of fins	At top of pile	-
5	Number of fins	4	-
6	Inclination of fin	-	0^0 82.40^0
7	Type of soil	-	Loose sand (D_r = 40%) Medium dense sand (D_r=55%)
8	Length of Pile (m)	-	18,24,30
9	L/D of pile	-	15,20,25
10	Loading condition	-	Lateral loading

5. RESULT AND DISCUSSIONS

The analysis was conducted on single conventional circular pile and triangular Spin Fin Pile subjected to lateral loading by considering different slenderness ratios (L/D=15,20,25). The comparison between triangular spin fin pile with inclined fins and straight fins were studied only for slenderness ratio (L/D) of 20. The load displacement curves for triangular spin fin pile with inclined fins and straight fins subjected to lateral load in loose sand and medium dense sand are plotted and are shown in figure 2 and figure 3 respectively. The load displacement curves for conventional circular pile and triangular spin fin pile subjected to lateral load in loose sand and medium dense sand are as shown in Figure 4 and Figure 5 for L/D=15, figure 6 and figure 7 for L/D=20 and figure 8 and figure 9 for L/D=25. The ultimate load capacity taken as the load corresponding to the displacement as per provisions of IS: 2911 (Part-4) 2013. The percentage increase in load carrying capacity of inclined fin and straight fin pile is shown in table 5 and percentage increase in load carrying capacity of circular pile and triangular spin fin pile is shown in table 6.

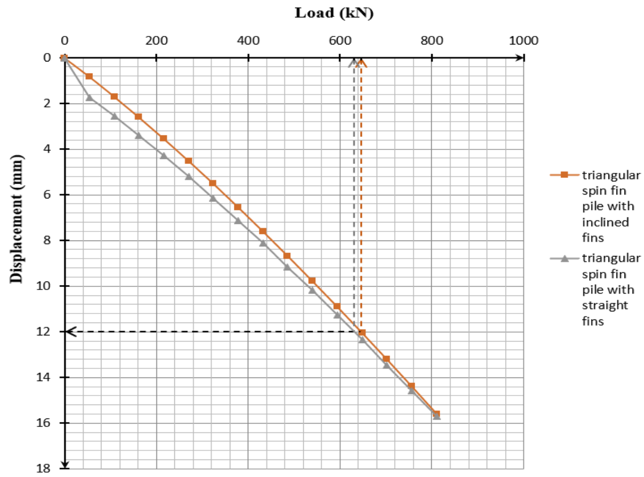


Fig-2: The load displacement curves for triangular spin fin pile with inclined fins and triangular spin fin pile with straight fins subjected to lateral load in loose sand for L/D=20

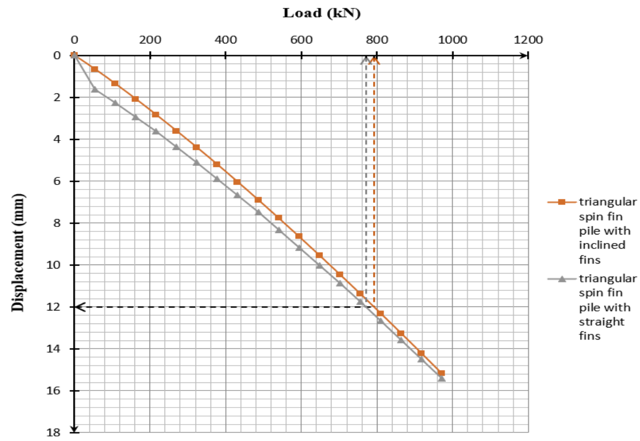


Fig-3: The load displacement curves for triangular spin fin pile with inclined fins and triangular spin fin pile with straight fins subjected to lateral load in medium dense sand for L/D=20

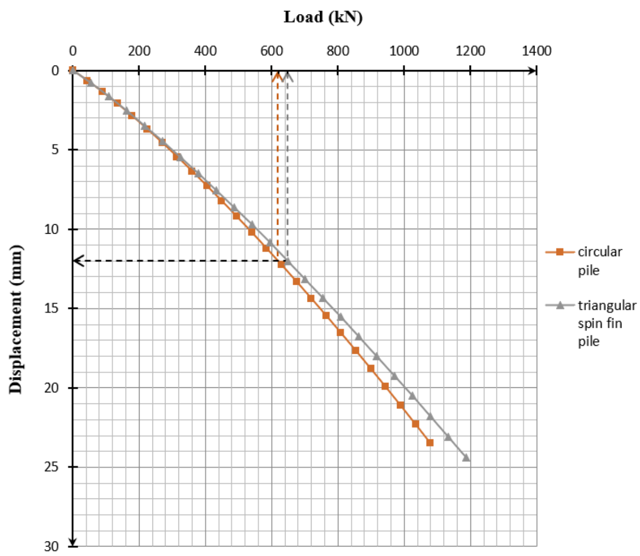


Fig-4: The load displacement curves for single circular pile and triangular spin fin pile subjected to lateral load in loose sand for L/D=15

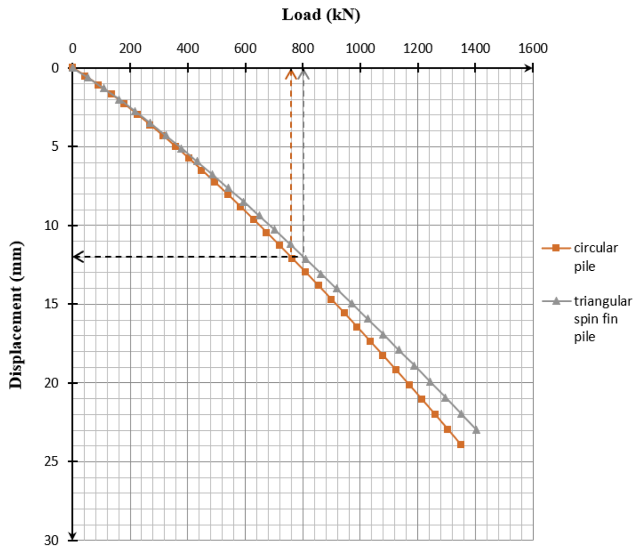


Fig-5: The load displacement curves for single circular pile and triangular spin fin pile subjected to lateral load in Medium dense sand for L/D=15

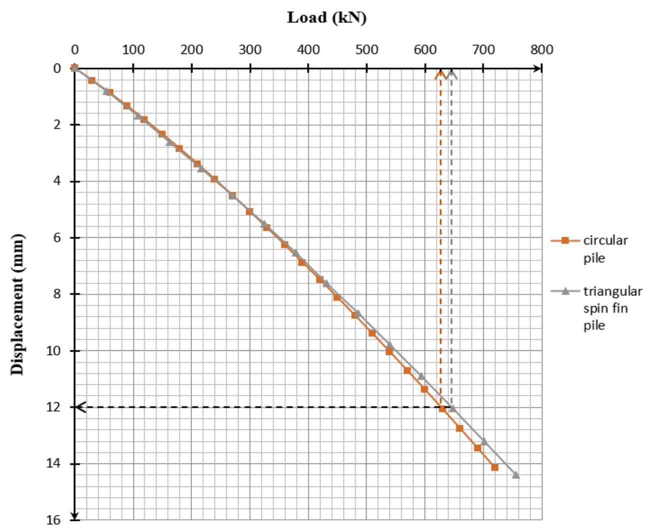


Fig-6: The load displacement curves for single circular pile and triangular spin fin pile subjected to lateral load in loose sand for L/D=20

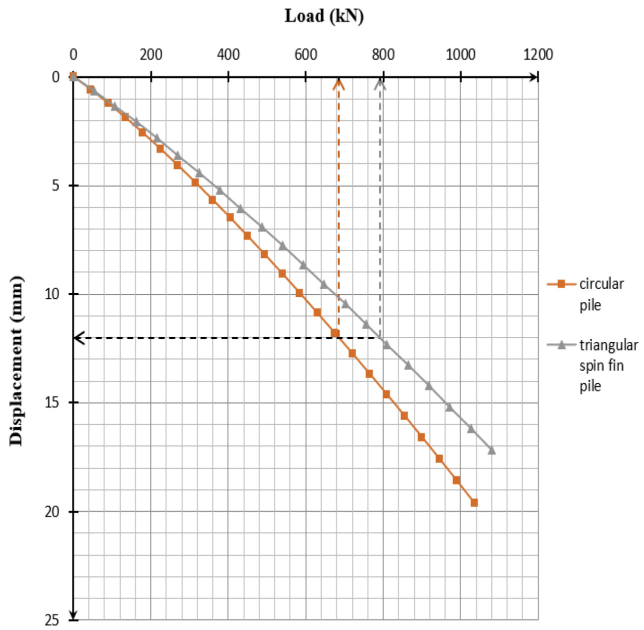


Fig-7: The load displacement curves for single circular pile and triangular spin fin pile subjected to lateral load in Medium dense sand for L/D=20

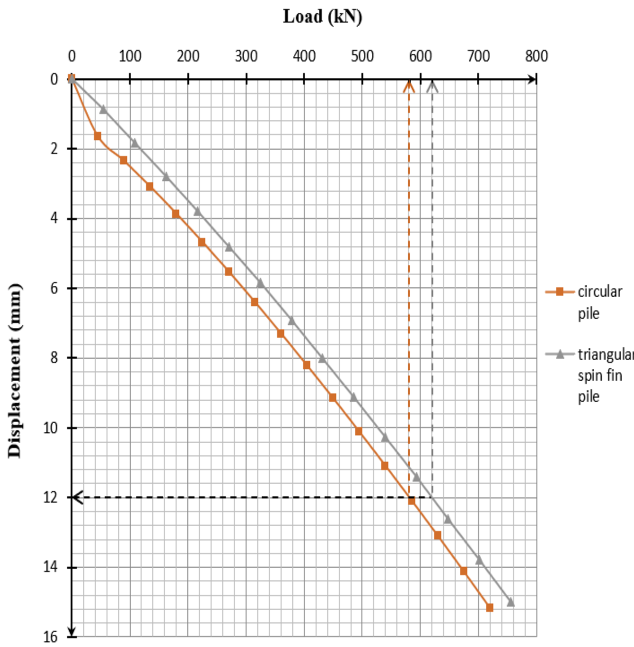


Fig-8: The load displacement curves for circular pile and triangular spin fin pile subjected to lateral load in loose sand for L/D=25

Table-5: Percentage increase in ultimate load carrying capacity of triangular spin fin pile compared with straight fin pile

Type of Loading	Relative density of sand	L/D ratio of pile	Ultimate load capacity of triangular spin fin pile (kN)		% increase in ultimate capacity
			Inclined fins	Straight fins	
Lateral loading	Loose sand	20	645	630	2.38
	Medium dense sand		792	770	2.86

Table-6: Percentage increase in ultimate load carrying capacity of triangular spin fin pile compared with circular pile

Type of Loading	Relative density of sand	L/D ratio of pile	Ultimate load capacity of circular pile (kN)	Ultimate load capacity of triangular spin fin pile (kN)	% increase in ultimate capacity
Lateral loading	Loose sand	15	619	648	4.68
		20	626	645	3.04
		25	580	620	6.90
	Medium dense sand	15	757	802	5.94
		20	684	792	15.79
		25	759	765	0.79

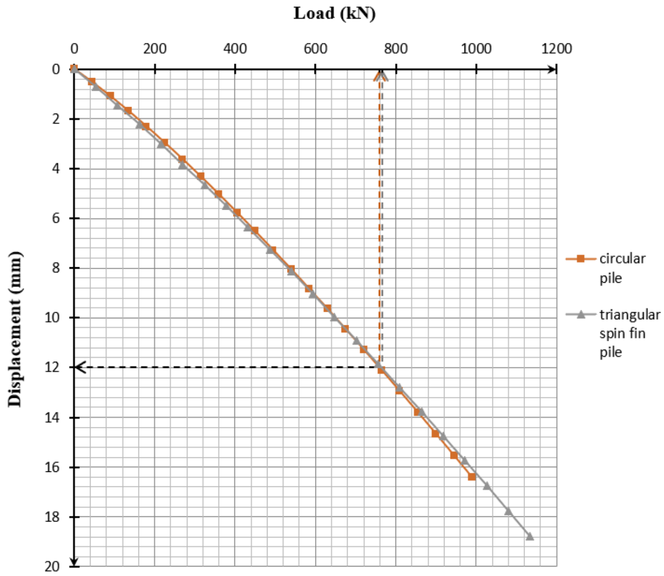


Fig-9: The load displacement curves for single circular pile and triangular spin fin pile subjected to lateral load in Medium dense sand for L/D=25

Values obtained from curves shown in figure 2, figure 3 are tabulated in table 5 and figure 4, figure 5, figure 6, figure 7 figure 8 and figure 9 are tabulated in table 6, from tables we can see that ultimate load carrying capacity of triangular spin fin pile with inclined fins is more than triangular spin fin pile with straight and conventional circular pile for all slenderness ratio considered for study for lateral loading. For lateral loading slenderness ratio of 15 gives maximum load carrying capacity values for loose as well as medium dense sand.

6. CONCLUSIONS

In this paper a comparative analysis of conventional circular pile and triangular Spin fin pile has been carried out in order to determine the increase in resistance of piles with different L/D ratio against lateral loading in loose and medium dense sand. Based on the results of the present study, the following conclusions are drawn:

1. The lateral load carrying capacity of conventional circular pile increases by addition of triangular fins to it.
2. The lateral load carrying capacity of triangular spin fin pile with slenderness ratio L/D=15 can be adopted for loose as well as medium dense sand as values of ultimate load is more for L/D=15.
3. The value of lateral load carrying of triangular spin fin pile with inclined fins is more than straight fin pile. Hence inclined fin pile can be considered as more economical.

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