Numerical Analysis on Trapezoidal Spin Fin Pile Subjected To Vertical Loading

Shubhravi M. Akotkar[1], Dr. Anant I. Dhatrak[2], Poonam P. Gawande[3]

[1]M.Tech Student, Dept. of Civil Engineering, Government College of Engineering Amravati, Maharashtra, India
[2]Dean Academics, Dept. of Civil Engineering, Government College of Engineering Amravati, Maharashtra, India
[3]Ph.D Scholar, Dept. of Civil Engineering, Government College of Engineering Amravati, Maharashtra, India

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Abstract - *Spin Fin pile is used as foundation for offshore structures. Spin Fin piles are traditional pipe piles fitted with flat, steel plates ("fins") attached at a slight angle over the lower or upper few feet of the pipe. The behavior of spin fin piles is difficult to explain using simple pile–soil theories or 2 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. The strength is derived from the pile tips end bearing and friction offered by pile and fins. Because of their load deformation characteristics, these piles allow substantial pile overload deformation without catastrophic failure even after repeated loading. The screw-shaped tip on the pile and friction from the pile shaft give the spin fin pile its strength. These piles can be successfully driven using both conventional impact and vibratory hammers, with templates and accessories. The dissertation work aims to study the performance of trapezoidal spin fin Pile foundation resting in sandy soil with respect to its various parameters. For this purpose, analytical model of spin fin pile shall be developed in MIDAS GTS NX 3D software to simulate the pile foundation with different parameters proposed. A define soil model represent loose sand, medium dense sand, and hollow steel pile embedded within sand subjected to large vertical loading.*

Key Words: Inclined Trapezoidal Spin fin pile, straight Trapezoidal Spin fin pile Vertical loading, screw tip, catastrophic failure, MIDAS GTS NX 3D

1. INTRODUCTION

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, in vertical loading the fins are provided at bottom because of pressure diagram requirement. A Spin Fin pile is described as a pile that has four plates welded to bottom or top tip of traditional monopile at 90° to each other covering complete circumference of pile. Section and plan of Spin fin pile is shown in Figure 1. Spin fin piles are most commonly used to provide geotechnical resistance for large tensile and compressive forces. The name for the spin fin pile is derived from the fact that the pile actually rotates while being driven due to the angled fins, much like a screw providing more anchorage in soil.

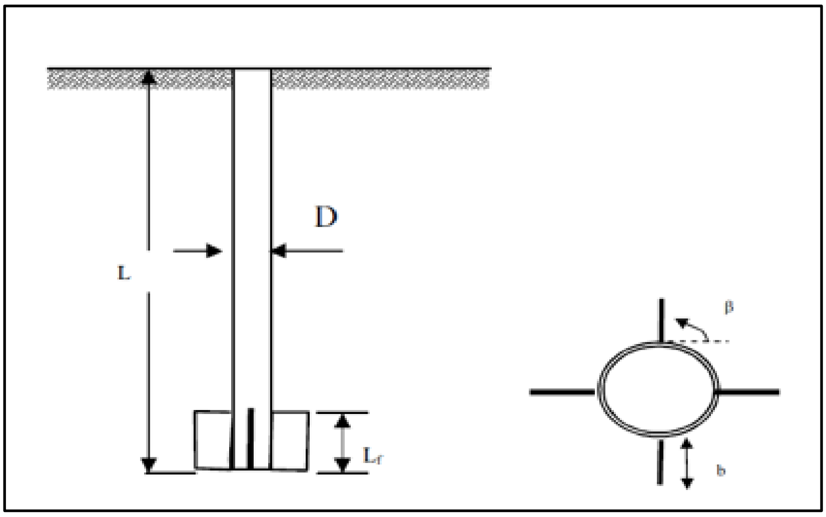


Fig- 1: Section and plan of Spin fin pile

2. LITERATURE REVIEW

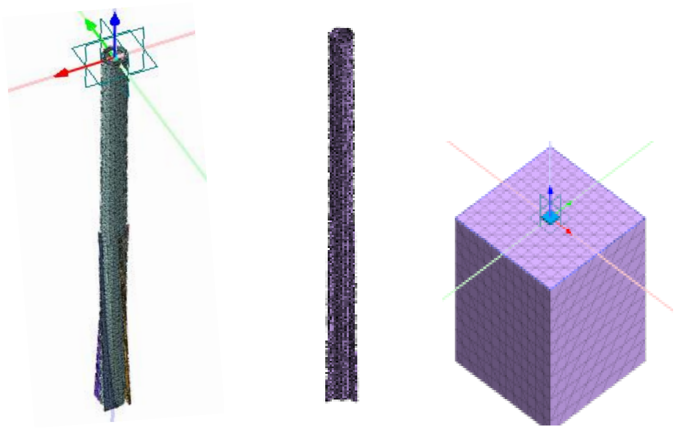
K.V. Babu et al. (2018)1 carried out analysis on Lateral Load Response of Fin Piles. They carried out numerical model studies on the lateral load response of regular piles (pile without fins) and fin piles in sand. Three dimensional finite element analyses were performed on regular piles as well as fin 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.

Rohan R. Deshmukh3et.al carried out a linear 3D analysis of monopile, finned pile and tapered fin pile foundation with an elastic plastic soil model (Mohr-Coulomb), an elastic pile material (steel), cushion model (Mohr-Coulomb) and interface elements are used to model the pile–soil interaction using MIDAS GTS-NX finite element software package. A define soil model represent medium dense sand and hollow steel pile embedded within sand subjected to large lateral loading. The boundary is a cube with sides of 22.5 times the diameter of the pile and a depth 2.5 times the pile length. Lateral load was applied in the range from 50MN to 200MN along the fin (in the direction of negative x-axis) and result was generated in the form of p-y curve, where 'y' is the pile head displacement (% pile diameter), it is concluded that lateral resistance of cushion-taper fin pile is more compared to finned pile, taper fin pile and monopile in all direction and that solid stresses in loading directions are minimum in monopile and cushion-tapered fin pile but maximum in the finned and tapered fin pile due to increase in steel quantity for making of fin and that shear stresses in loading directions are minimum in monopile and cushion-taper fin pile but maximum in the finned and tapered fin pile due to increase in steel quantity for making of fin.

3. METHODOLOGY

A three-dimensional finite element model was established in order to analyze the behavior of conventional and Trapezoidal Spin fin pile. The computations were carried out using MIDAS GTS NX 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 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 as shown in fig. 2. 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 pile and cap are as shown in Table I, II and III respectively.



(a) (b) (c)

Fig- 2: a) Three Dimensional View of inclined trapezoidal Spin Fin Pile, b) Three Dimensional View of straight trapezoidal Spin Fin Pile and c) Sand Block

Table-1: Properties assigned to soil layer for analysis

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/m^3	%	MPa		degree	kPa
Loose Sand	16.33	40	20	0.3	34	1
Medium dense sand	16.5	55	27	0.3	38	2

Table -2: Properties assigned to Spin fin pile for analysis

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	0.3	

Table -3: Properties assigned to Pile Cap for analysis

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

4. NUMERICAL ANALYSIS

Analysis was carried out to evaluate the performance of Trapezoidal Spin Fin Pile with inclined fins, trapezoidal spin fin pile with straight fins and conventional circular pile embedded in sand. The analyses were conducted on model pile foundation and the parameters selected for analysis given in Table IV and V.

Table -4: Constant Dimensions of Spin fin pile

Sr. no.	Parameter	Values
	Diameter of pile	1.2 m
2	Dimensions for Fins	L_f/L = 0.5, B_b/D = 0.5 and B_t/B_f=0.5
3	Thickness of Pile and Fin	0.075 m
4	Position of fins	At bottom of pile
5	Number of Fins	4

Table -5: Details of parametric study for Spin fin pile

Sr. no.	Parameter	Values
1	Type of soil	Loose sand (D_r = 40%)
		Medium dense sand (D_r =5 5%)
2	Length of Pile (m)	18, 24, 30

3	L/D of pile	15, 20, 25
4	Inclination of Fins	18m =3.81^0,24 m =2.86^0,30m =2.29^0

5. RESULTS AND DISCUSSIONS

The analysis was conducted on single conventional circular pile and single trapezoidal Spin Fin Pile with inclined and straight fin subjected to vertical loading by considering different slenderness ratios of (L/D=15,20,25) and B_t/B_f=0.5. The load settlement curves for conventional circular pile and trapezoidal spin fin pile subjected to vertical load in loose sand and medium dense sand are as shown in Figure 3 and Figure 4 for L/D=15; Figure 5 and Figure 6 for L/D=20; Figure 7 and Figure 8 for L/D=25; and the comparison of trapezoidal spin fin pile with inclined fin and trapezoidal spin fin pile with straight fin are shown in Figure 9 and Figure 10 for L/D=20 with B_t/B_f =0.5. The ultimate load capacity taken as the load corresponding to the settlement as per provisions of IS: 2911 (Part-4) 2013. The percentage increase in load carrying capacity is shown in table VI and VII.

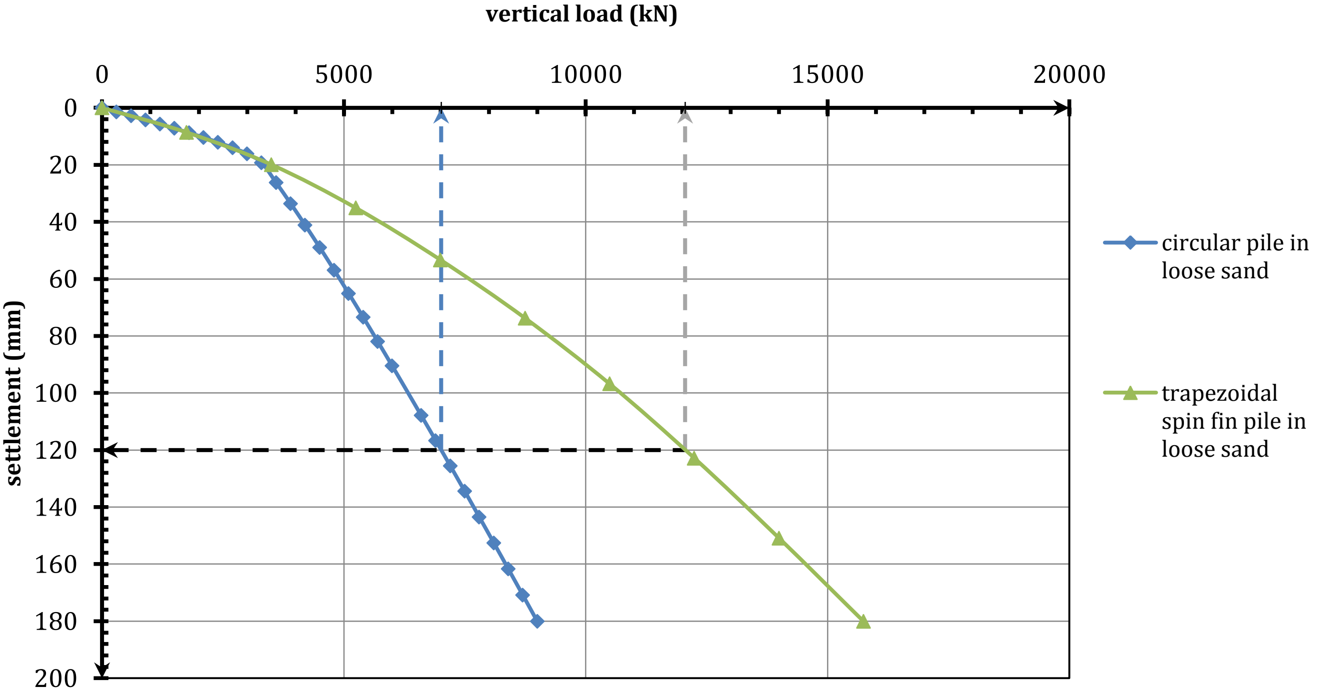


Fig- 3: The load settlement curves for single circular pile and trapezoidal spin fin pile with inclined fin subjected to vertical load in loose sand for L/D=15 with B_t/B_f=0.5

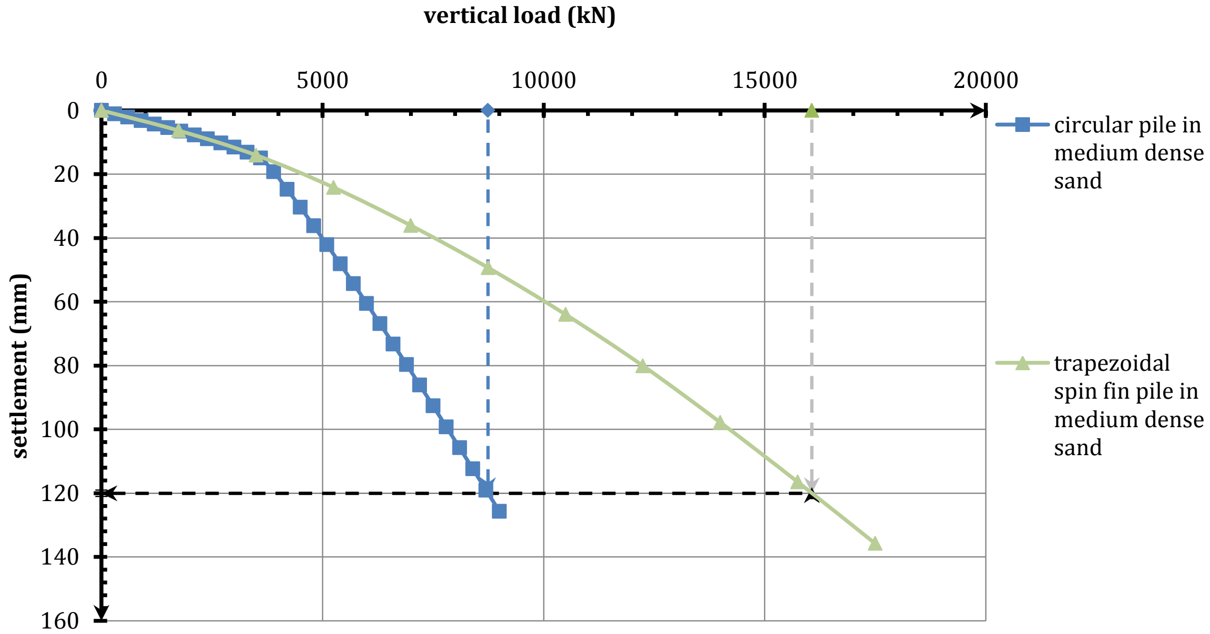


Fig- 4: The load settlement curves for single circular pile and trapezoidal spin fin pile with inclined fin subjected to vertical load in Medium Dense sand for L/D=15 with B_t/B_f=0.5

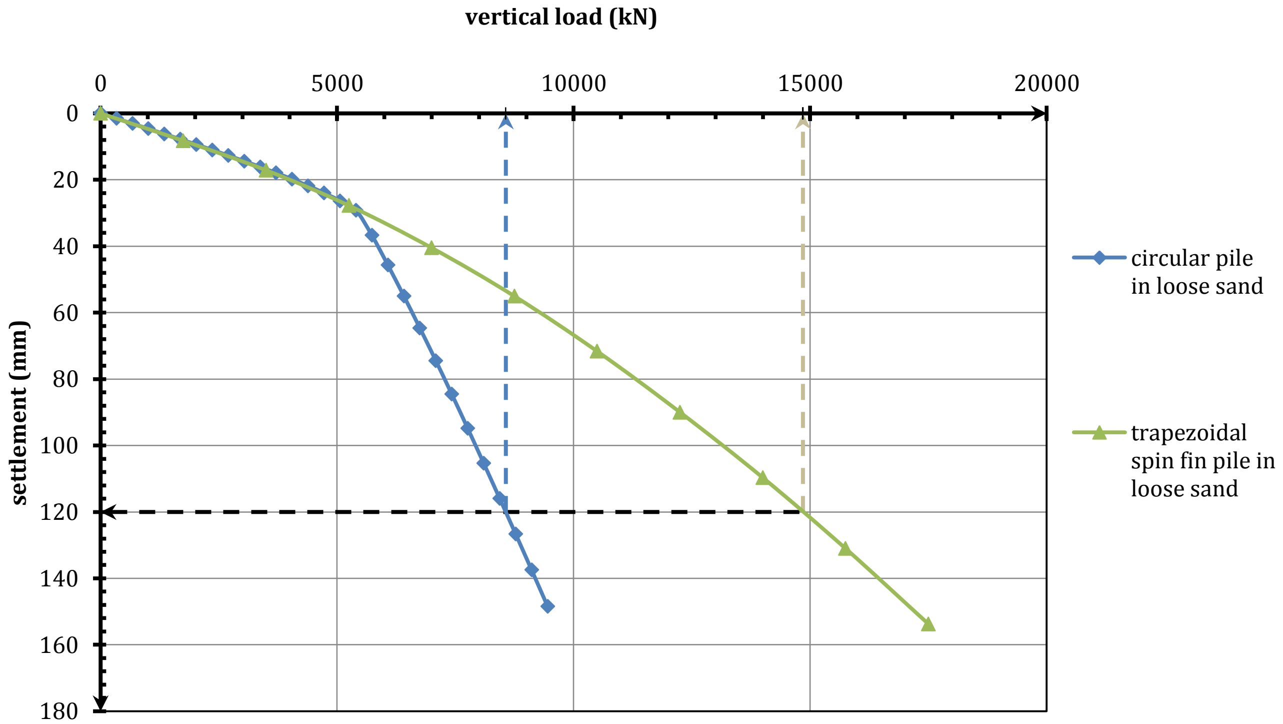


Fig- 5: The load settlement curves for single circular pile and trapezoidal spin fin pile with inclined fin subjected to vertical load in loose sand for L/D=20 with B_t/B_f=0.5

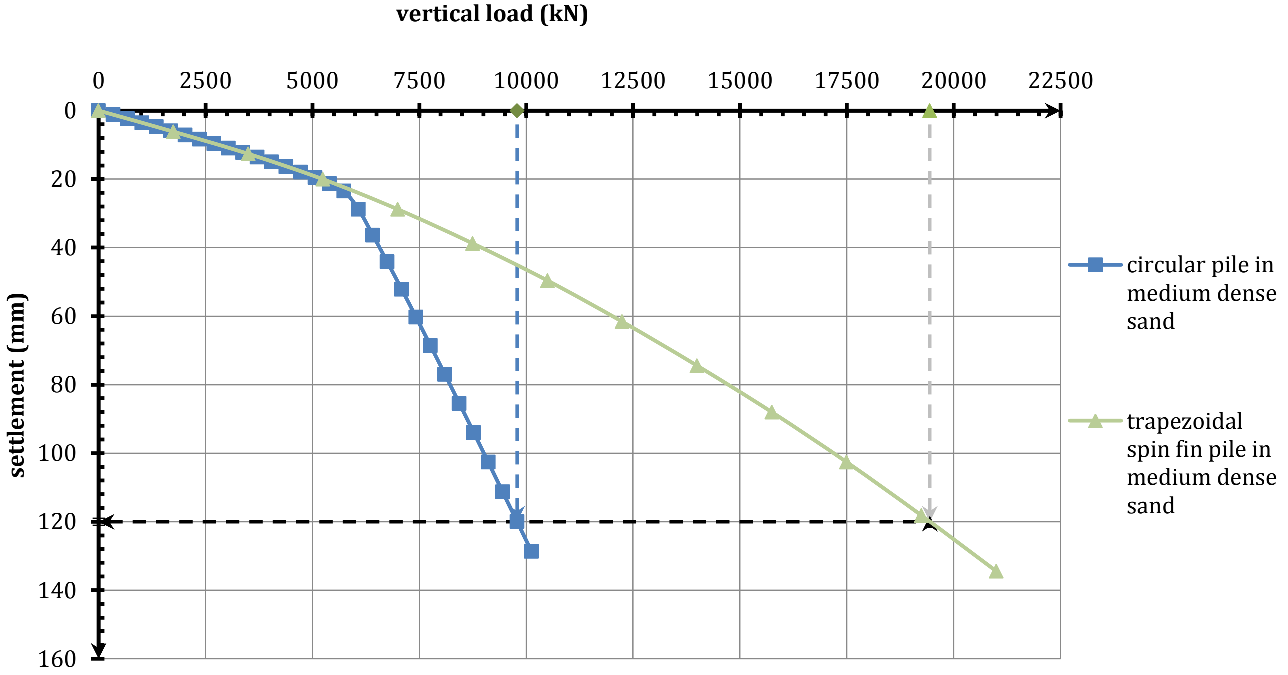


Fig- 6: The load settlement curves for single circular pile and trapezoidal spin fin pile with inclined fin subjected to vertical load in Medium Dense sand for L/D=20 with B_t/B_f=0.5

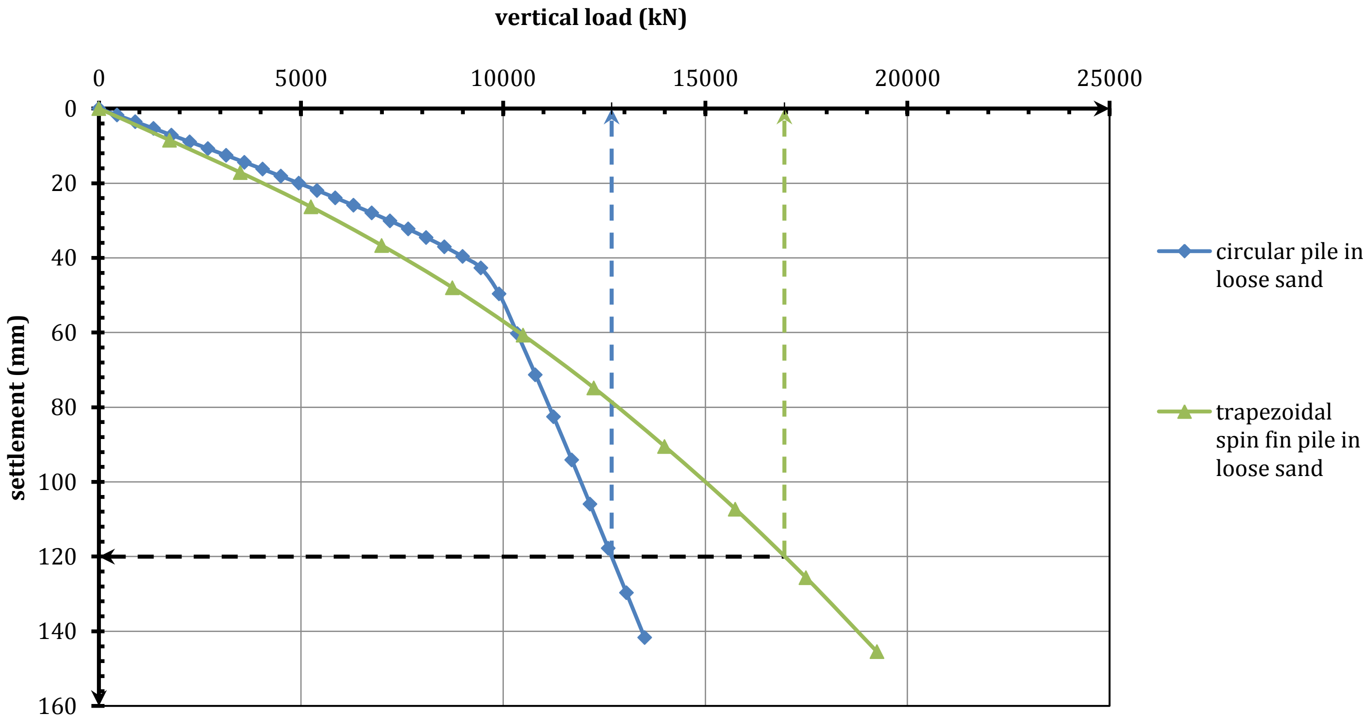


Fig- 7: The load settlement curves for single circular pile and trapezoidal spin fin pile with inclined fin subjected to vertical load in loose sand for L/D=25 with B_t/B_f=0.5

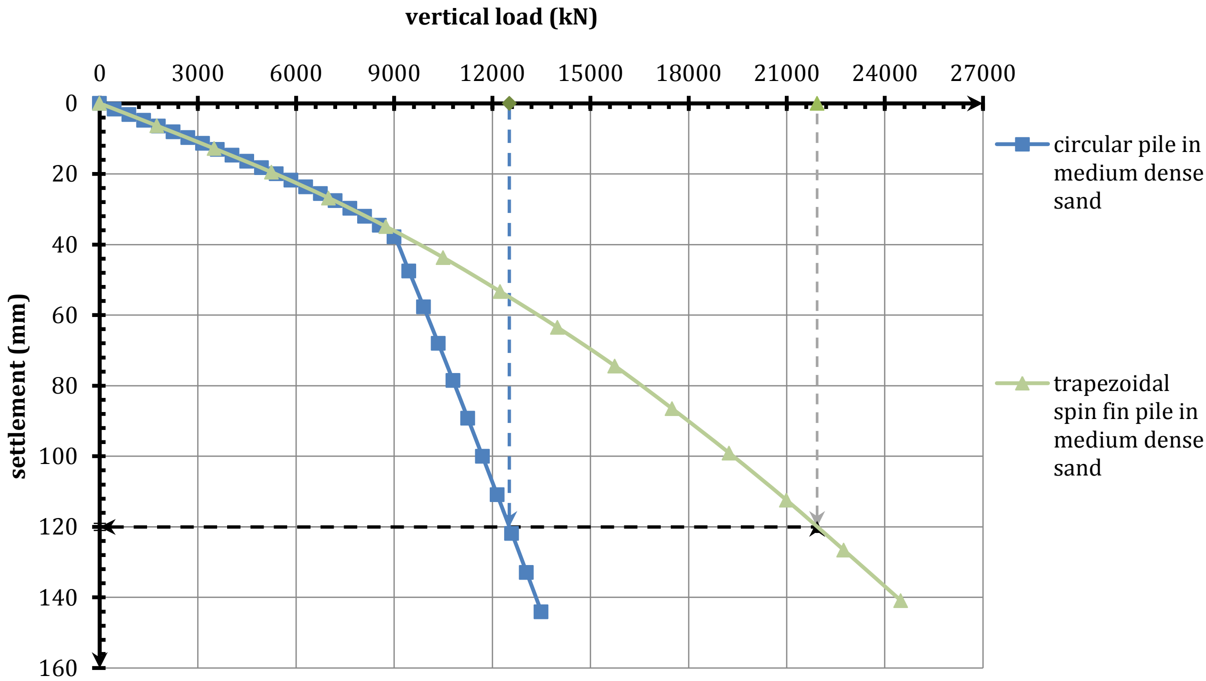


Fig- 8: The load settlement curves for single circular pile and trapezoidal spin fin pile with inclined fin subjected to vertical load in Medium Dense sand for L/D=25 with B_t/B_f=0.5

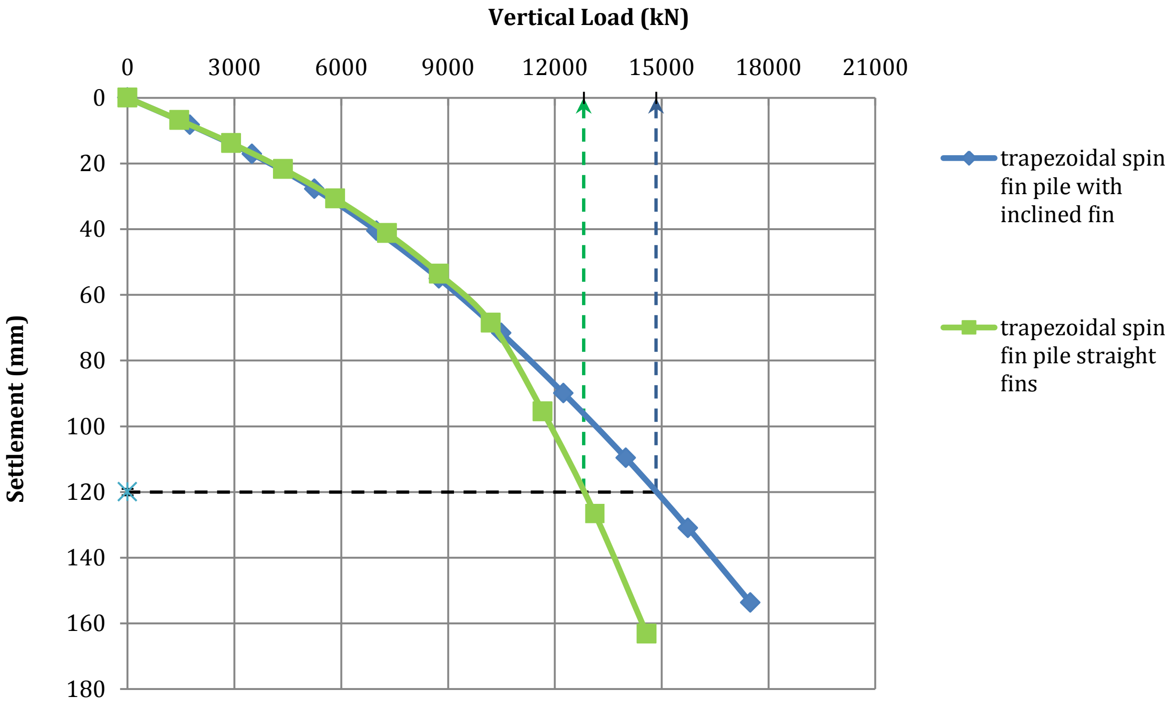


Fig- 9: The load settlement curves for inclined trapezoidal spin fin pile and straight trapezoidal spin fin pile subjected to vertical load in loose sand for L/D=20 with B_t/B_f=0.5

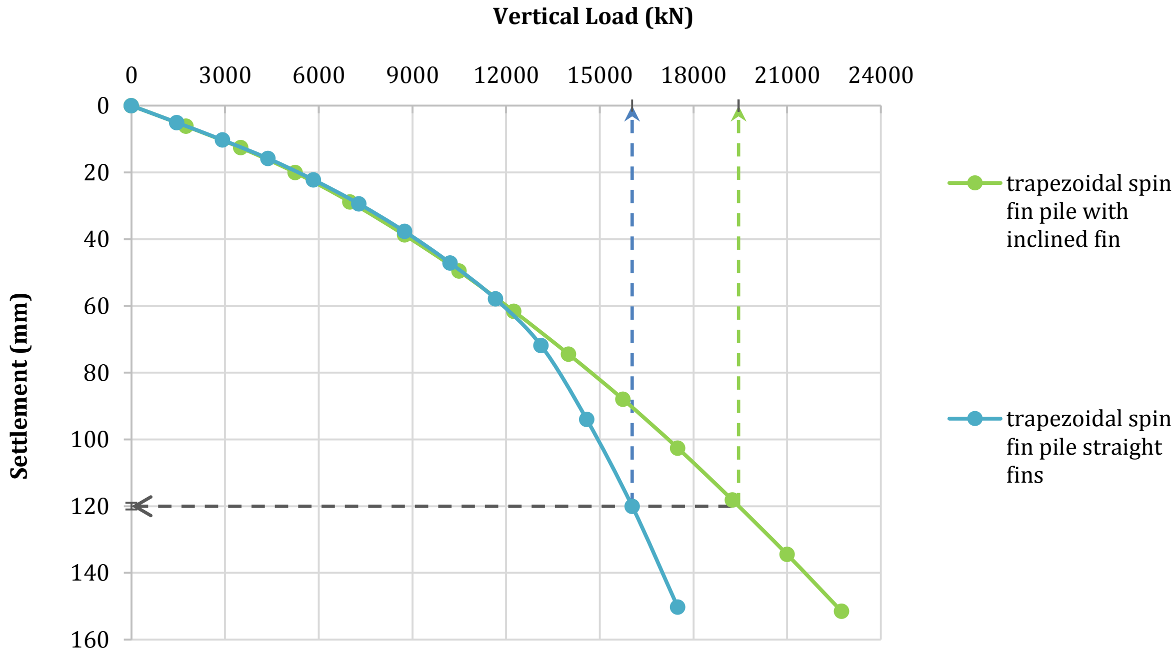


Fig-10: The load settlement curves for inclined trapezoidal spin fin pile and straight trapezoidal spin fin subjected to vertical load in Medium Dense sand for L/D=20 with B_t/B_f=0.5

Table -6: Percentage increase in vertical capacities of piles due to provision of trapezoidal fins for B_t/B_f=0.5

Relative density of sand	L/D ratio of pile	Ultimate load capacity of circular pile (kN)	Ultimate load capacity of inclined fin trapezoidal spin fin pile (kN)	% increase in ultimate capacity
Loose sand	15	7015	12055	71.92793
	20	8565	14345	73.31205
	25	12685	16955	33.69158
Medium dense sand	15	8745	16065	83.75267
	20	9790	19445	98.63152
	25	12525	21935	75.15154

Table -7: Percentage increase in vertical capacities of piles of trapezoidal fins for B_t/B_f=0.5 with straight and inclined fins

Relative density of sand	L/D ratio of pile	Ultimate load capacity of straight fin trapezoidal spin fin pile (kN)	Ultimate load capacity of inclined fin trapezoidal spin fin pile (kN)	% increase in ultimate capacity
Loose sand	20	12815	14845	15.84
Medium dense sand	20	16035	19445	21.26

6. CONCLUSIONS

From above study on inclined finned trapezoidal spin fin pile compared to circular and straight finned trapezoidal spin fin pile subjected to vertical loading, following are the conclusions drawn:

1. The vertical load carrying capacity of conventional circular pile increases by addition of inclined trapezoidal fins to it by upto 98.631% for B_t/B_f=0.5.

2. The vertical load carrying capacity of trapezoidal spin fin pile with slenderness ratio L/D=20 can be adopted for loose sand and medium dense sand, for B_t/B_f=0.5.

3. Inclined trapezoidal Spin Fin Pile are more effective than straight Trapezoidal spin fin pile in carrying vertical loads by upto 21.26%.

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