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Numerical Analysis on Trapezoidal Spin Fin Pile Subjected to Uplift Loading

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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 pile. 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 piles frictional resistance. 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 uplift loading.

Keywords: Trapezoidal Spin fin pile, Uplift loading, MIDAS GTS NX 3D

I. 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. A Spin Fin pile is described as a pile that has four plates welded to bottom 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.

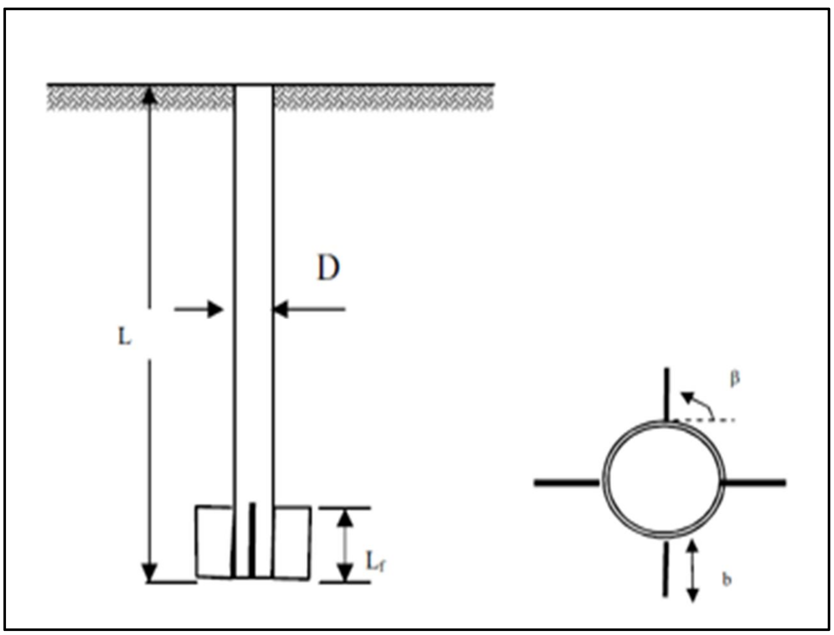

Figure 1: Section and plan of Spin fin pile

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II. LITERATURE REVIEW

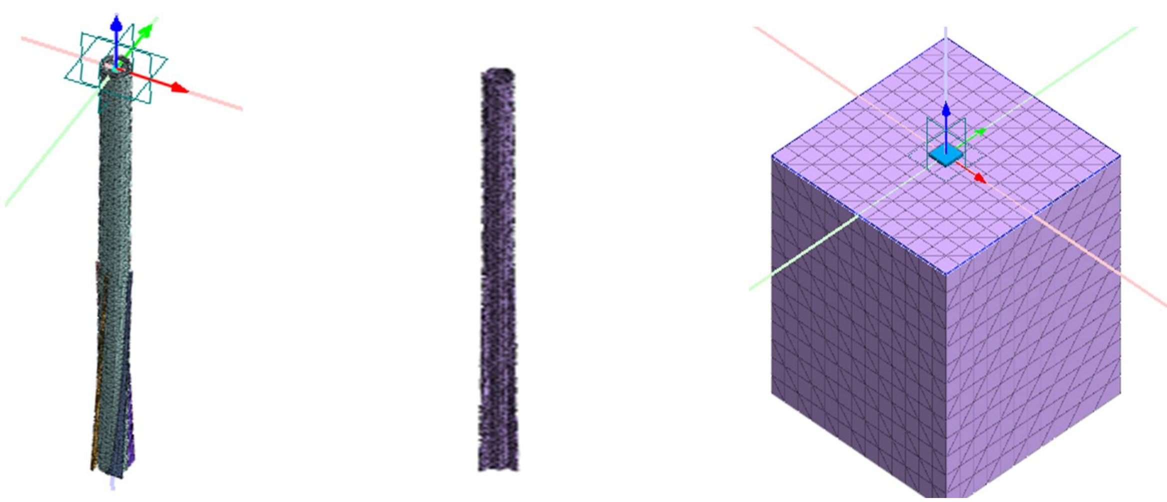
K.V. Babu et al. (2018)[1] carried out analysis on Lateral Load Response of Fin Piles. They carried out numerical model studies on the lateral load response of regular piles (pile without fins)and fin piles in sand. Three dimensional finite element analyses were performed on regular piles as well as 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 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. Deshmukh[3]*et.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.

III. 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)

Figure 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

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Table I: 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	Y	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 II: 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 III: 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	

IV. NUMERICAL ANALYSIS

Analysis was carried out to evaluate the performance of Trapezoidal Spin Fin Pile and conventional circular pile embedded in sand. The analyses were conducted on model pile foundation and the parameters selected for analysis given in Table III and IV

Table IV: 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 V: 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

V. 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 uplift 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 uplift 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.

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The percentage increase in load carrying capacity is shown in table VI and VII.

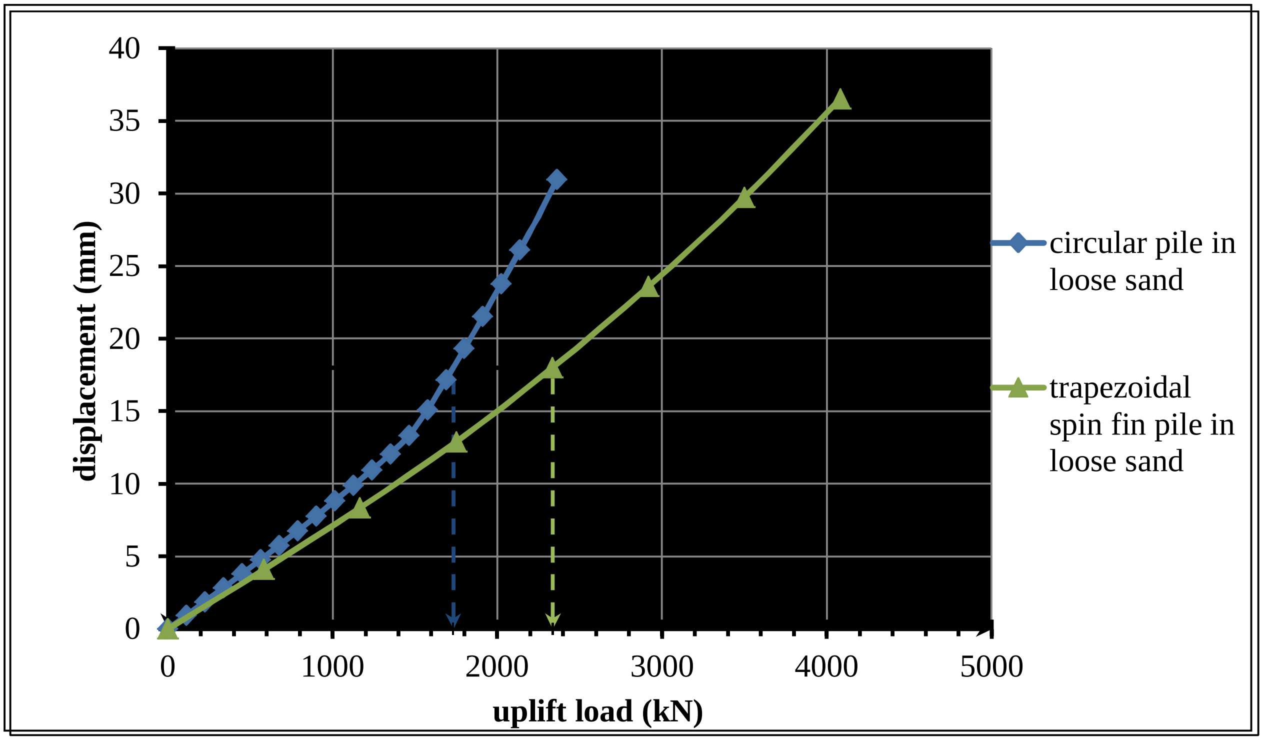

Figure 3: The load settlement curves for single circular pile and trapezoidal spin fin pile subjected to uplift load in loose sand for L/D=15 with B_t/B_f=0.5

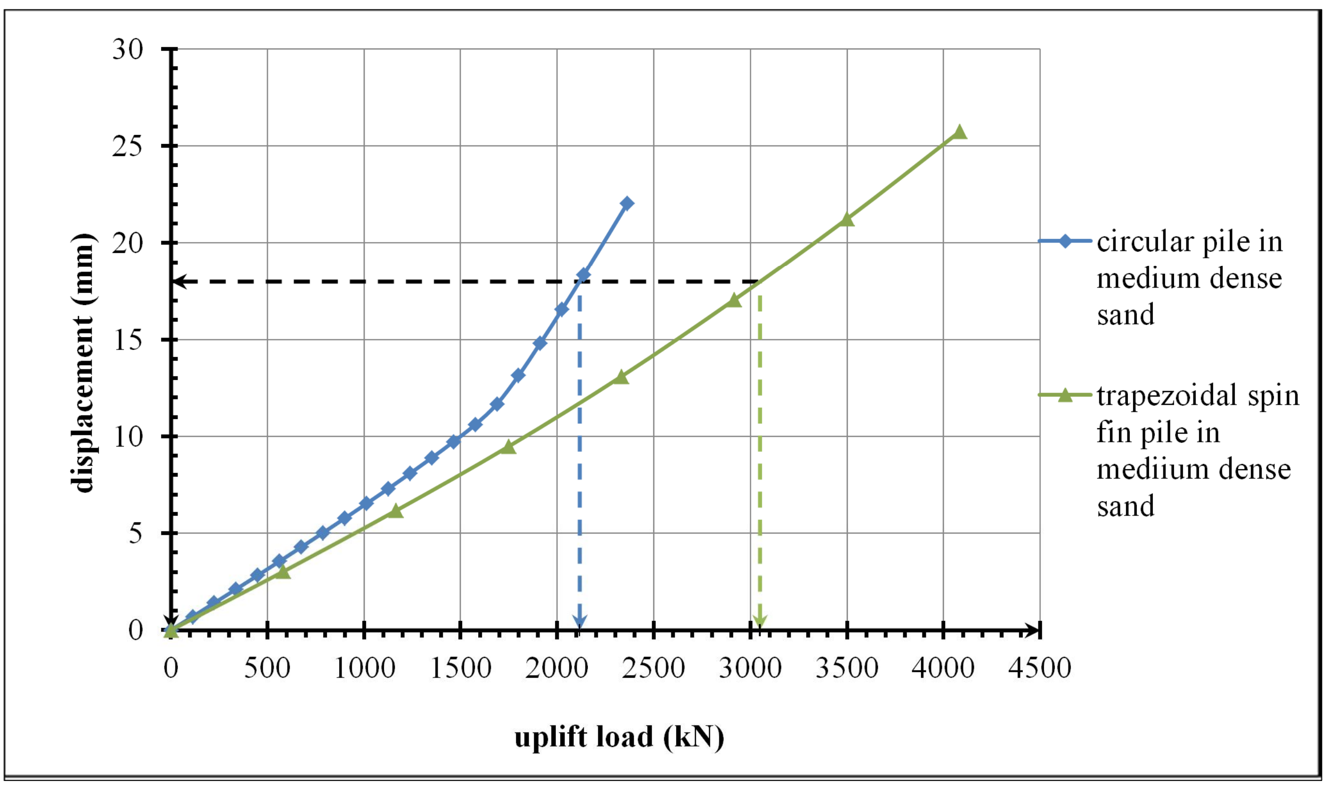

Figure 4: The load settlement curves for single circular pile and trapezoidal spin fin pile subjected to uplift load in Medium Dense sand for L/D=15 with B_t/B_f=0.5

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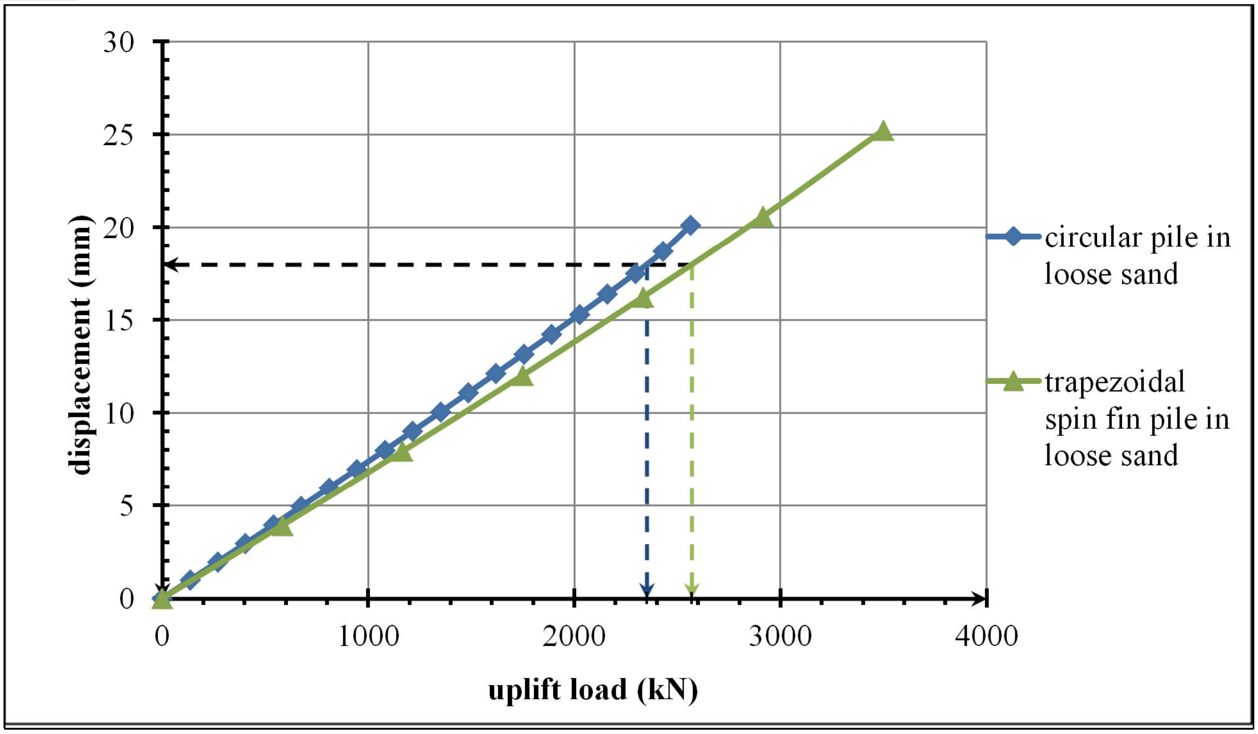

Figure 5: The load settlement curves for single circular pile and trapezoidal spin fin pile subjected to uplift load in loose sand for L/D=20 with B_t/B_f=0.5

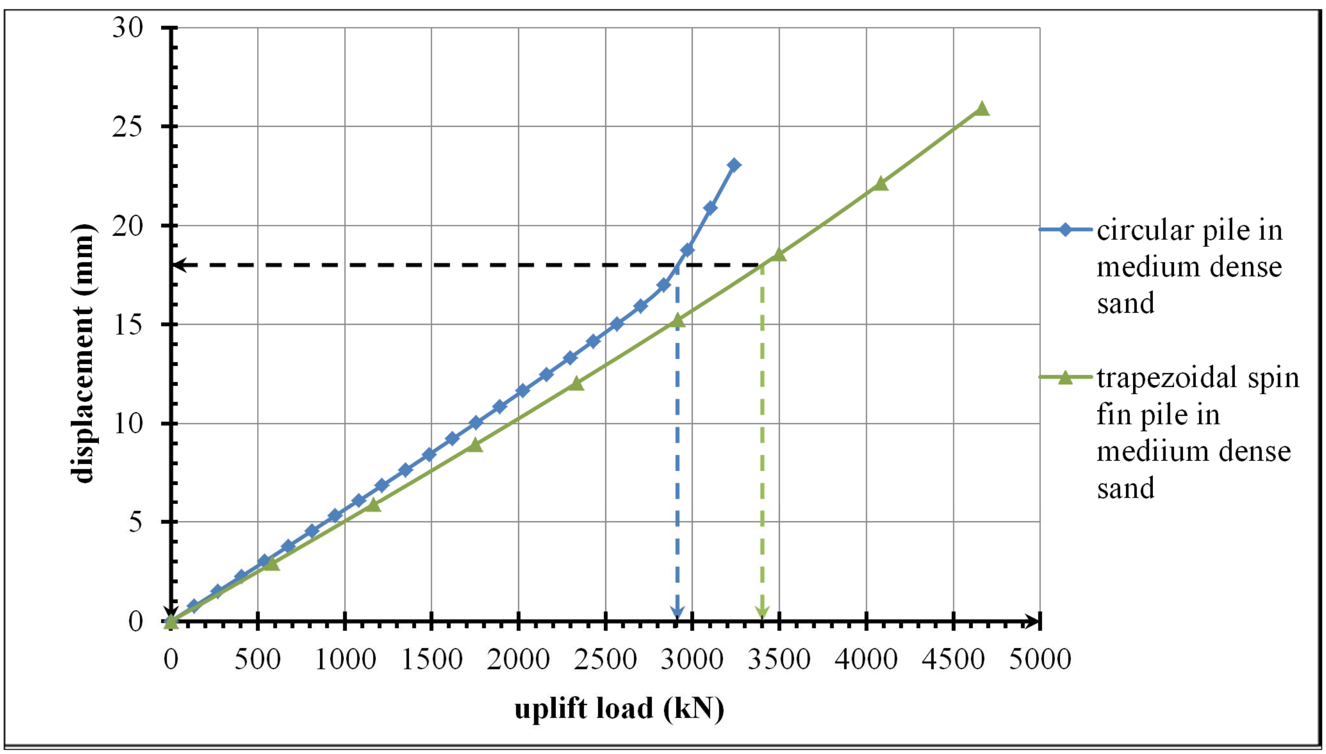

Figure 6: The load settlement curves for single circular pile and trapezoidal spin fin pile subjected to uplift load in Medium Dense sand for L/D=20 with B_t/B_f=0.5

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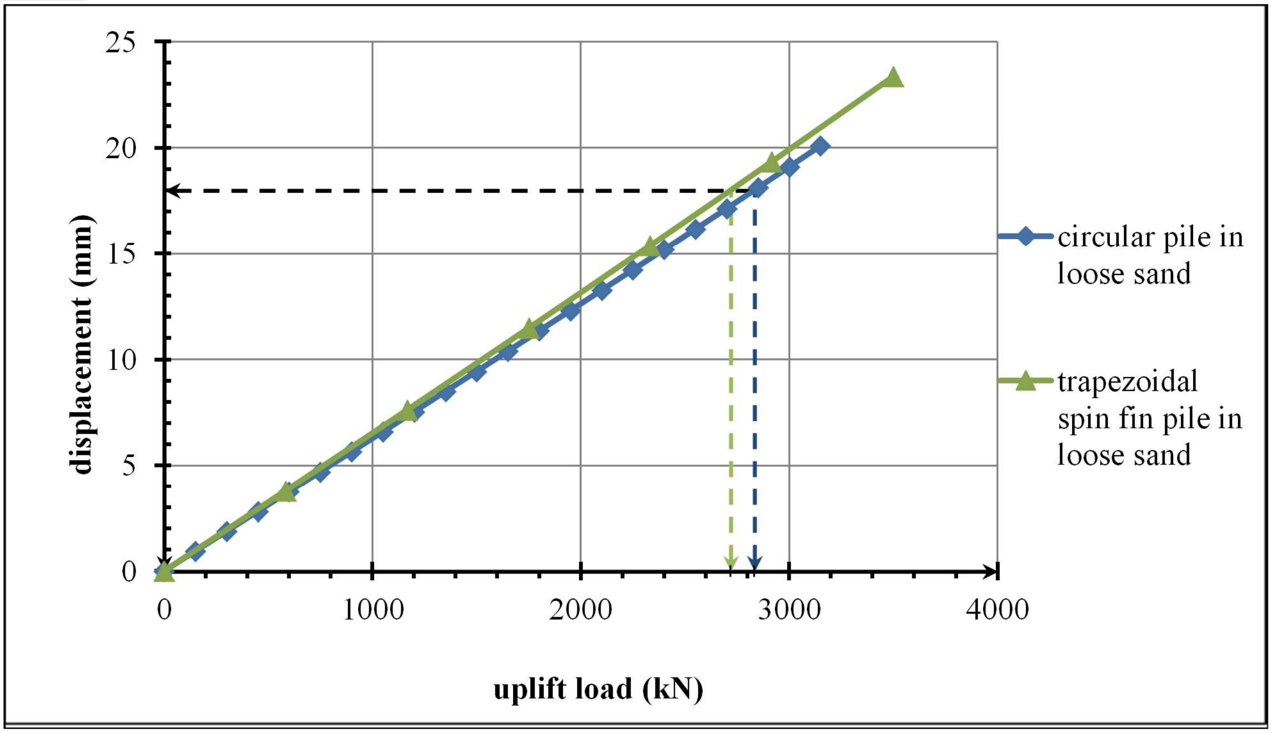

Figure 7: The load settlement curves for single circular pile and trapezoidal spin fin pile subjected to uplift load in loose sand for L/D=25 with B_t/B_f=0.5

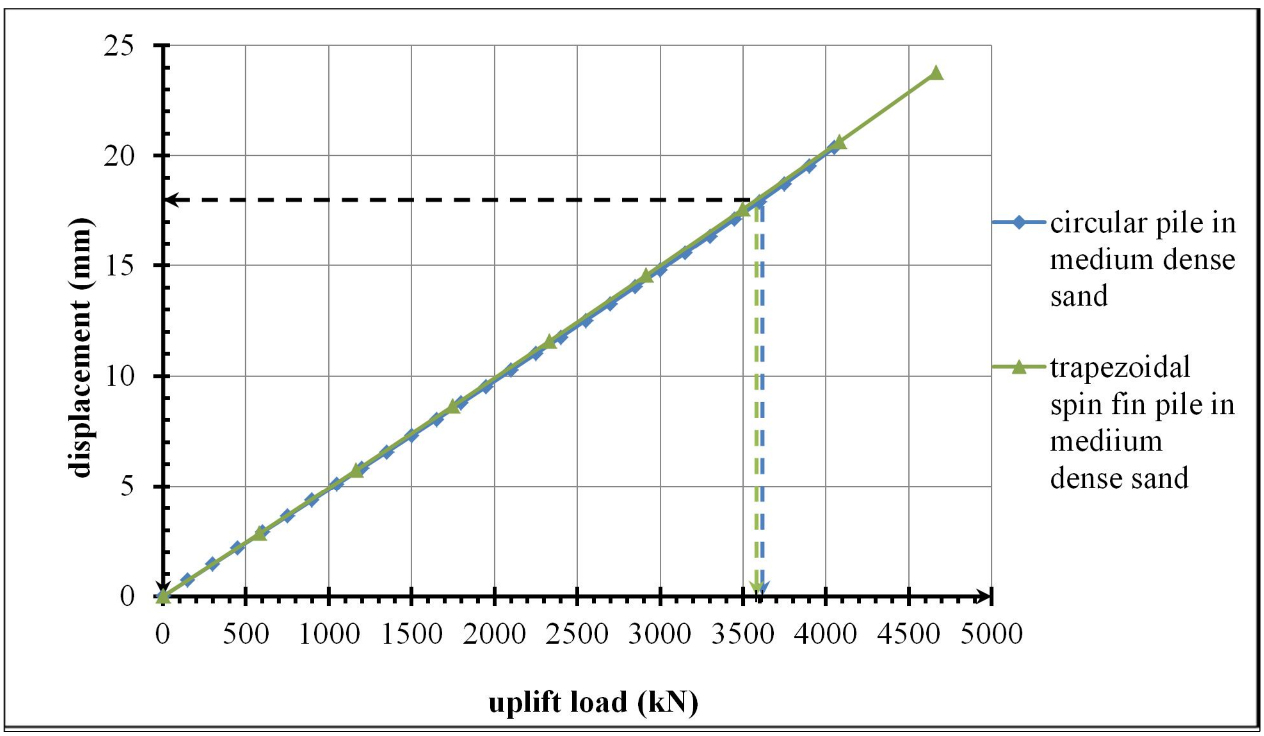

Figure 8: The load settlement curves for single circular pile and trapezoidal spin fin pile subjected to uplift load in Medium Dense sand for L/D=25 with B_t/B_f=0.5

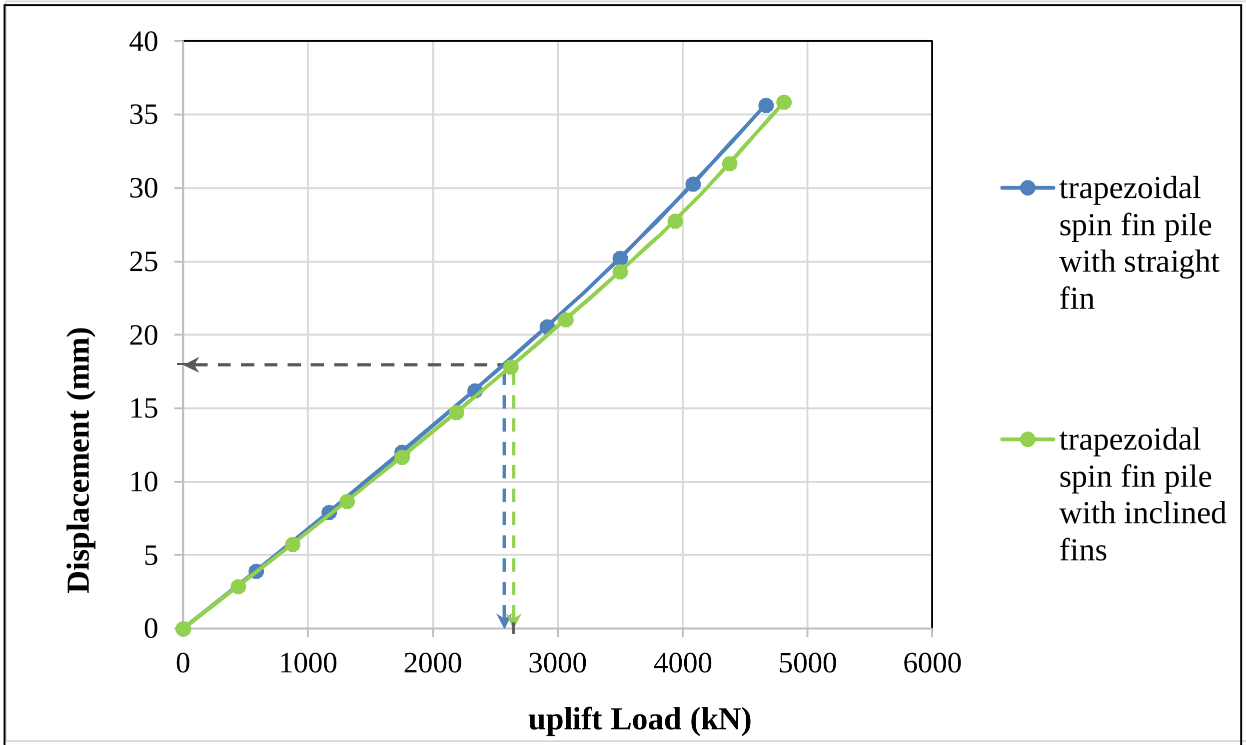

Figure 9: The load settlement curves for inclined trapezoidal spin fin pile and straight trapezoidal spin fin pile subjected to uplift load in loose sand for L/D=20 with B_t/B_f=0.5

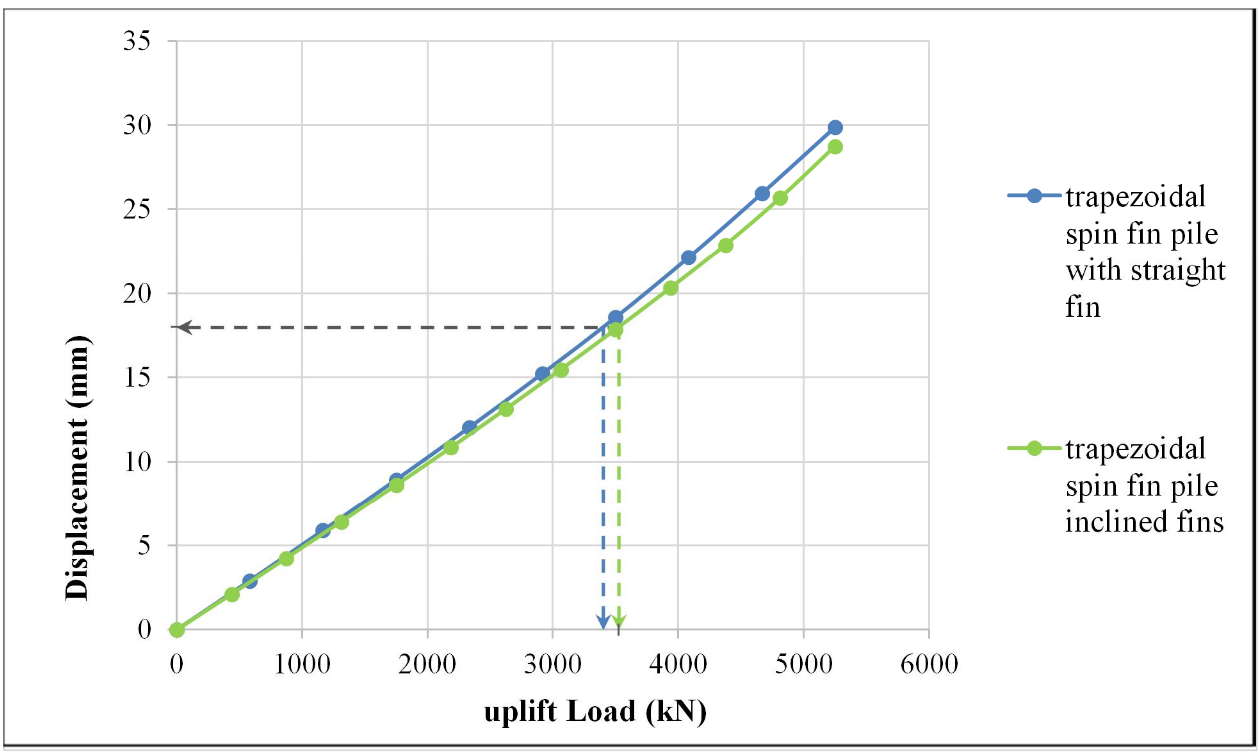

Figure 10: The load settlement curves for inclined trapezoidal spin fin pile and straight trapezoidal spin fin subjected to uplift load in Medium Dense sand for L/D=20 with B_t/B_f=0.5

Table VI: Percentage increase in uplift 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 trapezoidal spin fin pile (kN)	% increase in ultimate capacity
Loose sand	15	1735	2335	34.82946
	20	2350	2570	9.271765
	25	2835	2720	-4.0185
Medium dense sand	15	2115	3050	44.09541
	20	2915	3400	16.7612
	25	3615	3580	-0.99651

Table VII: Percentage increase in uplift 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	2570	2645	2.91
Medium dense sand	20	3400	3525	3.67

VI. CONCLUSIONS

A. The uplift load carrying capacity of conventional circular pile increases by addition of trapezoidal fins to it. 60.38% for B_t/B_f=0.5.

B. The uplift load carrying capacity of trapezoidal spin fin pile with slenderness ratio L/D=15 can be adopted for loose sand and medium dense sand, for B_t/B_f=0.5

C. Inclined trapezoidal Spin Fin Pile are more effective than straight Trapezoidal spin fin pile in carrying uplift loads by upto 3.67%.

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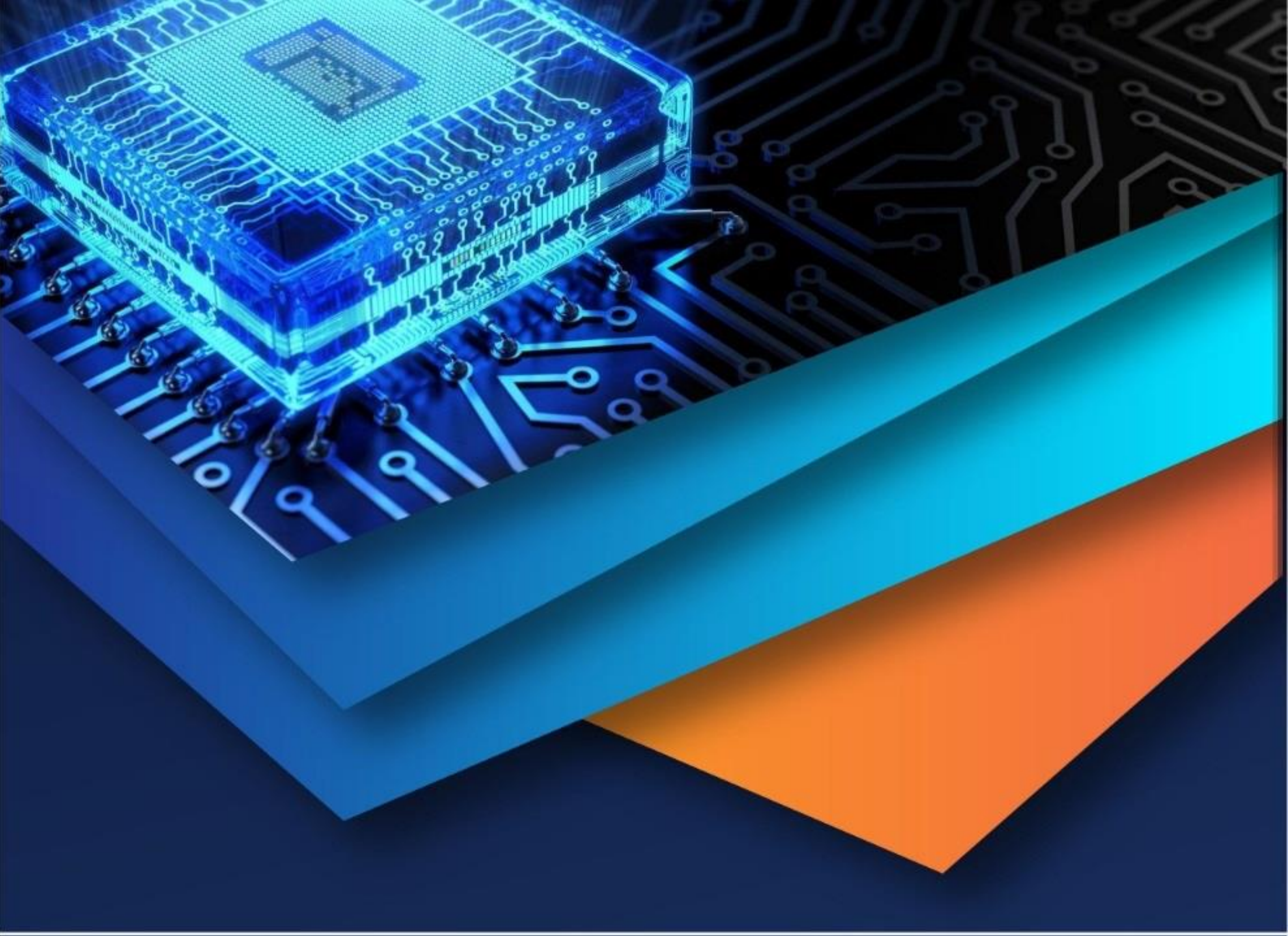

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