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Effect of Fin Inclination on Different Shapes of Fin under Axial Load

Poonam P. Gawande[1] and A. I. Dhatrak[2]

[1]Research Scholar, Civil Engg. Department, GCoE, Amravati - 444602
[2]Associate Professor, Civil Engg. Department, GCoE, Amravati - 444602
poonamgwnd25@gmail.com

Abstract: Traditional circular piles are frequently used as a foundation for offshore as well as onshore structures because of easy installation process. Though, in some critical cases, these traditional piles are not reliable for developing significant axial capacity during installation of pile. To overcome this problem, an innovative modification i.e. spin fin pile foundation over a circular pile is developed. Spin fin piles are circular piles equipped with steel plate known as fins which is attached at the upper or bottom section of piles. In this paper a numerical solution for triangular shape and trapezoidal shape spin fin pile under axially loading is presented. To developed model along with an elastic – plastic soil model, an elastic fin and pile material, and interface elements a MIDAS GTS-NX software is used. The behaviour of triangular shape and trapezoidal shape spin fin pile for different inclinations of fin and pile group for loose and medium dense sand are investigated. The load distribution within the spin fin pile and the set- tlement of pile are shown. Analysis shows that, the vertical resistance is more in trapezoidal shape fin pile as compare to triangular shape spin fin pile.

Keywords: Spin fin pile, axial loading, MIDAS GTS-NX, settlement, sand

1 Introduction

In case of deep foundation piles are more commonly used where loose soil and large loads comes in frame. Piles are more significant in taking vertical loads. The numerous structures such as bridge abutment, ocean engineering structures etc. are subjected to huge amount of vertical load. In case of circular pile, vertical resistance offered are insufficient as required, that's why there is need of improvement in foundation techniques.

Spin fin pile is best alternatives over these traditional circular piles. These fin pile foundation was first time developed by PND Engineers in 1983. The representations of fin pile are such as circular pile welded with steel plates known as fins. These fins are generally fitted at an upper or bottom portion of circular piles making slight angle with pile periphery. "The geometry of these fin pile is such that when it is seen from bottom to top, the top of one fin meets the bottom of the adjacent fin, thus giving 360 degree coverage. These fins are fitted along the circumference of the circular pile foundation." [6] Both traditional impact and vibratory hammers, along with templates and attachments, can successfully drive spin fin piles. These piles are more effective in taking loads as compare to circular pile because, when it is pushed into earthfill it actually rotates like screw. This rotation effect is caused by fins. These results in formation of strong bond with nearby soil, fins making it firmly fix into the soil. A soil cone is generated when the pile is pushed in compression thus increasing the pile's axial capacity.

Fin piles provide predominantly higher ultimate lateral capacity and lateral resistance when compared with a regular circular reference pile (Nasr et al., 2013, Peng et al., 2010, Britta et al., 2012, Bariker et al., 2020). The different shapes of fin such as triangular (Sakr et al., 2019, Ambi et al., 2018, Bariker et al., 2020), rectangular (Babu et al., 2018, Sakr et al., 2020, Tale et al., 2019, Ambi et al., 2018, Bariker et al., 2020, Thakare et al., 2019), tapered (Deshmukh et al., 2016) are effective in carrying. They found that increase in fin area influences capacity of pile.

Position of fins near the pile top provides higher resistance than pile bottom for lateral loading condition (Bariker et al., 2020, Deshmukh et al., 2016). Fins attached at the bottom of spin fin pile provide higher vertical load capacity in comparison with conventional pile (Tale et al., 2019, Thakare et al., 2019). Also, fins placed at the pile end have a significant impact in increasing the uplift load capacity (Sakr et al., 2019).

However, these studies of fin piles are limited upto straight fin for different loading only. Fin inclinations effect on vertical load needs attention.

2 Numerical Modeling

Numerical analysis was done by using MIDAS GTS – NX 3D software. The various Geotechnical Engineering problems such as tunneling, piling etc. are solved by MIDAS software package. Investigation was done by using a 3D finite element model for spin fin pile having triangular shape and trapezoidal shape. In this analysis linear elastoplastic sand was assumed as a foundation material. The simple and precise Mohr-Coulomb model was used to replicate the nonlinear behaviour of sand. drained conditions was preferred for modeling of fin and pile. Five essential inputs are needed for numerical modeling, which is cohesion (c), frictional angle (φ), young's modulus (*E*), Poisson's ratio (μ), and dilatancy (Ψ). The direct shear test was used for finding frictional angle and cohesion and unit weight was determined from modified proctor test for sands.

Sand properties used for analysis are shown in table 1. Spin fin piles were analyzed to allow comparisons of the fin inclinations with triangular shape fin and trapezoidal shape fin. Fins are placed at 0^0 to the pile and 90^0 to the pile; this represents straight orientation and inclined orientation of fin with circumference of pile as presented in fig.1 and 2. The model fin pile used in analysis was made up of hollow circular mild steel pile having outer diameter (D) 1.2 m with wall thickness 75 mm. At the bottom of pile four numbers of fins were welded to each other. Because of axial load fins were welded onto the bottom of pile. The geometry of spin fin pile is same for both the shapes of fin. In case of trapezoidal fin, the ratio of top width of fin to bottom width of fin (B_{tf}/B_{bf}) was kept 0.5. Hollow portion of piles were filled with sand having same properties as shown in table 1. The dimensions of the spin fin piles used in the numerical analyses are given in Tables 2.

Table1. Sand properties

Property	Loos e Sand	Medi-um Dense Sand
Relative density (%)	40	55
Unit weight (kN/m^3)	16.33	16.5
Young's modulus (MPa)	20	27
Poission's ratio	0.3	0.3
Friction angle	34	37.88
Cohesion (kN/m^2)	1	2

Table2. Spin fin pile properties

Property	Value
Pile diameter, D (m)	1.2
Pile thickness (m)	0.075
Fin thickness (m)	0.075
Pile length (m)	24
Slenderness ratio	20
Fin length / Pile length	0.5
Fin width (m)	0.6
No. of piles	1, 3, 4, 5, 6
Pile spacing, S (m)	3*D
Size of Pile cap (m)	S+2D+0.3
Depth of Pile cap (m)	0.6

Material	Mild steel
Poisson's ratio	0.3
Young's modulus (GPa)	200
Unit weight (kN/m^3)	78

Assumption was made that fin pile to be driven in normally consolidated soil having Ko = 0.42. In order to reduce the estimated strength of structural members, when they come into contact with one another, a strength reduction factor is used. The strength reduction factor should be given in between interface surface element, which is sand – spin fin pile interaction. The value of strength reduction factor is considered 0.65. This factor is directly taken from sand -steel interfaces. The relations between interface properties, soil strength parameters and strength reduction factor of soil layer are as follows:

$$\tan\phi^i = R_{int} \tan \phi^{'}$$
$$C_i = R_{int}\, C^{'}$$
$$\Psi_i = 0 \text{ if } R_{int} < 1 \text{ otherwise } \Psi_i = \Psi$$

Where ϕ^i, Ψ and C_i are the frictional angle, dilatancy angle of interface and cohe- sion of soil, respectively.

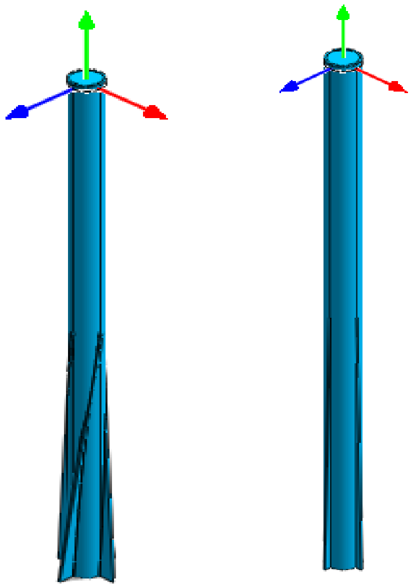

Fig. 1. Triangular shape fin pile in 3D view with a) Inclined fin b) Straight fin

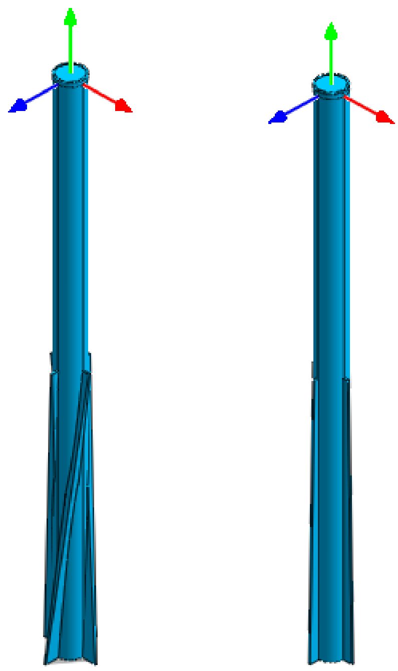

Fig. 2. Trapazoidal shape fin pile in 3D view with a) Inclined fin b) Straight fin

3 3D geometry of fin pile and meshing

3D geometrical model of two different shapes was developed in MIDAS GTS NX software for the analysis. Triangular and trapezoidal shapes of fin pile were modeled with soil block as a foundation material. "A soil bed with sides 22.5 times the fin pile's diameter and a depth 2.5 times its length was chosen." [12]. Depth pile cap was kept constant 0.6 m for analysis and area was varying according to pile group. The axial capacities for triangular and trapezoidal shape fin piles were analyzed in comparison with fin inclinations. For comparison purpose, the cross sectional area of inclined fin and straight fin pile was kept same, but the cross sectional area of trapezoidal fin and triangular fin was different.

The investigations were executed by changing different fin shape for single and group of pile. Pile group arrangement as presented in Fig.3. 3D view of 4 group fin pile embedded in sand is presented in Fig. 4. Boundary conditions and loading can be applied to geometric shapes, nodes and elements also.

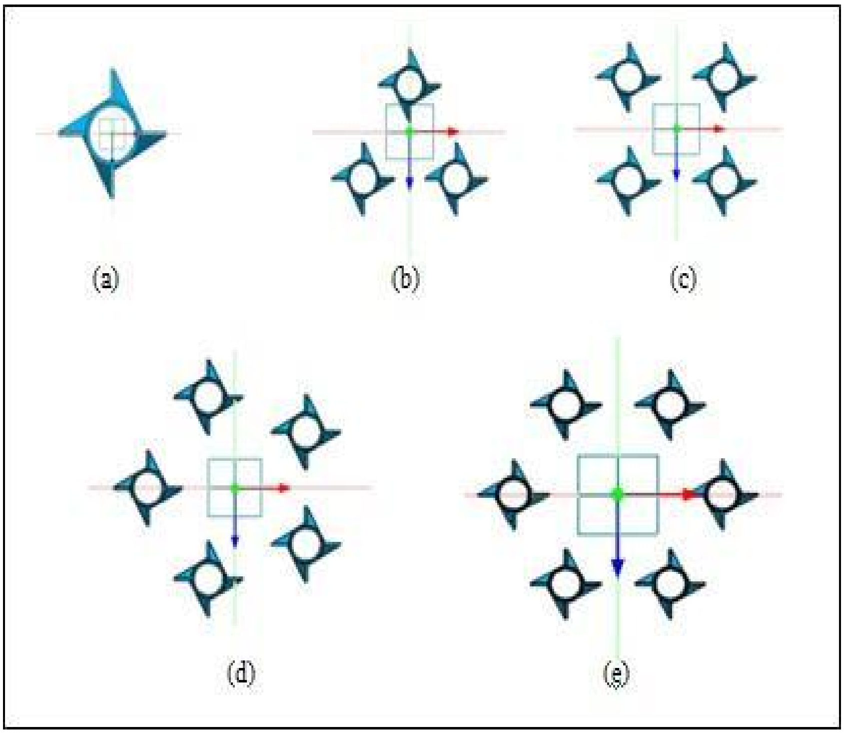

Fig.3. Plan view of group of triangular shape inclined fin pile arrangement for (a) single; (b) three; (c) four; (d) five and (e) six

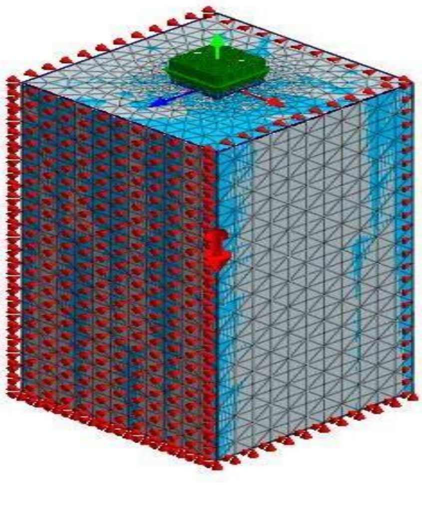

Fig.4. 3D view of 4 group of fin pile embedded in soil

4 Results and discussions

The load - settlement curves for triangular shape and trapezoidal shape spin fin pile is plotted. As per criteria set into IS: 2911-2013 (Part- IV) the ultimate axial load of pile was taken. Axial load for different shapes of fin pile was compared with selected parameters such as density and pile group. Load - settlement (*P–Y*) curves extracted from numerical analyses for spin fin pile with loose sand is shown in Fig. 5-9. The same patterns are followed for medium dense spin fin pile. But, some of the curves are shown due to space restriction.

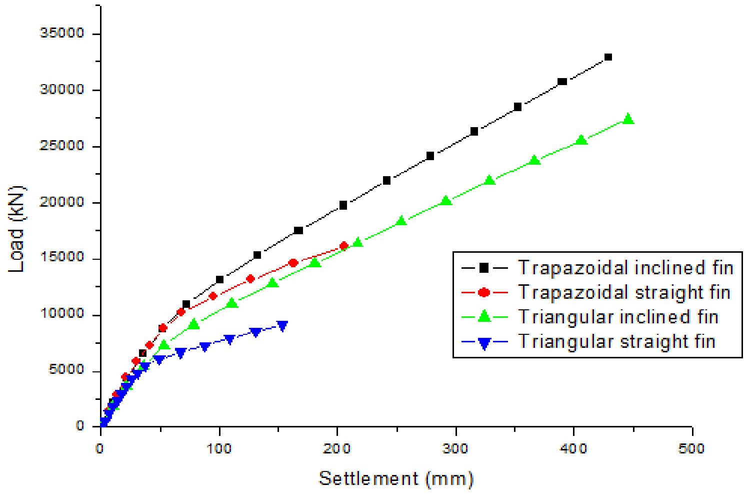

Fig. 5. P-Y curves for single fin pile

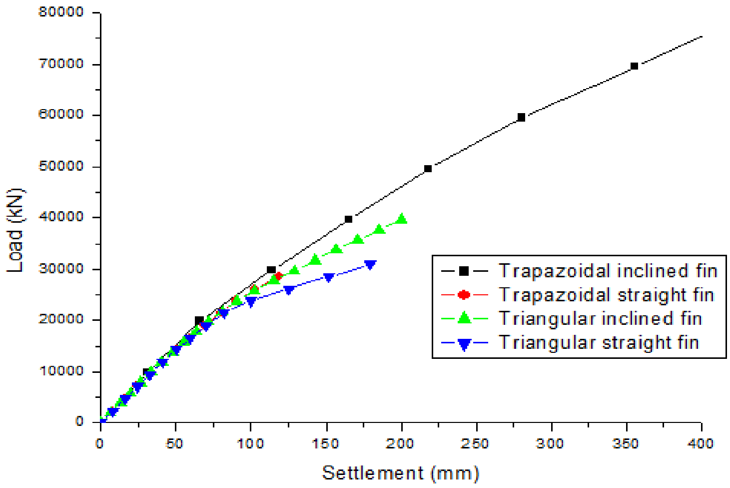

Fig. 6. P-Y curves for group of three fin pile

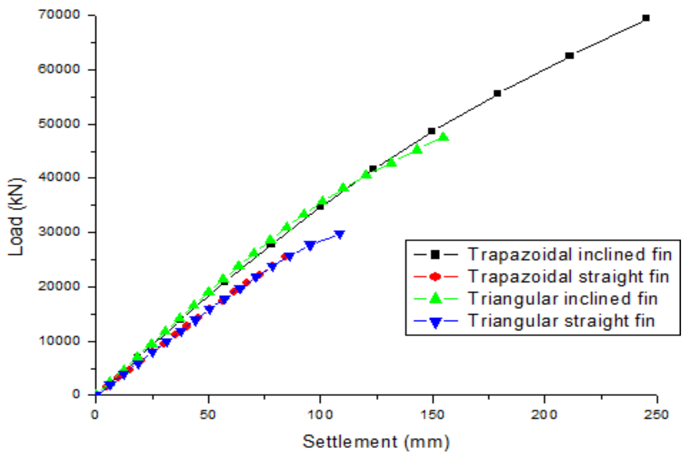

Fig. 7. P-Y curves for group of four fin pile

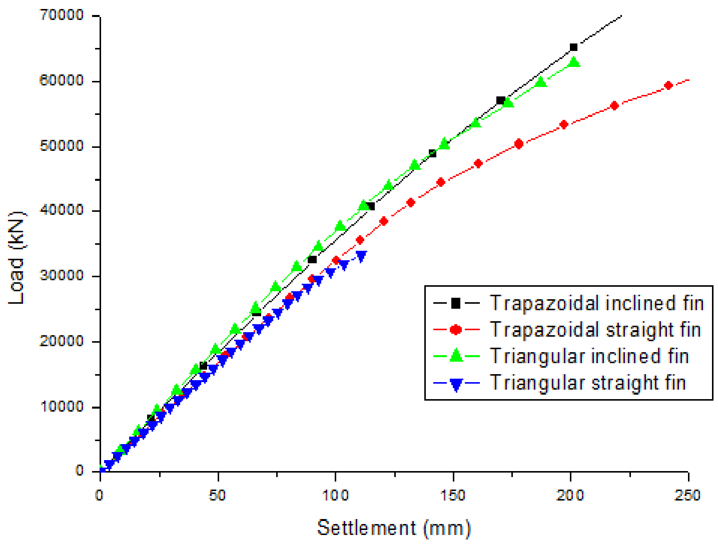

Fig. 8. P-Y curves for group of five fin pile

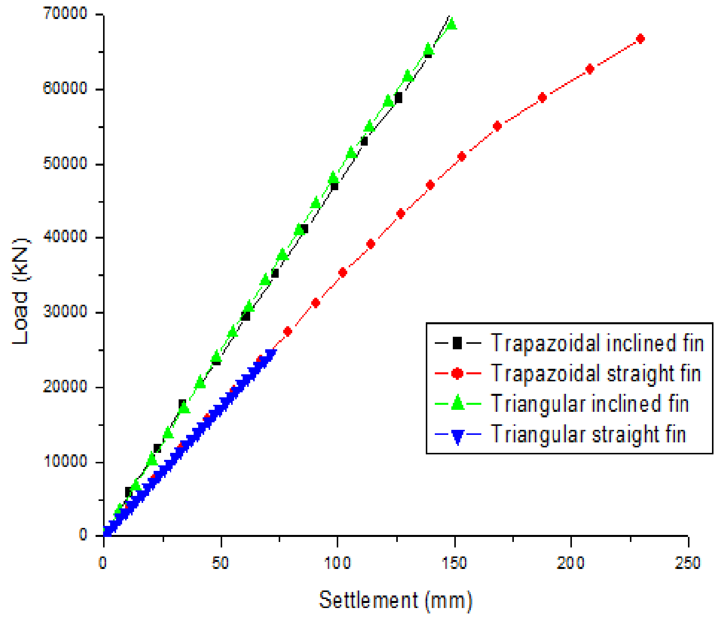

Fig. 9. P-Y curves for group of six fin pile

4.1 Effect of fin shape on vertical capacity

The comparison between rectangular fins and triangular fins with different area, but same width for lateral loading was made by Nasr (2013), Sakr et. al.(2020) and Bariker et. al (2020). To ascertain how fin affects performance, analyses were performed on triangular and trapazoidal fins for vertical loading. Figure 5-9 depicted the variations of vertical load vs vertical deflection for different fin shapes. It is prominently observed that the vertical load of the pile improves significantly when fins of any shape are used, as the inclusion of fins at the pile's base increases soil resistance. (Tale et.al. 2019). It follows that the axial load of piles with trapezoidal-shaped fins increased by around 26% compared to heaps with triangular-shaped fins. This is explained by the larger area of soil resistance present in a trapezoidal finned pile, which raises the ultimate vertical load even more.

4.2 Effect of fin inclination on vertical capacity

From figure10 and 11, it is evident that piles with inclination fins offer a significantly stronger vertical resistance and stiffer behaviour than that of straight fin for both the shape of fins. Based on the outcomes for slenderness ratio of L/D = 20 the axial load of incline finned pile is increased by about 43% and 45%, over that of a straight finned pile for both the shape of fins i.e. trapezoidal shape of fin and triangular shape fin pile respectively. The inclined finned pile has the more vertical resistance capacity because it covers whole peripheral surface of the pile.

4.3 Effect of sand density on vertical capacity

Figure 10 and11confirm that there is increment in ultimate vertical load with sand density for trapezoidal shape of fin and triangular shape fin pile. As sand density rises, the stiffness and shear strength of the sand also increases. In case of triangular shape fin pile, as sand density went from 40% to 55%, the increment in the axial load was found 38%, and for trapezoidal shape fin piles, was found to be 39% with same increment.

4.4 Effect of number of piles on vertical capacity

Analysis was conducted on group of spin fin piles for vertical loading. The piles in group was varied as one, three, four, five and six with varying pile configurations having constant spacing between the piles as 3D and fins were provided at bottom for Spin Fin pile. The results clearly showed that axial load increases with the increase in number of piles for both the densities. The axial load of single spin fin pile increased by maximum upto 160% and 185%, over that of a group of six fin pile for both the shape of fins i.e. trapezoidal shape of fin and triangular shape fin pile respectively.

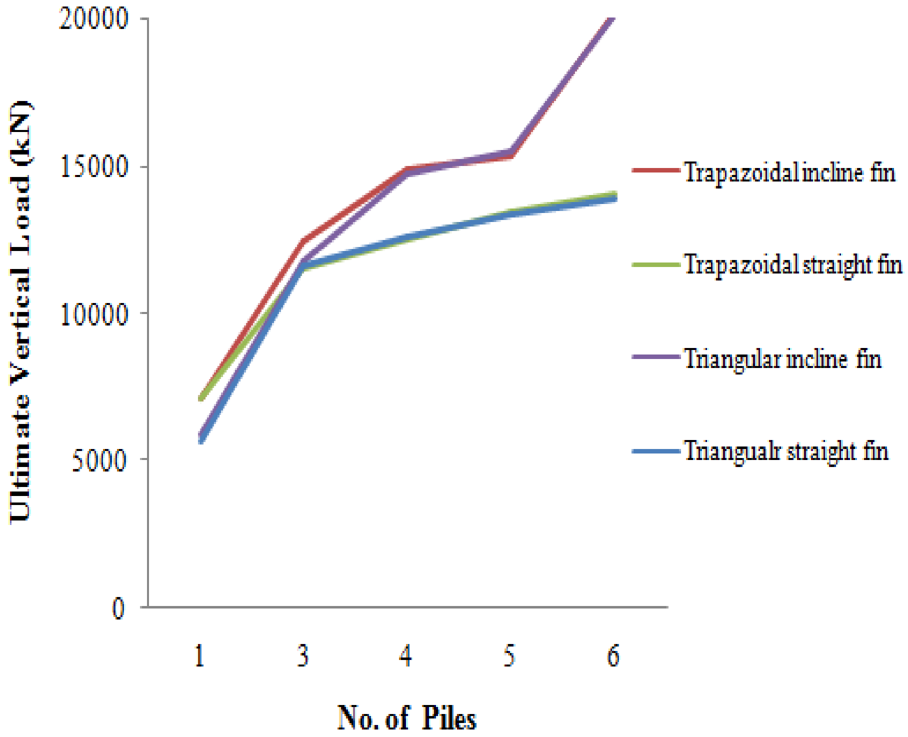

Fig.10. Variation of no. of piles versus ultimate vertical load for loose sand

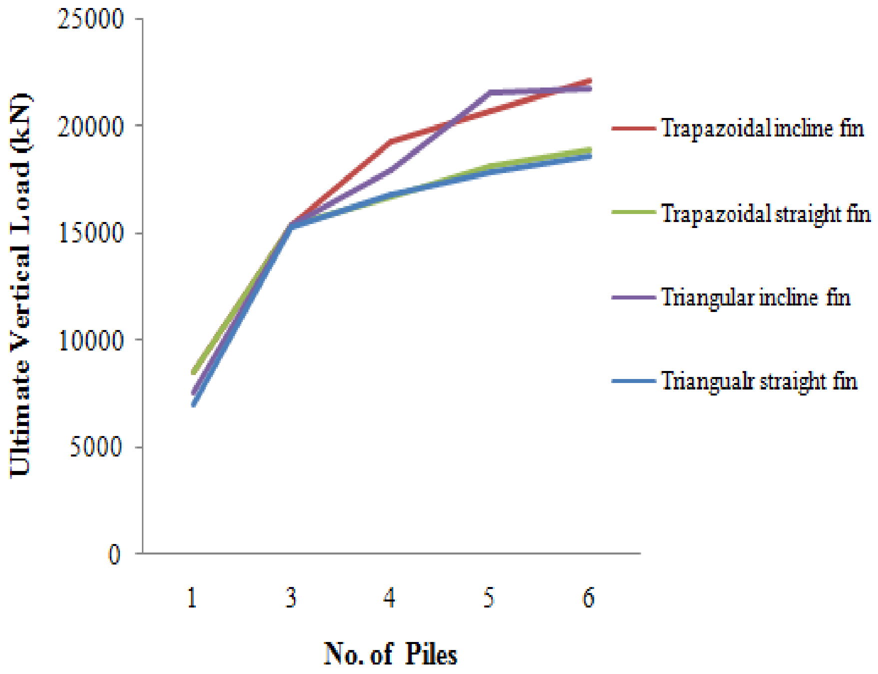

Fig.11. Variation of no. of piles versus ultimate vertical load for medium dense sand

5 Conclusions

The following key conclusions can be made in light of the research:

- Trapezoidal shape of spin finned pile provides markedly higher axial loads and pile resistance when compared with triangular shape spin finned piles.
- Inclined fin piles are more effective than that of straight fin piles when compared with both the shape of fins.
- Axial load capacity in dense sand is found to be greater that of loose sand for spin fin pile.
- There is increment in axial load capacities with pile numbers for triangular and trapezoidal shape fin pile.

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