Research Article

Comparative Analysis of Circular and Spin Fin Pile for Axial Loading

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Article History: Received: 10 January 2021; Revised: 12 February 2021; Accepted: 27 March 2021; Published online: 4 June 2021

Abstract: Conventional circular piles are more commonly used for onshore as well as offshore structures due to their ease of installation. However, in some crictical cases to develop significant vertical capacity during driving the use these circular piles are not reliable. Spin fin pile foundation is an innovative modification over a conventional circular pile foundation. Spin fin piles are traditional pipe piles fitted with steel plates; fins are attached at a slight angle over the upper or bottom portion of circular piles. This paper presents a numerical solution for axially loaded circular pile and triangular shape spin fin pile group in linear-elastic soil profiles. In this study, a MIDAS GTS-NX software is used to developed model. The behaviour of circular pile and triangular shape spin fin pile with loose sand and medium dense sand for different slenderness ratio are examined. The load dispensation within the circular and fin pile and the settlement of pile are shown. Analysis shows that, the vertical resistance increases in triangular shape spin fin pile as compare to circular pile.

Keywords: circular pile, MIDAS GTS-NX, settlement, Spin fin pile, vertical resistance

1. Introduction

Piles are adopted as foundation where large loads or weak soil comes in frame. There are various structures like bridge abutment, transmission towers, chimneys, ocean engineering structures, marine dolphins etc. are subjected to large vertical loading condition. Vertical resistance will be smaller for these types of loads in case of conventional circular pile, hence needs improvement. Pile foundations are generally long and slender members.

Spin Fin pile is a modification over a conventional pile foundation, introduced by PND Engineers in 1983. Spin fin piles are described as a traditional pipe piles fitted with, steel plates called as fins. These fins are attached at a slight angle over the upper or bottom portion of circular piles. The geometry of the spin fin pile is such that when it is viewed from bottom to top, the top of one fin meets the bottom of the adjacent fin, thus providing 360 degree coverage. These fins are attached along the periphery of circular pile L. R. Chernauskas et al. (2009). As the name of the spin finned pile itself indicate that the pile actually rotates when it is driven into soil due to the fins, like a screw. While driving in it forms bond with soil surrounding the fins making it tightly fit in soil and hence improves the transmission of load more effectively than simple circular pile.

2. Review of Literature

Ahmed M. A. Nasr et al. (2013) conducted experimentation on lateral capacity of finned piles in sandy soil. In which the improvement in lateral load capacity of a finned pile placed close to the pile head was evaluated. Studies were done by changing the relative density, pile length, fin width, shape of the fins (Triangular and rectangular) and pile type. The results of prototype-scale and the model were compared. It was concluded that piles with attached fins provide significantly higher ultimate lateral load capacity and lateral resistance as compared with a regular circular reference pile.

Mohamed A. Sakr et al. (2019) carried out investigation on single pile with triangular shaped wings in sand for uplift loading condition. A numerical study utilizing finite component examination PLAXIS-3D was run on piles without wings and with wings. Studies were done by changing the wing-width proportion, number of wings. The effects of sand relative densities were moreover considered. Results indicated that the adopted wings at the pile end have an impressive impact in increasing the uplift load carrying capacity with lesser deformation.

S. W. Thakare et al. (2019) studied rectangular shape spin fin pile for different loading modes experimentally. In the experimental investigation, three different positions of fins in the spin fin pile were considered viz., fins at middle, botto m and top of the pile. Results indicated that the vertical and uplift capacity of spin fin pile with fins at bottom provides much higher strength as compared to conventional circular pile. Spin fin pile having fins at top provides higher lateral load capacity compared to conventional circular pile.

N.G. Tale et al. (2019) carried out numerical analysis using MIDAS GTS 3D software for spin fin pile with different loading conditions. Studies were done by changing the relative density, loading conditions and positions of fin. Analysis shows that spin fin pile with fins at bottom provides higher vertical capacity compared to that of conventional pile.

P. Bariker et. al. (2020) conducted an experimental study on lateral capacity of triangular fin pile in sand. Studies were done by changing the relative density, pile length, number of wings, fin position, fin dimension and pile type. It was concluded that fin piles provide considerably significant lateral resistance in comparison with regular circular pile. Fins positioned near the pile head provide greater resistance than that of pile bottom.

3. Numerical Modelling

A circular pile and triangular shape spin fin pile was investigated using a 3D finite element model. MIDAS GTS-NX software program system was used to perform numerical analysis. This software package is most commonly used for numerical analysis for solving variety of Geotechnical Engineering problems. A linear elastic perfectly plastic type of sand was assumed in the analysis. To replicate the nonlinear behaviour of sand, Mohr–Coulomb model was used. This is a simple model having adequate number of model parameters, and precision in modelling. To model piles an elastoplastic analysis with drained conditions was used. The five fundamental input parameters are required for elastic– plastic Mohr–Coulomb model. They are young's modulus (*E*), Poisson's ratio (μ), cohesion (*c*), frictional angle (φ), and dilatancy (Ψ). Frictional angle and cohesion were determined from the direct shear test results for sands. Table 1 shows the properties of sand used in finite element analysis. Hollow portion of circular and spin finned pile were filled with sand having same properties as shown in table 1. Table 2 shows the properties of triangular shaped fin and pile material.

Table 1: Properties assigned to sand

Parameter	Symbol	Loose Sand	Medium Dense Sand
Relative density	Dr (%)	40	55
Unit weight	ϒ(kN/m^3)	16.33	16.5
Young's modulus	E (MPa)	20000	27000
Poission's ratio	μ	0.3	0.3
Frictional angle	φ (^{0})	34	37.88
Cohesion	c (kN/m^2)	1	2

Table 2: Properties assigned to fin and pile

Parameter	Symbol	Value
Outer diameter	D (m)	1.2
Pile wall thickness	T_p (m)	0.075
Fin wall thickness	T_f (m)	0.075
Pile length	L_p (m)	18, 24, 30
Fin length / Pile length	L_f / L_p	0.5
Fin width	B_f (m)	0.6
Slenderness ratio	L/D	15, 20, 25
Pile spacing	S (m)	3*D
Size of Pile cap	(m)	S+2D+0.3
Depth of Pile cap	(m)	0.6
Material type		Mild steel
Poisson's ratio	μ	0.3
Young's modulus	E (GPa)	200
Unit weight	ϒ(kN/m^3)	78

It was supposed that the spin fin pile was driven in a normally consolidated sand with value of Ko= 0.42. It must be pointed out that in between the sand filling and the fn pile to model the sand filling – fin pile interaction, interface elements were added. The strength reduction factor of the interface element is kept 0.65, along the spin fin pile. This factor is taken from sand -steel interfaces. The relation between strength reduction factor, soil strength parameters and interface properties of soil layer is as follows:

$\tan\phi^i = R_{int} \tan \phi'$

$C_i = R_{int} C'$

$\Psi_i = 0$ if $R_{int} < 1$ otherwise $\Psi_i = \Psi$

Where ϕ^i, Ψ and C_i are the frictional angle, dilatancy angle of interface and cohesion of soil, respectively. The triangular shape fined pile and circular pile, shown in Fig. 1.

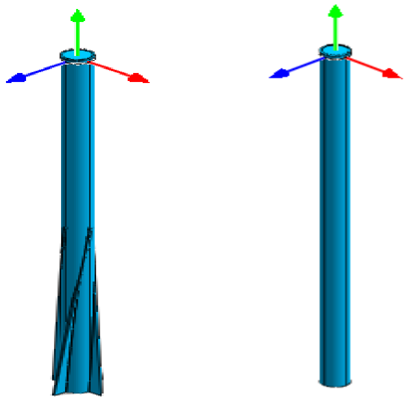


Fig. 1: a) Three dimensional view of geometric modelling of triangular shape spin fin pile and

b) conventional circular pile

3D Geometry of Spin Fin Pile and Sand Meshing

For the analysis, a 3D model of triangular shape spin fin pile foundation with a soil block was modeled. FEM software program MIDAS GTS NX was used to developed model. Soil model of size with sides 22.5 times diameter of spin fin pile and depth 2.5 times length of spin fin pile was selected (J. R.Peng, 2010). For pile cap of 0.6 m depth was modelled. The vertical load capacities and settlement of triangular shape fin piles driven in sand bed were inspected in comparison with conventional circular piles. For comparative analysis, the cross section area of triangular shape fin pile and conventional circular pile was same throughout.

The investigations were executed by changing different the slenderness ratio of pile (L/D), relative density of soil for single and group of pile. The analysis was done on single as well as group of three, four, five and six pile with varying slenderness ratio. Three dimensional view of group of four spin finned pile embedded in soil is shown in **Fig. 2.** The load and boundary conditions can be applied not only to the nodes and elements but also directly to geometric shapes.

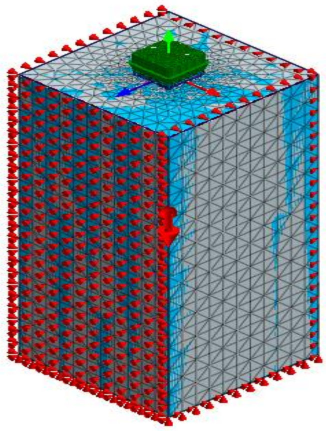
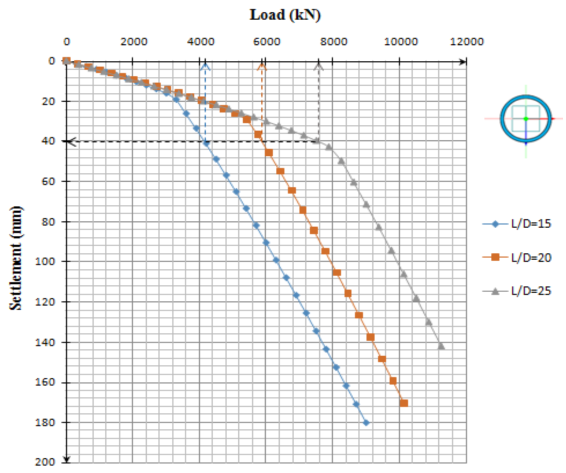


Fig.2: Three dimensional view of group of four spin finned pile embedded in soil

4. Interpretation and discussion of results

The analyses were conducted on conventional circular pile and triangular shape spin fin pile for loose and medium dense condition. The load - settlement curves for these pile subjected to vertical loading in loose and medium dense sand for L/D ratio = 15, 20, 25 are plotted. The ultimate vertical load of pile was obtained as per criteria laid down by IS: 2911-2013 (Part- IV). The effects of selected parameter on ultimate load capacities of piles were determined and results for triangular shape spin fin piles were compared with that of conventional circular pile having constant area of cross section. Vertical load and settlement (*P–Y*) curves from the results extracted from the numerical analyses for conventional circular pile is shown in Fig. 3. The same patterns are followed for group of conventional circular pile. Due to restriction of space only some curves are shown. Fig. 4 – 8 shows vertical load and settlement (*P*–*Y*) curves for triangular shape spin fin pile.



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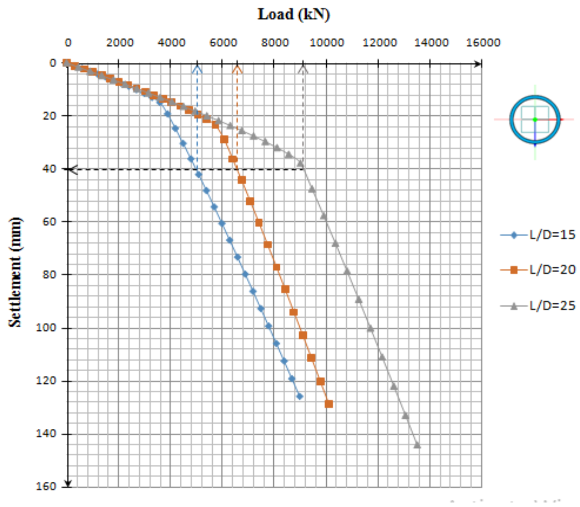
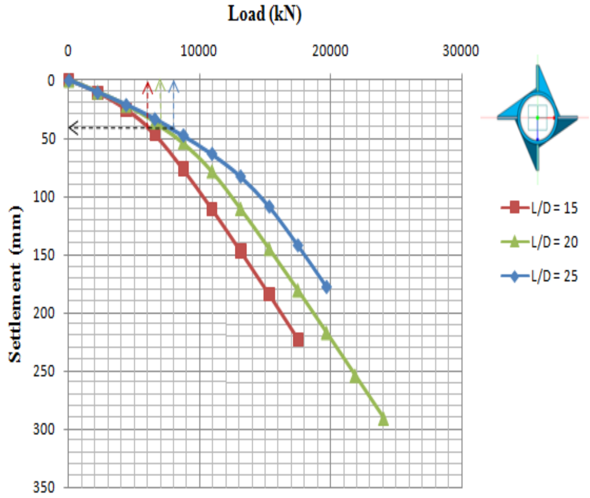


(b)

Fig. 3: Load vs. Settlement Curves for Single Conventional circular Pile for Vertical Loading in (a) Loose and (b) Medium Dense Sand



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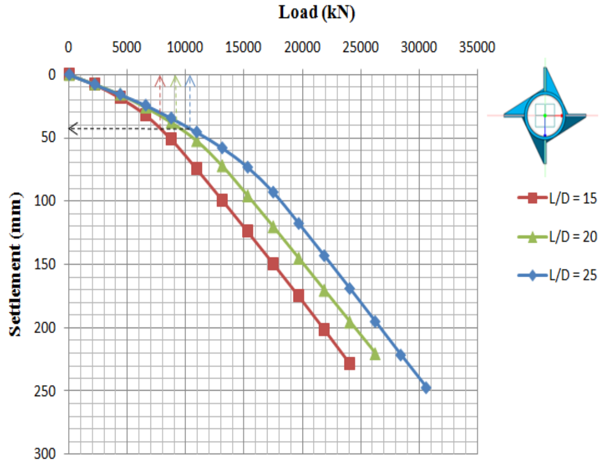
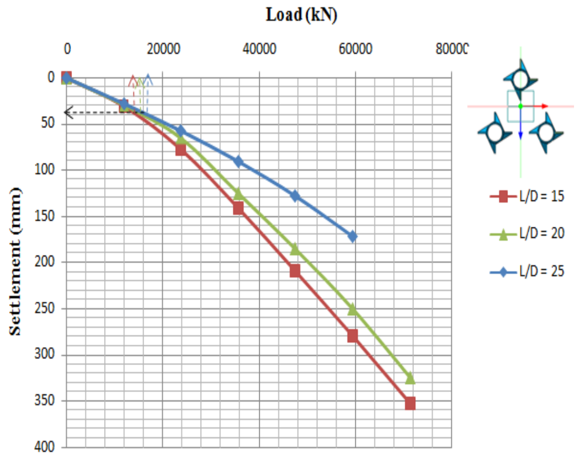


(b)

Fig. 4: Load vs. Settlement Curves for Single Spin Fin Pile for Vertical Loading in (a) Loose and (b) Medium Dense Sand



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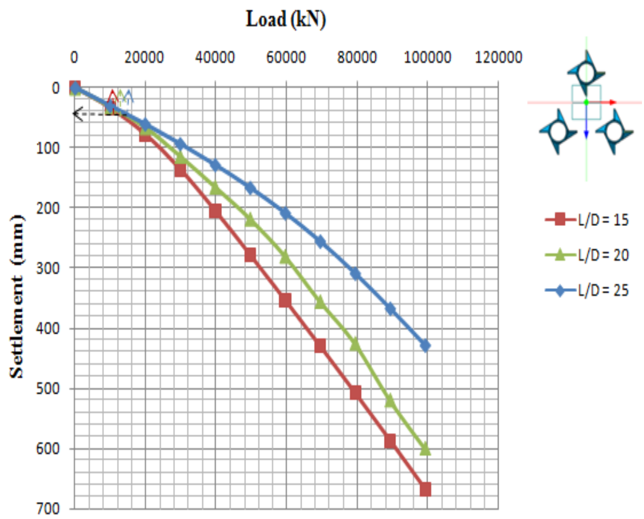
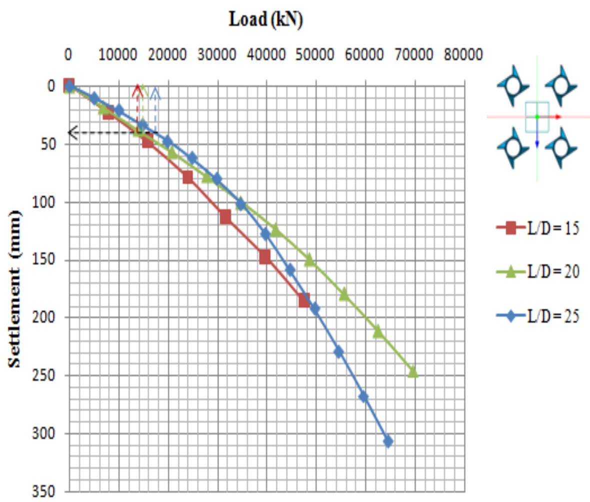


(b)

Fig. 5: Load vs. Settlement Curves for Three Spin Fin Pile for Vertical Loading in (a) Loose and (b) Medium Dense Sand



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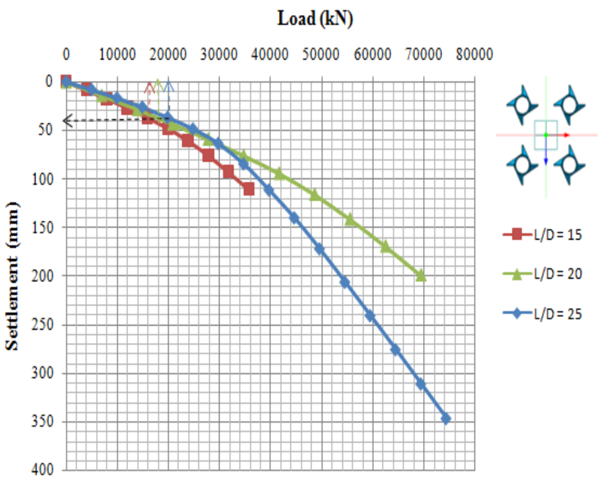
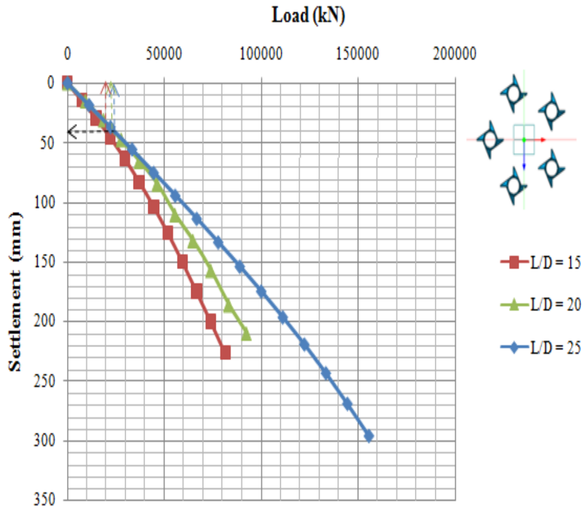
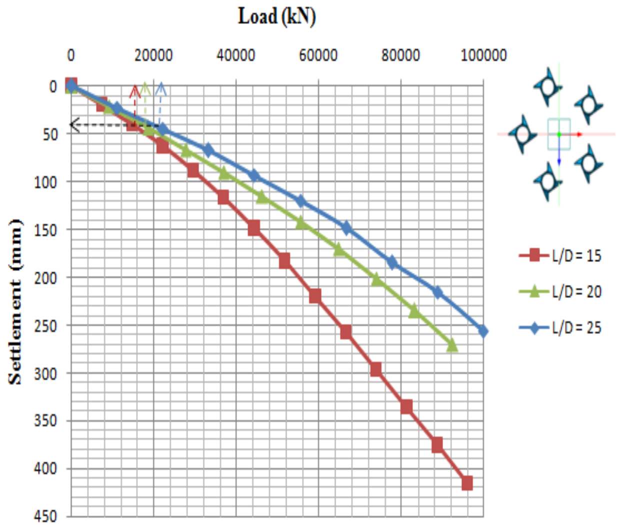


(b)

Fig. 6: Load vs. Settlement Curves for Four Spin Fin Pile for Vertical Loading in (a) Loose and (b) Medium Dense Sand

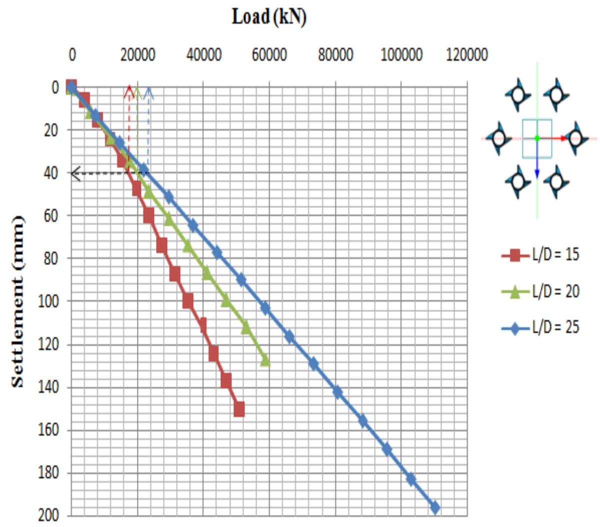


(a)



(b)

Fig. 7: Load vs. Settlement Curves for Five Spin Fin Pile for Vertical Loading in (a) Loose and (b) Medium Dense Sand



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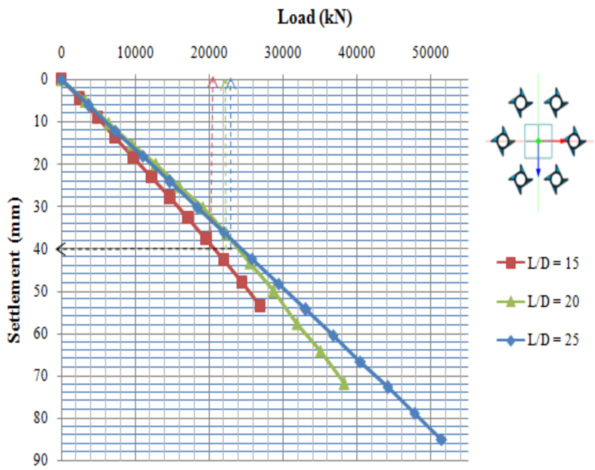

(b)

Fig. 8: Load vs. Settlement Curves for Six Spin Fin Pile for Vertical Loading in (a) Loose and (b) Medium Dense Sand

In this current study, the fin effectiveness was noted by changing different slenderness ratio i.e pile length / diameter of the pile. The slenderness ratio changes from L/D =15 to 25, such that performance of long-pile as well as short-pile could be examine. The variations of load – settlement with different L/D ratio for relative density (Dr = 40% and 55%) are shown in Fig. 3 - 8. It can be noted that vertical load carrying capacity of both piles in case of dense sand is more than loose sand.

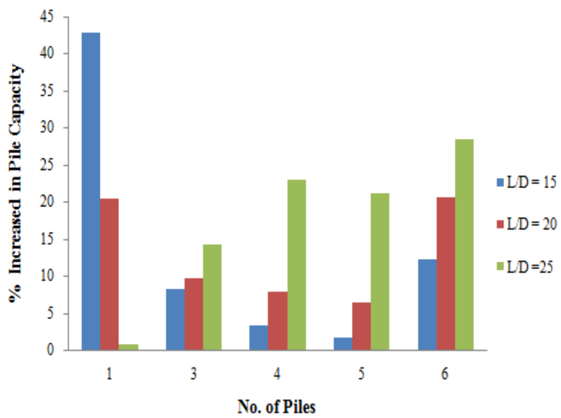

Fig.9: Variation of Slenderness Ratio versus % increase in Pile Capacity for Loose Sand.

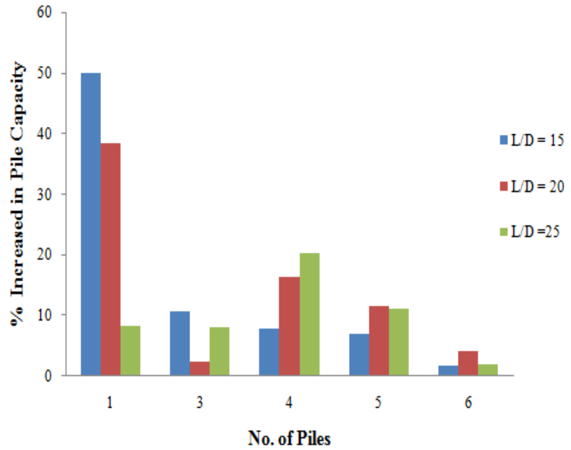

Fig.10: Variation of Slenderness Ratio versus % increase in Pile Capacity for Medium Dense Sand.

The results clearly showed that effectiveness of load depends on pile stiffness. It is noticed that any increase in pile length cause to a progressively increase in vertical load. Fig. 9 and 10 show the % increase in triangular shape spin fin pile capacity compared with conventional circular piles for different slenderness ratios. It is clearly seen from the figures that triangular shape spin fin piles provide substantially higher ultimate vertical loads compared with a conventional circular pile.

5. Conclusions

The behaviour of conventional circular pile and triangular shape finned piles tested to a vertical load condition for different relative densities. The results

extracted from numerical analyses on MIDAS GTS NX software were compared. The numerical analyses conclude that:

- Triangular shape spin fin piles provide markedly ultimate vertical loads and pile resistance in comparison with conventional circular pile.
- Ultimate vertical load capacities of spin fin pile in dense sand is much more than that of loose sand.
- The vertical pile resistance increases with increase in slenderness ratio for both loose and medium dense sand.
- The ultimate vertical load capacities of conventional circular pile and triangular shape spin fin pile increases with increase in number of piles.

6. Acknowledgements

The authors would like to acknowledge the financial support provided by the NDF AICTE–India.

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