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Influence of Taper Angle and Bell Angle on Lateral Resistance of Belled-wedge Piles in Sands

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Abstract-

Foundations of offshore structures generally experience larger lateral loads than the onshore structures. Hence, this attempt is to study the lateral resistance of the belled-wedge pile which can carry larger lateral loads than the regular pile. Very few researches have been carried out experimentally and numerically in determining lateral capacity of Belled-wedge pile. Belled-wedge pile is a combination of belled pile and tapered pile. In the present paper, a series of model tests were conducted in a model box to investigate the influence taper angle (α) and bell angle (ɵ) on the lateral resistance of belled-wedge pile embedded in sand for two taper angles of 1° and 2° and also for relative densities of 35% and 55%. The effects of taper angle and bell angle were tested for ɵ value of 30˚, 45˚ and 60˚ by varying the bell to shaft diameter ratios (D_b/D_s) of 1.5 and 2. To compare with Belled-wedge pile results, tests were also conducted on tapered pile for different combinations. It was found from the present study the optimum bell angle is equal to 45˚. It was also concluded that with increase in relative density and D_b/D_s ratio the lateral resistance was found to increase. It was found that when compared to tapered pile alone belled-wedge pile is more efficient in resisting lateral loads.

Key words- Lateral load, Taper angle, Bell angle, Relative density, Deformation

I. INTRODUCTION

Pile foundation is a type of deep foundation which transmits load into deeper strata. This is preferred in areas where soil beneath the ground surface is very loose or doesn't have much load bearing capacity. Pile load carrying capacity depends on the factors like pile length, size, shape, soil properties and installation techniques. Vertically loaded piles resist the uplift and lateral loads through friction between pile and the surrounding soil. Taking into consideration structures such as transmission towers, tall chimneys and jetty structures subjected to overturning loads and marine structures are more prone to lateral load due to wave forces and wind actions.

For better enhancement of lateral capacity providing bell at bottom of the pile is often more suitable. Belled-wedge piles will have characteristics of both belled piles and tapered piles. These kind of piles are very effective in resisting lateral loads in both offshore and onshore structures. Studies on lateral resistance of belled-wedge pile are very limited, so these piles improve both side resistance when compared to conventional tapered piles and belled cross-section piles.

The work was carried to know the influence of bells and pile taper on its performance under static horizontal loads and the objective of the study is to know the lateral load resistance of belled-wedge pile. This study focuses on determining the lateral load carrying capacity of the belled wedge pile by comparing with tapered pile.

II. LITERATURE REVIEW

Research on lateral resistance of belled-wedge piles are essential for the advance construction practice. Few researches have been carried out experiments and numerical analysis on belled wedge piles. Some of the earlier works are considered in this literature survey.

Gangqiang Kong (2011) studied the comparative analysis and field load tests. From the study he concluded that due to increase of diameter of pile-head, spacing between piles and soil stiffness at pile end, distribution of friction of pile shaft and pile tip resistance will be in equilibrium. This makes belled wedge pile more effective than other conventional piles.

Gangqiang Kong et.al (2012) studied analytical part of single belled wedge pile in soft soils. Comparative analysis on belled pile models, uniform section pile and tapered pile of same volume as that of belled-wedge pile were built. They concluded that belled-wedge piles are economical compared to the other comparative piles and improvement in bearing capacity is much better than the other model piles used.

Dhatrak A.I. et.al (2018) carried out experimental research on Single and group of piles with circular, belled and wedge shaped piles placed in sand bed. Spacing between the piles and number of piles of belled wedge piles are taken into consideration. Results from the model pile load indicated that single and group of belled wedge pile provides better and higher uplift and vertical capacities than circular pile.

III. MATERIALS AND METHODS

Tests are conducted in a model mild steel tank, cohesionless soil as soil medium i.e., sand as foundation bed and aluminum material was used for different bells (ɵ) and tapered pile (α) models. Tests are conducted in both medium dense and loose condition of sand. Description of each material is explained below.

A. Soil sample

To determine the engineering properties of dry river sand, IS tests were conducted. Properties of Soil sample are listed below in the Table 1.

Table 1: Properties of Soil sample

Properties	Soil sample
Uniformity coefficient (C_u)	2.71
Coefficient of curvature (C_c)	0.91
Specific gravity (G)	2.62
Maximum unit weight (γ_{max}), e_{min}	17.6 kN/m^3, 0.48
Minimum unit weight (γ_{min}), e_{max}	15.6 kN/m^3, 0.65
Angle of internal friction (φ)	32° (D_r=35%), 36° (D_r=55%)
IS Classification	SP

B. Pile models

The tapered pile length of 300mm with two different tapered angles of 1° and 2° are used. The base diameter of pile shaft was used 48mm for belled wedge pile. Bell angles of 30°, 45° and 60° are used in the present study. The bell diameter (D_b) to tapered pile diameter (D_s) ratios of 1.5 and 2 were used to know the effect of bells on lateral load resistance capacity. The belled-wedge pile model properties shown in Table 2 and the schematic representation of tapered pile and belled-wedge pile are shown in Fig. 1. Belled-wedge piles have taper angles of 1° and 2° with bell angle of 30° are shown in Fig. 2.

Table 2: Properties of Belled-wedge pile

Parameter	Model of pile
Material	Aluminum
Modulus of elasticity, E (GPa)	70
Tapered pile length (mm)	300
Taper angle (α)	1° and 2°
Outer base diameter (mm)	48
Thickness of pile shaft (mm)	5
Bell angle (ɵ)	30°, 45°, 60°
Bell diameter (mm)	72 (D_b/D_s=1.5), 96 (D_b/D_s=2)

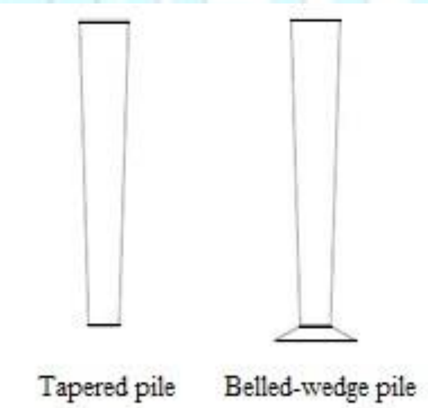

Fig. 1: Schematic representation of the tapered pile and belled-wedge piles

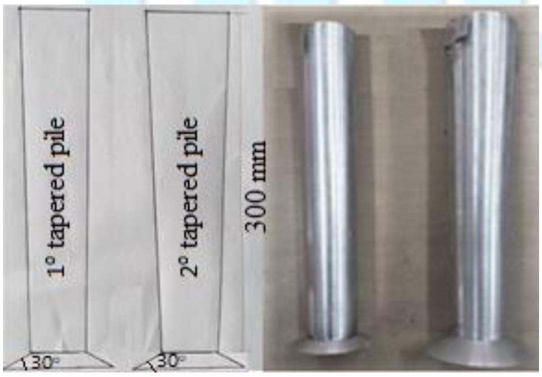

Fig. 2: Belled-wedge piles have taper angles of 1° and 2° with bell angle of 30°

C. Experimental setup

Pile models were used in this study, tapered pile length of 300mm with two different tapered angles of 1° and 2°. Base diameter of the pile was 48mm for tapered pile and for belled-wedge piles, the different bell angles like 30°, 45° and 60° were used. Sand is placed to the tank by using rainfall technique. The lateral load is applied to the pile through hand winch with belt attached to saddle and displacements are monitored for applied load increment with the help of mounted magnetic dial gauge. The schematic representation of the experimental setup on belle-wedge pile is shown in Figure 3.

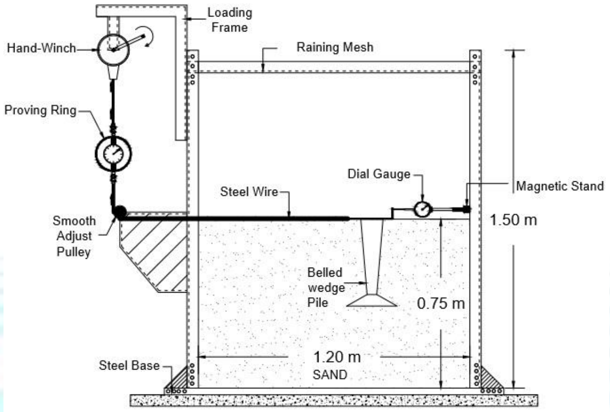

Fig. 3: Schematic representation of the experimental setup

D. Experimental procedure

The experimental set up consists of mild steel tank with the size of 1.20 m X 0.72m X 0.75 m, in which wedge pile of base diameter 48mm, bell diameter of 72mm and 96mm with shaft thickness of 5mm were employed. The experiment on wedge pile of taper angle 1° and 2° with the bell angles of 30°, 45° and 60° were used. The study on tapered pile of 48mm base diameter with taper angle of 1° and 2° and having thickness of 5mm. The testing tank was filled by dry sand, using rainfall technique which was achieved by placing the sand through attached raining box in tank as shown in Figure 4, this height of fall to achieve required relative density.

Fig. 4: Sand rainfall to achieve required relative density

The unit weight of each layer was checked by placing sampling containers and it was noted that the adopted procedure of rainfall technique produced good reproducible relative densities. Test readings were taken up to the deformations of 50mm by mounted dial gauge. The procedure was continued with relative densities of 35% and 55%, different taper angles and D_b/D_s ratios (Where, D_b = diameter of bell and D_s = diameter of pile shaft). For all the model tests finally deformation corresponding to lateral load were plotted, from which peak loads were obtained.

IV. RESULTS AND DISCUSSIONS

A series of static lateral load tests were performed on tapered pile and belled-wedge pile with varying D_b/D_s of 1.5 and 2 and also by varying bell angles of 30°, 45° and 60° respectively and relative densities of 35% and 55% and the results were compared with tapered piles of taper angles 1° and 2°.

The variations in lateral load and lateral deformation curves are plotted for different combinations and the corresponding results are shown in following graphs (Fig. 5 to Fig. 14). It can be observed that as the taper angle increases the peak lateral resistance was found to increase. Also for all the combination increase in relative density increases the lateral resistance of belled wedge pile. It can also be observed that the displacement required to achieve peak load increases with increase in taper angle. Also with increase in bell angle up to 45° the load carrying capacity was found to increase.

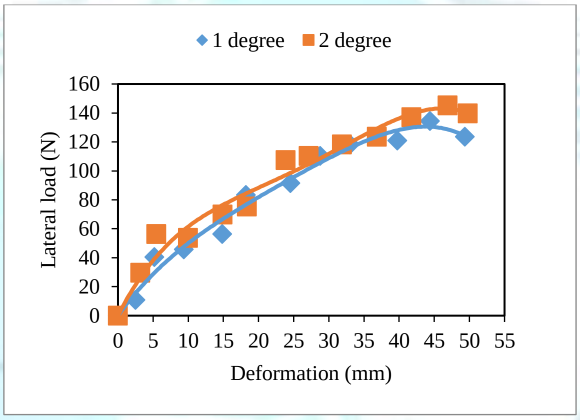

Fig. 5: Lateral load - deformation curve for different taper angles and relative density of 35%

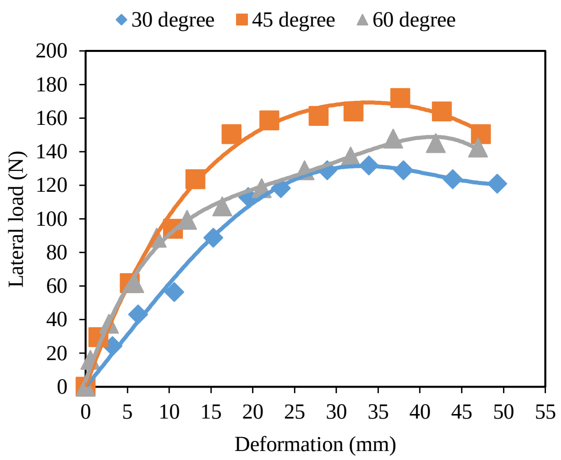

Fig. 6: Lateral load - deformation curve for taper angle of 1° and D_b/D_s=1.5 with relative density of 35%

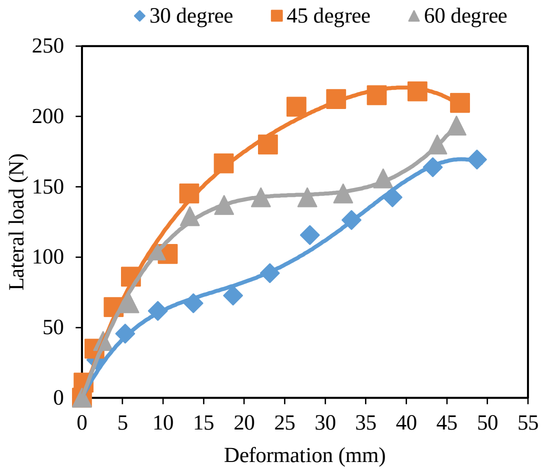

Fig. 7: Lateral load - deformation curve for taper angle of 2° and D_b/D_s =1.5 with relative density of 35%

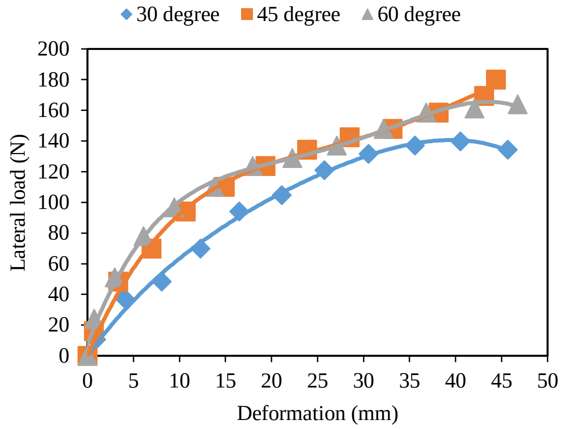

Fig. 8: Lateral load - deformation curve for taper angle of 1° and D_b/D_s=2 with relative density of 35%

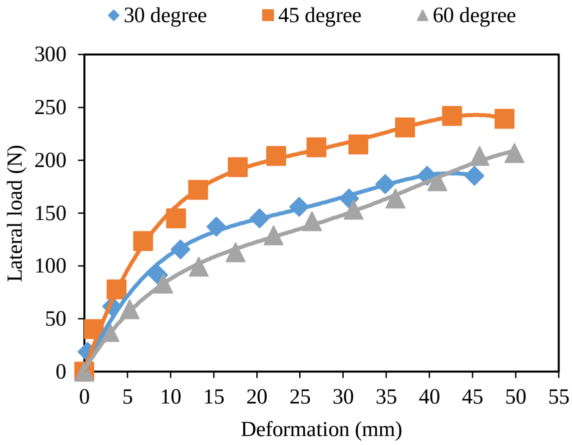

Fig. 9: Lateral load - deformation curve for taper angle of 2° and D_b/D_s=2 with relative density of 35%

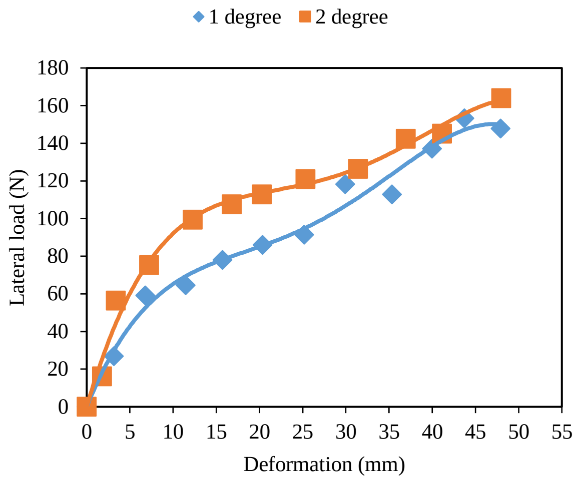

Fig. 10: Lateral load - deformation curve for different taper angles and relative density of 55%

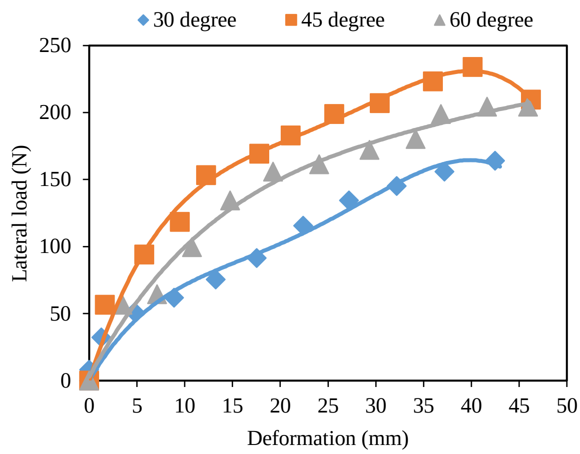

Fig. 11: Lateral load - deformation curve for taper angle of 1° and D_b/D_s =1.5 with relative density of 55%

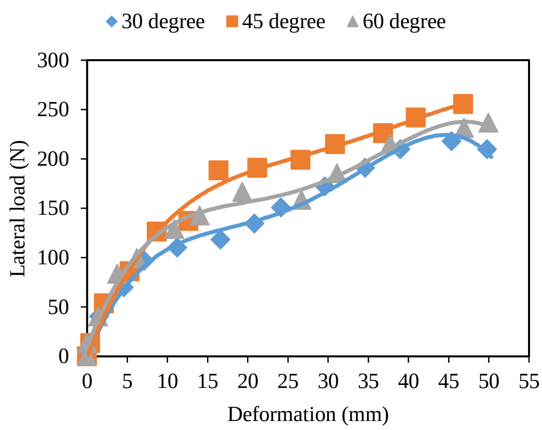

Fig. 12: Lateral load - deformation curve for taper angle of 2° and D_b/D_s=1.5 with relative density of 55%

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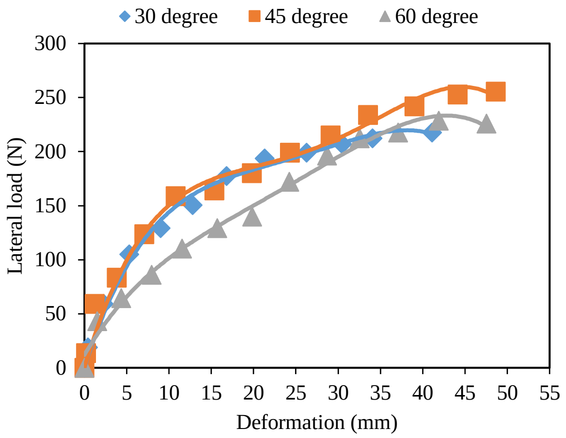

Fig. 13: Lateral load - deformation curve for taper angle of 1° and D_b/D_s= 2 with relative density of 55%

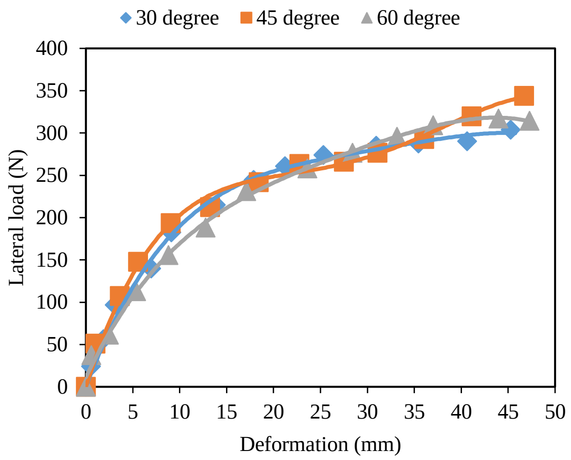

Fig. 14: Lateral load - deformation curve for taper angle of 2° and D_b/D_s = 2 with relative density of 55%

The observed ultimate lateral loads of tapered and belled-wedge piles for varying combinations from Fig. 5 to Fig. 14 are mentioned in the Table 3.

Table 3: Ultimate lateral load (N) for different conditions

Relative density (D_r)	**35%**		**55%**	
Taper angle	1º	2º	1º	2º
Bell angle (θ)	**D_b/D_s=2**			
30º	140	188	220	300
45º	178	240	260	340
60º	166	210	235	320
	D_b/D_s=1.5			

30°	132	170	172	225
45°	170	220	230	255
60°	150	200	205	240
Tapered pile	130	144	150	164

The increase in percentage of ultimate lateral load for belled-wedge pile with respect to tapered pile is mentioned in the Table 4.

Table 4: Ultimate lateral load (%) in Belled-wedge pile with reference to tapered pile

Relative density (D_r)	**35%**		**55%**	
Taper angle (α)	1°	2°	1°	2°
Ball angle (θ)	$\mathbf{D_b/D_s=2}$			
30°	7.7	30.6	46.7	82.9
45°	36.9	66.7	73.3	107.3
60°	27.7	45.8	56.7	95.1
	$\mathbf{D_b/D_s=1.5}$			
30°	1.5	18.1	14.7	37.2
45°	30.8	52.8	53.3	55.5
60°	15.4	38.9	36.7	46.3

V. CONCLUSIONS

A series of tests were conducted on pile models like belled-wedge piles and tapered piles for taper angles of 1° and 2°. To determine the effect of taper angles and bell angles, belled wedge piles were tested with different bell angles of 30°, 45° and 60° and also by varying bell diameter to average shaft diameter ratio (D_b/D_s) for 1.5 and 2. All the tests were conducted for relative densities of 35% and 55%.

Comparisons are made between belled wedge pile and tapered piles test results, the following conclusions are drawn:

1 Increase in relative density and with increase in D_b/D_s ratio there is better improvement of peak load in bell wedge pile compared to the tapered pile. This is due to increase in medium dense state of sand at D_r=55% which provides more resistance to the displacement of pile than compared to D_r =35% which is of loose state.

2 Increase in bell angles of 30°, 45° and 60° with taper angle of 1° and 2° there is better improvement in peak load in belled-wedge pile compared to tapered pile. The bell angle of 60° and taper angle of 2° at D_r =55% there is 97.5% increase in peak load with reference to tapered pile.

3 The ultimate lateral loads for belled-wedge piles are higher compare to tapered piles for all the varying conditions. This is because, as base diameter increases, base resistance of pile increases which causes increase in lateral resistance of bell-wedge piles.

4 Piles were tested by varying bell angles of 30°, 45° and 60°, lateral resistance of 45° bell angle was more compared to 30° and 60°. This shows that as the lateral resistance was found to increase up to bell angle of 45°, then after which load carrying capacity was decreased.

5 Bell angle of 45° acts as optimum. Also the surface area circumscribing the 45° was more than 60° bell angle, shaft friction increases for 45° bell angle resulting in increase in peak lateral resistance. As D_b/D_s ratio of 1.5 to 2, increase was found more in ultimate lateral load for varying combinations.

6 Tapered piles shows more equitable distribution of pile material in several aspects leading to the overall economy. It was found that when compared to tapered pile alone belled wedge pile is more efficient in resisting lateral loads.

7 The larger surface area of belled wedge pile in contact with surrounding soil both at top and bottom of the pile as a result the resistance to displacement and movement of pile during application of lateral load is more compared to that of tapered pile which as very less surface contact area at bottom compared to the belled wedge pile.

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