A Comparative Study of Lateral Load Carrying Capacity of Cylindrical & Belled Piles.

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Abstract : Experimental investigation of a single pile & pile group of triangular pattern (2x1 piles), diamond pattern (2x2 piles) pattern and square pattern (2x2 piles) have been carried out using the model RC piles of cylindrical and belled shaped. The piles were made up of concrete (M20) , having diameter of 20mm and of varying length of 310mm , 350mm and 390mm so as to have the length to diameter (l/d) ratio 15.5, 17.5 and 19.5. All the piles and corresponding pile groups are tested under Lateral loading. Spacing between the two piles in various pile groups were kept 3 times pile's diameter in all experiments. Based on the experimental results, behavior of lateral capacity for different piles and pile groups of cylindrical and belled shaped, effect of base enlargement and effect of grouping of piles are discussed in this paper.

***Index Terms* – Belled piles, lateral load carrying capacity, Pile groups, cylindrical piles.**

I. INTRODUCTION

Pile foundations are used frequently to transmit the loads of the super structure to deeper strata if the soil in the subsurface is of inadequate strength. The quick growth of main offshore structures in the last two decades all over the world led to a rapid increase in the number of offshore structures even in unfavorable ground condition. The foundation of offshore structures on such unfavorable sub ground presents a challenge for both geotechnical and structural engineers.

Pile foundations are generally preferred when heavy structural loads have to be transferred through weak subsoil to hard strata. These foundations in some situations are subjected to significant amount of lateral loads besides vertical loads. Lateral forces may be due to impact of ships during berthing and wave action in the case of off shore structures. Piles are commonly used to support bridge structures, tall buildings, and transmission line towers. Towers and offshore structures are usually subjected to overturning moments due to wind, wave pressure and ship impact. These overturning moments transferred to the foundation of the structure in the form of horizontal and vertical loads. The type of foundation usually recommended for such loading conditions is pile foundations. In practice piles are used in groups and are connected by a cap at the pile heads. The spacing between the piles, arrangement of piles and direction of load has an important role in the assessment of load deformation behavior of pile groups under lateral loads.

The behavior of laterally loaded pile groups are generally analyzed using the concept of subgrade modulus or considering the soil as an elastic continuum. Meyerhof and Yalcin (1992) investigated behavior of single free headed model flexible vertical pile under central inclined loads in two layered soil. The ultimate capacity of pile is found to depend on the layered soil, load displacement of flexible piles are presented on the basis of resultant influence factors that are related to load inclination, and distribution of soil modulus with depth. Patra and Pise (2001) have investigated load-displacement response, ultimate resistance and group efficiency to predict the ultimate lateral capacity of a single pile & pile groups. Zang, et al (2005) developed a method for determination of ultimate soil resistance to piles including frontal side resistance and side shear resistance in cohesionless soil

Studies on deflection of single batter piles and pile groups are reported by Murthy (1965). He investigated the behavior of model instrumented piles subjected to horizontal load.

Ooi and Duncan (1994) presented a simple method for estimating pile group deflection and maximum bending moments based on the theories of Poulos (1971) and Focht and Koch (1973). Lateral deflection and maximum bending moment are calculated using the group amplification procedure. Juvekar and pise (2008) developed a group amplification factor group efficiency of battered pile subjected to lateral loading.

Therefore, experimental investigations have been carried out to study the behavior of lateral load carrying capacity vs. the lateral displacement of single pile and pile groups of cylindrical and belled shaped piles in sand with different configurations such as triangular, square etc. have been conducted.

II. EXPERIMENTAL INVESTIGATION & TEST RESULTS

Tests on model piles were carried out in a steel tank of size 750mm x 750mm x 750mm. The tank was sufficiently large enough to take care of the effects of pressure bulbs on the test results.

Model piles were casted from 20mm diameter solid concrete pile with its length of 310mm, 350mm & 390mm. Tests were carried out for single pile, 2x1triangular pattern and 2x2 diamond and square pattern of pile groups of cylindrical and belled shaped. The diameter at base of belled piles (D_u) was kept 2 times diameter (d) of pile and the length (l_1) of belled portion was kept 40mm constant in all cases of l/d ratio's 15.5, 17.5 and 19.5. In case of pile groups the spacing between two piles was kept 3d. The model piles were embedded in dry sand bed.

Table 1: Details of soil properties.

Relative Density (%)	0
Angle of internal friction , ϕ	36°
γ_{min} (g/cc)	1.54
γ_d (g/cc)	1.54
Uniformity coefficient of sand	3.5
γ_{max} (g/cc)	1.71

Piles were subjected to lateral load with the help of a pulley arrangement with a flexible wire whose one end is attached to pile cap and other end to the tension proving ring through which the load was increased gradually. The least count of the proving ring was 1 division = 0.41773 Newtons (N) load and the ultimate capacity of proving ring was 250 N, the least count of the dial gauge was 0.01mm which was used to measure the lateral displacement. The load was increased at an interval of 10 divisions of proving ring. The corresponding lateral displacement to various load intervals were measured. The failure of the pile was marked when the proving ring showed the readings in reverse order. Dial gauges were attached at diagonal ends of the pile cap to measure the lateral displacement of piles.

The lateral load carrying capacity with lateral displacement of cylindrical & belled piles with **L/d = 15.5** for single pile & pile groups for various patterns are represented in Figure 1 – 4.

Figure 1: Variation of Lateral Load vs. Lateral displacement for L/d = 15.5 single cylindrical & belled pile.

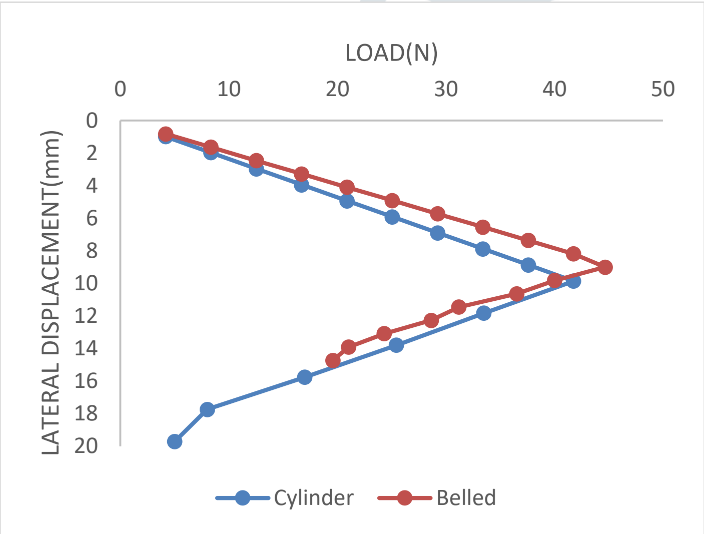


Figure 2: Variation of Lateral Load vs. Lateral displacement for L/d = 15.5 cylindrical & belled pile group in triangular pattern.

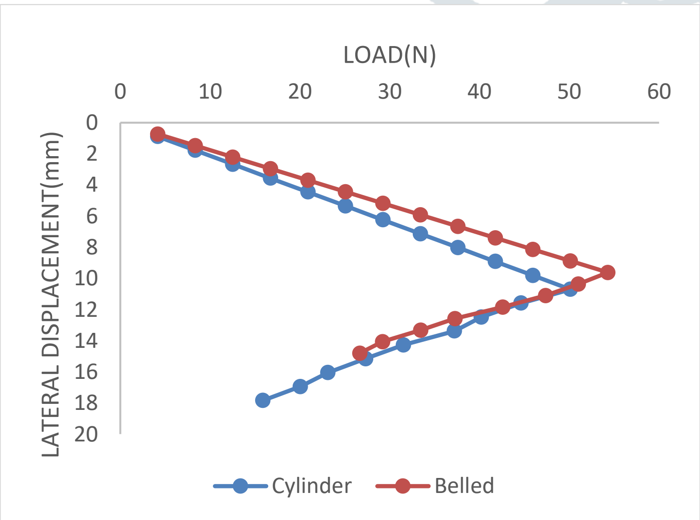


Figure 3: Variation of Lateral Load vs. Lateral displacement for L/d = 15.5 cylindrical & belled pile group in square pattern.

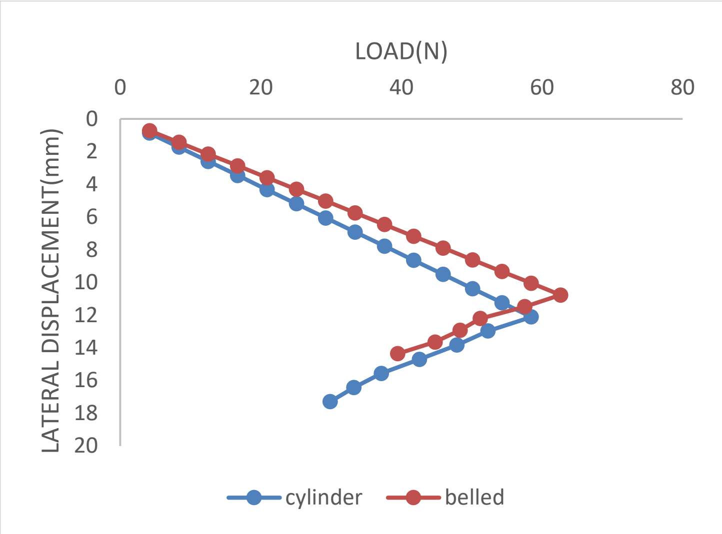
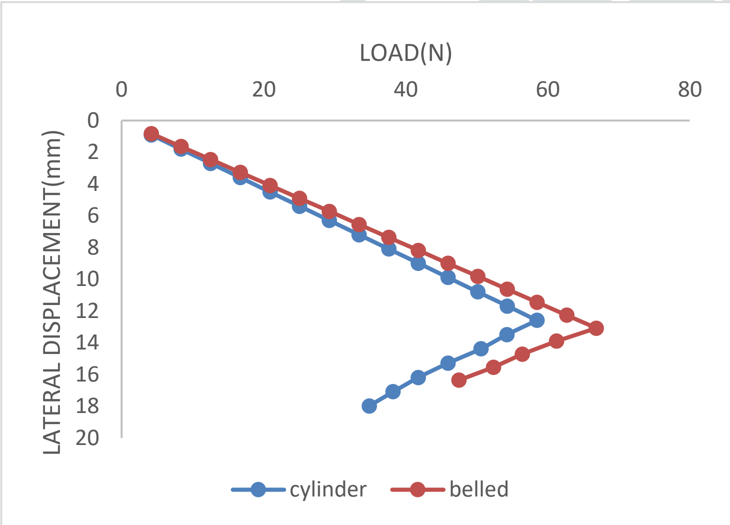


Figure 4: Variation of Lateral Load vs. Lateral displacement for L/d = 15.5 cylindrical & belled pile group in diamond pattern.



The lateral load carrying capacity with lateral displacement of cylindrical & belled piles with **L/d = 17.5** for single pile & pile groups for various patterns are represented in Figure 5 – 8.

Figure 5: Variation of Lateral Load vs. Lateral displacement for L/d = 17.5 single cylindrical & belled pile.

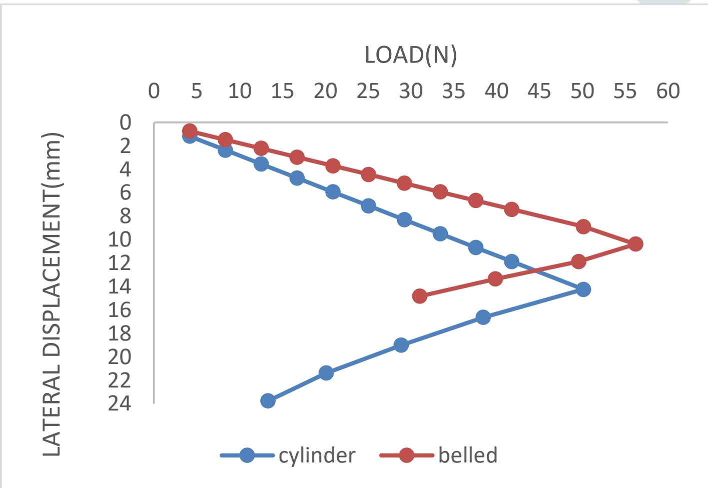


Figure 6: Variation of Lateral Load vs. Lateral displacement for L/d = 17.5 cylindrical & belled pile group in triangular pattern.

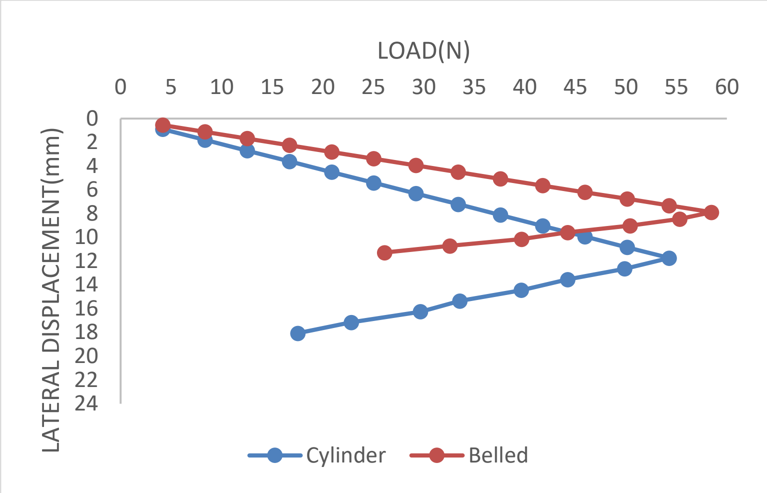


Figure 7: Variation of Lateral Load vs. Lateral displacement for L/d = 17.5 cylindrical & belled pile group in square pattern.

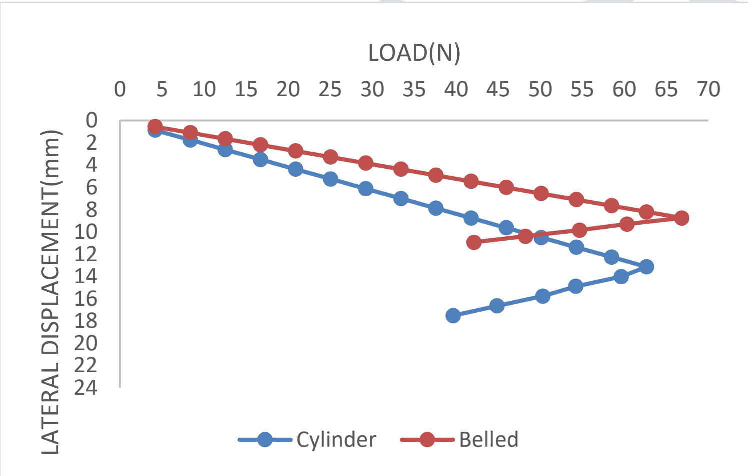
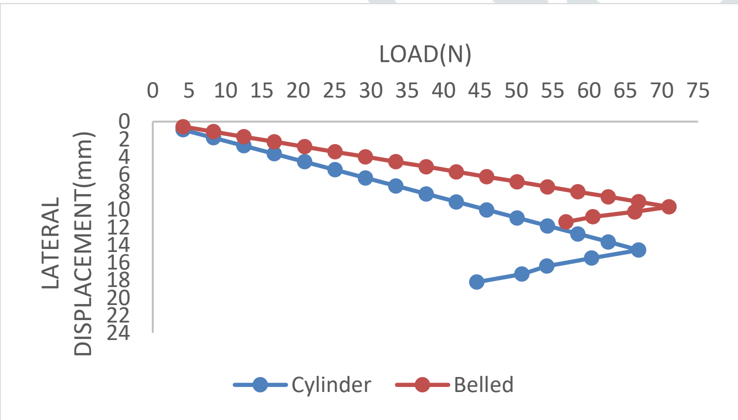


Figure 8: Variation of Lateral Load vs. Lateral displacement for L/d = 17.5 cylindrical & belled pile group in diamond pattern.



The lateral load carrying capacity with lateral displacement of cylindrical & belled piles with **L/d = 19.5** for single pile & pile groups for various patterns are represented in Figure 9 – 12.

Figure 9: Variation of Lateral Load vs. Lateral displacement for L/d = 19.5 single cylindrical & belled pile.

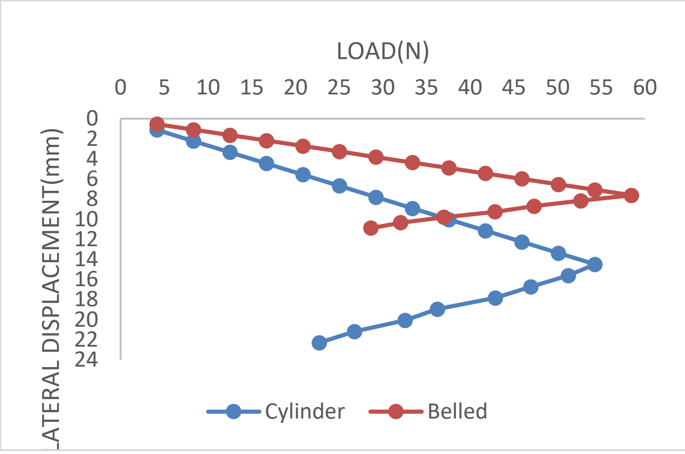


Figure 10: Variation of Lateral Load vs. Lateral displacement for L/d = 19.5 cylindrical & belled pile group in triangular pattern.

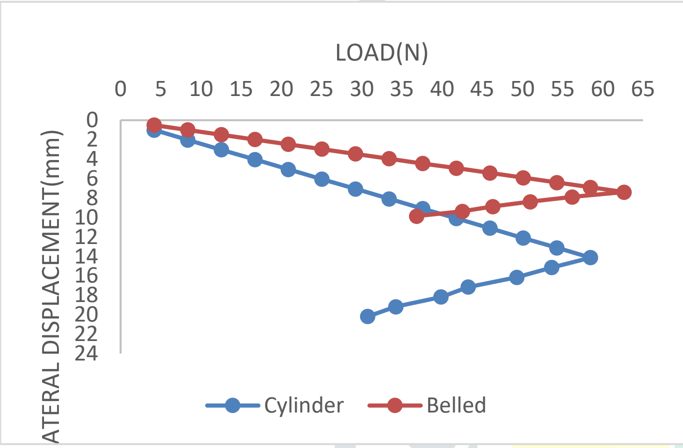


Figure 11: Variation of Lateral Load vs. Lateral displacement for L/d = 19.5 cylindrical & belled pile group in square pattern.

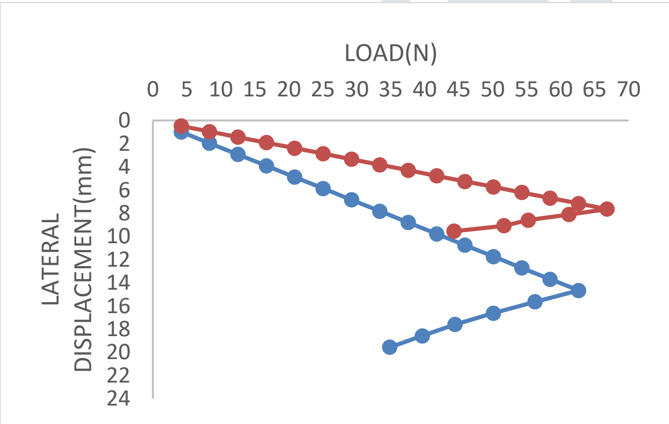
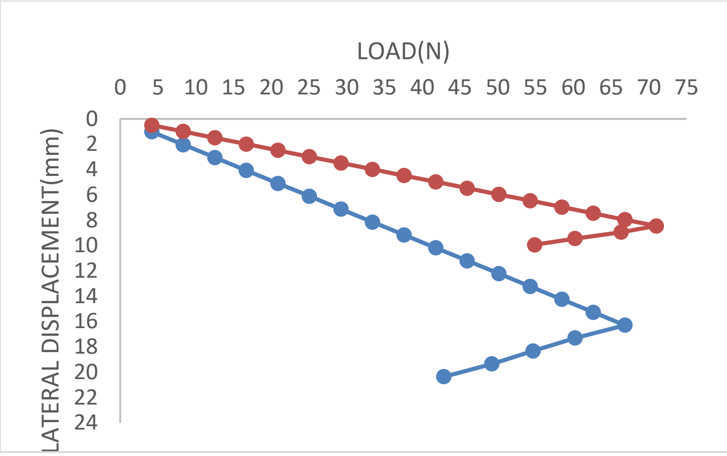


Figure 12: Variation of Lateral Load vs. Lateral displacement for L/d = 19.5 cylindrical & belled pile group in diamond pattern.



Based on Experimental work carried out, the ultimate lateral load carrying capacity of single pile & pile groups arranged in various patterns for various L/d ratios are reported in Table 2.

Table 2: Details of Ultimate Lateral Load Carrying Capacity of Piles.

Type of Pile	Pile Pattern	L/d Ratio	Ultimate Lateral Load(N)
Cylindrical	Single	15.5	41.77
	Triangle		50.12
	Square		58.48
	Diamond		58.5
	Single	17.5	50.12
	Triangle		54.3
	Square		62.65
	Diamond		66.83
	Single	19.5	54.3
	Triangle		58.42
	Square		62.65
	Diamond		66.83
Belled	Single	15.5	44.67
	Triangle		54.3
	Square		62.65
	Diamond		66.83
	Single	17.5	56.23
	Triangle		58.48
	Square		66.83
	Diamond		71.01
	Single	19.5	58.42
	Triangle		62.65
	Square		66.95
	Diamond		71.85

III. CONCLUSION

The following conclusions have been drawn out from the present study.

- The ultimate Lateral load carrying capacity of single belled pile & pile group is more than that of cylindrical piles for all L/d ratios.
- The increase in l-d ratio increases the lateral load carrying capacity of both cylindrical & belled piles by 4-5%.
- The ultimate lateral load carrying capacity of belled piles is maximum in diamond configuration.
- For cylindrical piles, square & diamond pattern yields almost same lateral load carrying capacity, hence square pattern can be adopted for more economical design.

IV. REFERENCES

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