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Performance of Barrette Foundations in Sandy Soil Subjected to Vertical Loading

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Abstract This paper presents the results of experimental investigations of barrette foundations of various shapes, viz, rectangular, T-shape, cruciform shape and H-shape, resting in the sand and subjected to vertical loading. Model pile load tests were conducted in a laboratory setup and ultimate vertical capacities of the piles were determined. The results show that Barrettes have much higher ultimate vertical capacities as compared to that of circular pile of same c/s area. The shape of barrette has an influence on the ultimate vertical loading capacity of pile.

Keywords: Barrette Foundation, ultimate vertical capacity, Experimental investigations

1 Introduction

Barrette piles are cast-in-situ reinforced concrete pile which is formed in deep trench excavated under bentonite or polymer slurry by diaphragm walling equipment. These are generally rectangular piles; however, various other shapes may also be adopted. Barrettes provide resistance to horizontal stress and to bending moments better than circular piles of the same cross-section. Barrettes provide an alternative to large diameter bored and cast-in-place piles or drilled shafts. In real situations, Barrette foundation may be used for high rise buildings, skyscrapers, elevated expressways, towers, overpass bridges, underground car parks etc.

The barrette pile's having considerably larger bearing capacity compared to that of the conventional circular pile is a crucial advantage in meeting the increasing demand for loading from tall buildings. Besides, the time required for trenching of barrette piles is less than that required for the drilling method employed for circular piles. Therefore, barrette piles have become increasingly common in the construction of high-rise buildings. Its cross-section and construction method differ from those of conventional circular bored piles, resulting in different bearing behaviours for the two types of piles.

2 Literature Review

A.Z. El Wakil *et. Al. (2013)* has experimentally presented behaviour of laterally loaded small scale rectangular barrette in sand. 28 model tests were carried out to study effect of density, aspect ratio, eccentricity and loading directions. As the aspect ratio increased, the performance of barrette pile also increased. Relative density has significant effect on the performance of barrette. Lateral resistance of barrette was greater when loaded along the major axis as compared to the minor axis. C. Submaneewong. *et al* (2009) conducted static pile load tests to verify the lateral load capacities of T-shape barrette and bored piles. For the design approach, the back analysis suggests that input soil stiffness for T-shape barrette should be about 3 times of empirically calculated value to predict deflection values before concrete cracking similar to those of actual measurement by finite element software. Finite element analysis overestimated the later capacity ignoring the concrete cracking. Salem D. Ramaswamy *et al.*(1986) had presented a paper on construction of barrettes for high-rise foundation. According to researchers, by adopting barrette, the designer would be able to increase the inertia and bending moment resistance in the required direction without having to increase the concrete area by properly orientating the barrette. Researcher specified the safe bearing load for the different shape of barrette with general sizes. Charles, W. W. Ng, *et al.*(2000) had presented field studies of well-instrumented barrette in Hong Kong. L. M. Zhang *et al* (2003) presented the behaviour of large section rectangular barrette subjected to lateral load. The load capacity was highest along the major axis and decreased as deviated from major axis to minor axis.

3 System Development

For the study of vertically loaded barrettes in sand, laboratory model tests were conducted on barrettes of various shapes.

3.1 Test Setup

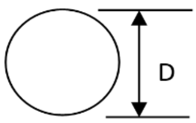
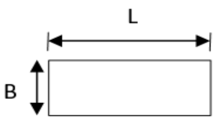
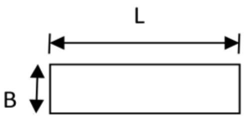
The test setup for vertical load tests on barrette consisted of loading frame, test tank, hydraulic jack, proving ring and dial gauges. The test tank was made of steel frame with an inside dimension of 0.90 m (length), 0.50 m (width), and 0.65 m (depth). The bottom and vertical edges of the box were stiffened using angle sections to avoid lateral yielding during soil placement and loading of the barrette pile model. Hydraulic jack of 5 kN capacity was used to apply static loads to the pile. The settlements were measured with the help of two dial gauges with 25mm travel and least count of 0.01mm. The dial gauges were fixed to the magnetic bases which in turn were fixed to the sides of the tank. Proving ring of 5 kN capacity was used to precisely record the load applied on the barrettes. Proving ring was fixed to the bottom plunger to transfer load from hydraulic jack to the model barrettes. The test setup is shown in fig 1.

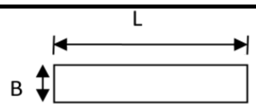
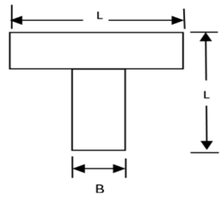
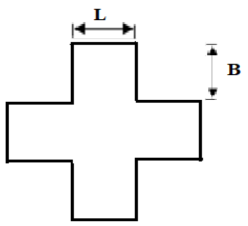
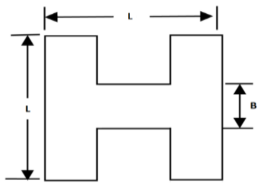
Fig. 1. Test setup used for vertical loading on Barrette piles

3.2 Materials

Model Piles. The model barrette piles were made from aluminium. The c/s area of the barrette piles was kept similar to the c/s area of circular pile of diameter 20 mm (i.e. 314 mm^2). Length of all piles was kept same and equal to 300 mm. Table 1 shows the shapes and dimensions of Model Piles used in experimental investigation.

Table 1. Shapes and Dimensions of Model Piles used in experimental investigation

Sr No.	Cross section of pile	Description	Dimensions
1		Circular	Diameter D = 20 mm A =314 mm^2
2		Rectangular-1 Aspect ratio (L/B) =2	Length (L) = 25 mm Width (B) = 12.5 mm
3		Rectangular-2 Aspect ratio (L/B) =3	Length (L) = 31 mm Width (B) = 10 mm

4		Rectangular-3 Aspect ratio (L/B) =4	Length (L) = 36 mm Width (B) = 9 mm
5		T-Shape	Length (L) = 24.8 mm Width (B) = 7.4 mm
6		Cruciform	Length (L) = 8 mm Width (B) = 8 mm
7		H-Shape	Length (L) = 25 mm Width (B) = 5 mm

Soil. For the model tests, uniformly graded dry cohesionless sand was used as the foundation soil. This sand is available in Vidarbha region of Maharashtra. Table 2 gives the properties of sand as determined in laboratory as per relevant IS codal procedures.

Table 2. Properties of sand

Sr. No.	Properties of sand	Values
1	Specific gravity	2.67
2	IS Classification	SP (Medium Sand)
3	γ_{max} (kN/m^3)	17.5
4	γ_{min} (kN/m^3)	15.7
5	Angle of internal friction (ϕ)	38
6	Cohesion (kN/m^2)	0

3.3 Experimental Procedure

The piles were placed at the centre of the tank vertically in the sand bed with the help of special guide tool. The relative density of soil was maintained at 40% (medium dense) by sand rainfall technique. Initially the tank was filled up to the pile tip level and then the model test pile is lowered in the test tank. This procedure of pile installation was assumed to simulate the stress conditions similar around cast in situ piles in the field. The pile head was screwed with the pile cap made of steel plate of 3 mm thickness. The sand was filled in to the tank up to 250 mm height of pile and top 50 mm of the pile was kept projecting above soil bed. The top surface of formed sand bed was leveled with the help of thin sharpened steel plate.
The vertical compressive load to the piles was applied with the help of hydraulic jack fitted to the loading frame. The proving ring was attached to the bottom of the jack. One metal rod was connected to the bottom threads of proving ring and rested directly on the groove made on the pile cap. Dial gauges were placed on the pile cap to measure the vertical displacement. Loads were applied in increments and settlements of the piles were measured with the help of dial gauges. Each load increment was kept constant till the rate of settlement became less than 0.1 mm per 30 minutes. Application of loads increments were continued till failure of the model pile which was indicated by rapid settlement of the pile.

The parameters selected for the study are presented in Table 3

Table 3. Parameters of study

Sr. No	Details of Parameter	Constant Parameters	Varied Parameters
1	Height of embedded pile in soil	250 mm	-
2	Diameter of circular Pile	20 mm	-
3	Slenderness ratio (L/D)	15	-
4	Relative Density of Sand	40 %	-
5	Aspect ratio of rectangular barrette pile	-	2, 3, 4
6	Type of Loading	-	Vertical Loading
7	Shapes of Barrette piles		i) Rectangular ii) T- shape iii) Cruciform iv) H-shape

4 Test Results and Discussions

The pile load tests were carried out on conventional circular and barrette piles and load-settlement curves was plotted to study the performance of barrette pile. The curves plotted in Fig 2 to Fig 4 shows the performance of circular and barrette pile subjected to vertical loads in medium dense cohesionless sand.

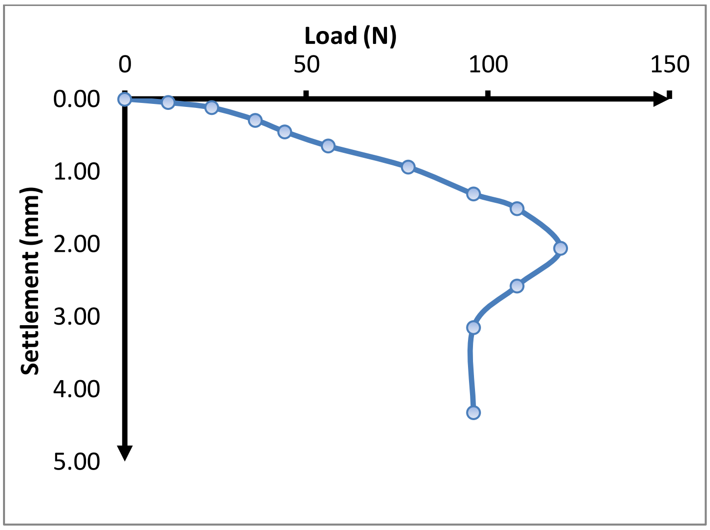


Fig .2. Load-Settlement curve for circular pile

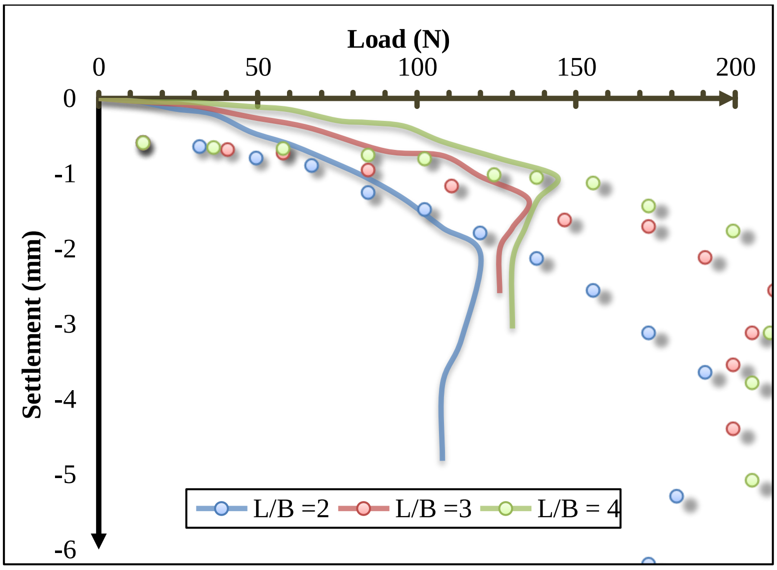


Fig. 3. Load-Settlement curves for rectangular barrettes

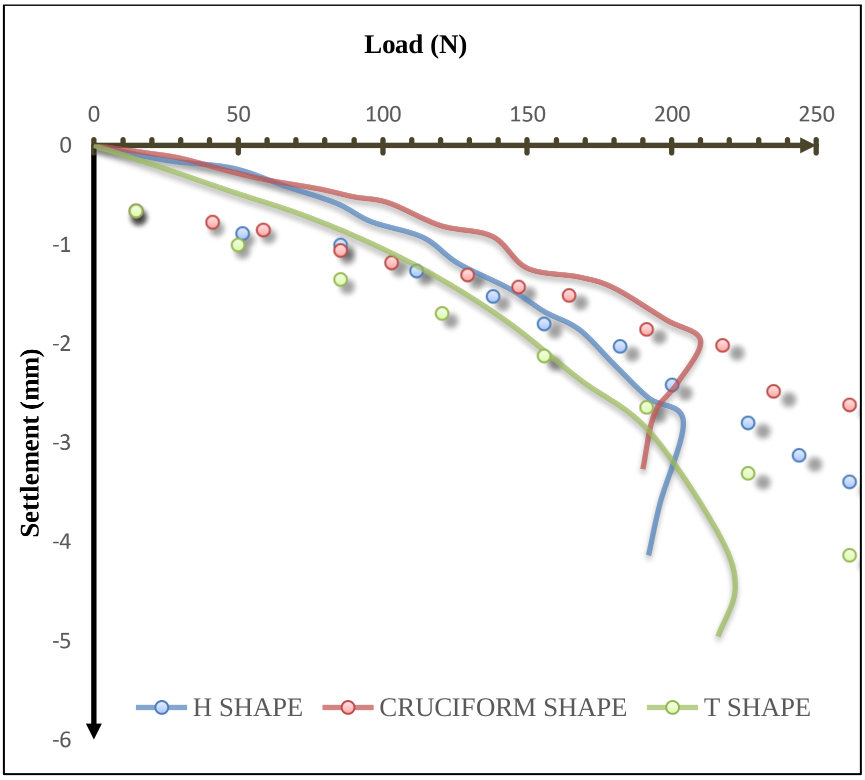


Fig. 4. Load-Settlement curves for H-Shaped, Cruciform and T-shaped Barrette

The ultimate vertical load capacity is determined from the load-settlement curves. The ultimate vertical load capacities of the piles are shown from Table 4 to 6.

Table 4. Ultimate vertical loading capacity of conventional circular piles

Shape of Pile	Ultimate Vertical Capacity (N)
Circular	120

Table 5. Ultimate vertical loading capacities of rectangular barrettes of different aspect ratio

Shape of Pile	Ultimate Vertical Capacity (N)
Rectangular (L/B=2)	120
Rectangular (L/B=3)	134
Rectangular (L/B=4)	142

Table 6. Ultimate vertical loading capacities of barrette pile of various shapes

Shape of Pile	Ultimate Vertical Capacity (N)
H-Shape	205
Cruciform	210
T-Shape	220

The percentage increase in the ultimate vertical loading capacity of barrette compared to conventional circular pile is shown in Fig 5.

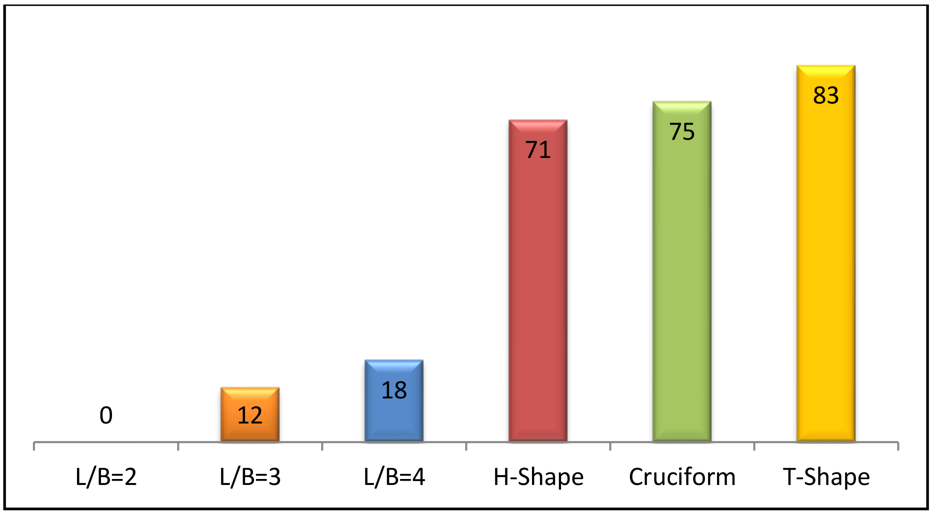


Fig.5. Percentage increase in ultimate vertical loading capacity of barrette pile

The results show the vertical loading capacities of the rectangular barrettes are higher (0-20%) as compared to conventional circular pile and the vertical capacities of different shapes of barrette are higher (70-85%) when compared to circular pile of same cross sectional area.

5 Conclusions

The capacities of Barrette piles of various shapes in sand and subjected to vertical loads were investigated using laboratory model tests. Based on the results, the effect of various parameters influencing the performance of barrette was investigated. Within the framework of the present investigation, the following broad conclusions are drawn.

1. With higher surface area, barrettes offer higher skin friction which results in increased ultimate vertical loading capacity.

2. The ultimate vertical load capacities of various shapes of Barrettes viz. rectangular, H shape, cruciform and T shape are higher as compared to the circular pile of same cross sectional area.
3. In case of rectangular barrettes, the ultimate vertical capacity increases with increase in the aspect ratio of the pile.
4. The ultimate vertical load capacity of T-shaped barrette pile is much higher than other shapes of barrette pile and 83 % higher than that of circular pile.

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