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Performance of Barrette Foundations in Sandy Soil Subjected to Lateral 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, in the sand, and subjected to lateral loading. Model pile load tests were conducted in a laboratory setup and the ultimate lateral capacities of the piles were determined. The results show that Barrettes have much higher ultimate lateral capacities as compared to that of a circular pile of the same cross-sectional area. The shape of the barrette and the direction of lateral loading influence the ultimate lateral capacity of the pile.

Keywords : Barrette Foundation, ultimate lateral capacity, Experimental investigations.

1 Introduction

A barrette is a cast-in-place reinforced concrete pile, which can take high axial loads and high moments in comparison with a circular pile of the same cross-sectional area. Barrettes are ideal for boulder ground and alluvial soil but adaptable to most types of ground. Barrettes have much of the same purpose and design as the piles. The barrette has various shapes, but the rectangular shape is generally adopted. The barrette pile's significantly 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. The field applications of a barrette pile include skyscrapers, elevated expressways, towers, overpass bridges, underground car parks, etc.

The main difference between a barrette pile and a conventional circular pile is the shape and the equipment used for construction. Construction for barrette pile is done by using the same equipments as used for the diaphragm and cut-off walls, such as Grab-bucket or Hydro-fraise type drilling tools. By using these drilling tools various cross-sections can be formed such as Rectangular, Cruciform (crosses), H shaped and, T shaped piles. Also, the time needed for excavation of barrette piles is smaller than that required for circular piles. Therefore, the use of barrette piles as the foundation of high rise buildings becomes very popular in recent years.

2 Literature Review

A.Z.EI Wakil *et al.* (2013) had presented the results of the study of the behavior of laterally loaded small scale rectangular barrettes in the sand. Twenty-eight model tests were performed to study the effect of sand relative density, the aspect ratio of pile cross-section, loading direction, and load eccentricity. From an experimental investigation, the author concluded that the performance of barrette increased with an increase in the aspect ratio of the pile. The performance of barrette significantly changed as sand relative density changed. The lateral resistance of the barrette was greater along the major axis in comparison to the minor axis. C. Submaneewong. *et al*. (2009) presented the results of analytical studies of the T-shape barrette foundation. The static pile load tests were conducted to verify the lateral load capacities of T-shape barrette and bored piles. Two sets of tests were conducted in Bangkok subsoil; one on 5 m^2 cross-sectional area T-shape barrette and another on 1.65 m diameter bored pile with a pile tip founded in the dense silty sand layer about 55 m depth below ground surface. Salem D. Ramaswamy *et.al*.(1986) had presented a paper on the 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. San-Shaylin, *et al*. (2014) had described the axial capacity of barrette piles embedded in gravel Layer. The axial performance of two heavily instrumented barrette piles, with and without grouting, socket into the gravel layer in Taipei was evaluated. According to the author's study, it was concluded that toe grouting improved not only the end bearing capacity but also the frictional resistance of both test piles.

3 Experimental Investigations

Experimental investigations were carried out small scale barrettes of various shapes in a laboratory experimental setup, as per the following details.

3.1 Test Tank

The test tank made of M.S. sheets and frame with an inside dimension of 0.65 m (length), 0.65 m (width), and 0.65 m (depth), as shown in Fig. 1, was used for the experimental investigation. 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.

3.2 Loading Frame

The loading frame to apply static lateral loads on piles is shown in Fig. 2. The static lateral loads were applied to the pile caps utilizing dead weights placed on a loading pan connected to a flexible steel rope, strung over a pulley supported by a loading frame. Pullies of mild steel having diameter 3 cm were used in the set up to support the mild steel wires for application of lateral loads.

Fig. 1. Test Tank used for Experimental Investigations

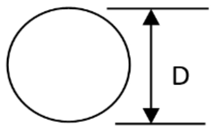
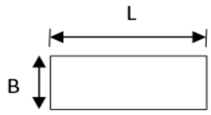
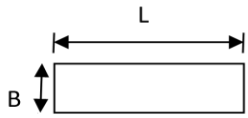
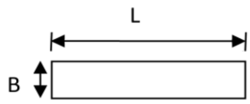
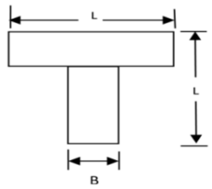
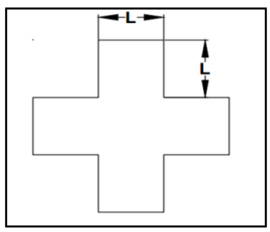
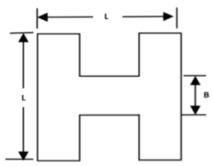
Fig. 2. The Test setup used in experimental investigations for applying lateral loads

3.3 Materials used

i) Model Piles

The model barrette piles were fabricated by the casting process from aluminium material. The diameter and length of the circular pile were 20 mm (i.e. cross-sectional area = 314 mm^2), and 300 mm respectively. The cross-sectional area and length of barrette piles were kept the same as that of the circular pile. 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
7		H-Shape	Length (L) = 25 mm Width (B) = 5 mm

ii) Soil

The soil used in the experimental investigation was uniformly graded dry cohesionless sand. The sand is available in the Vidarbha region of Maharashtra. The properties of this sand were determined as per IS codes and tabulated in Table 2.

Table 2. Properties of sand used for experimental investigations

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/m2)	0

3.4 Preparation of Sand Bed

When several tests are to be carried out, it becomes necessary to have a constant density of sand so that test results are reliable. The sand bed of constant relative density may be prepared either by compacting the known weight of sand in the layers of the known thickness or by the rainfall technique. In the present experimental investigations, the relative density of sand bed was maintained by using sand rainfall techniques. The height of fall to achieve the desired relative density was determined as a priory by performing a series of trials with different height of fall. In the present investigation, the height of fall was selected as 22.5cm in the rainfall technique and the corresponding relative density was maintained at 40 %. After filling the tank with the sand to the required level, the bed was leveled and checked by using a spirit level.

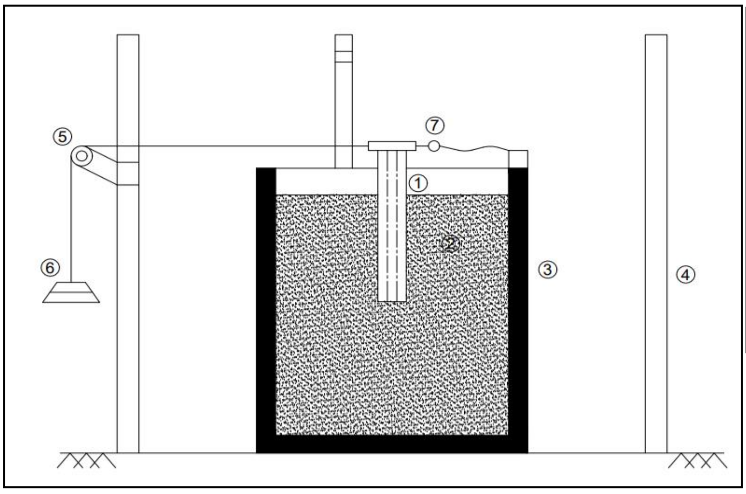
3.5 Placing of Piles in the Sand Bed

The method referred to as the undisturbed pile installation method, which represents no displacement in the soil around the pile during installation, was adopted for placing the piles. The piles were placed vertically by using a special guide (steel ring) in the tank as shown in Fig 3. Initially, the sand was filled up to the pile tip, and then the pile was kept in its position vertically. The preparation of sand bed was then continued by the rainfall method. During this process, it was ensured that the pile remained vertical.

Fig. 3. Undisturbed Method of Pile Installation During Experimental Investigations

3.6 Lateral Load Tests on Model piles

The Schematic Diagram of Test Setup for lateral loading is shown in Fig 4. The static lateral pile load tests were conducted on a model pile foundations to evaluate their ultimate lateral pile capacities. Lateral loads were applied in increments and lateral displacements of the top of the piles were measured with the help of two dial gauges. Each load increment was kept constant until the rate of displacement became less than 0.1 mm per 30 minutes. Application of loads increments was continued till failure of the model pile which was indicated by rapid lateral displacement of the pile. The results of the tests were plotted in the form of lateral displacement versus lateral load curves.



1. Barrette pile
2. Sand bed
3. Testing tank
4. Loading frame
5. Pullies
6. Standard weight
7. Dial gauges

Fig. 4. The Schematic Diagram of Test Setup for Lateral Loading

3.7 Parameters selected for the study

The parameters selected for the experimental study are listed in Table 3.

Table 3. Parameters selected for the experimental study

Sr. No	Details of Parameter	Constant Parameters	Varied Parameters
1	Height of embedded pile in soil	250 mm	-
2	The diameter of circular Pile	20 mm	-
3	Slenderness ratio (L/D)	15	-
4	Relative Density of Sand	40 %	-
5	Shapes of Barrette piles	-	i) Rectangular ii) T- shape iii) Cruciform iv) H-shape
6	The aspect ratio of rectangular barrette pile	-	2, 3, 4
7	Loading direction	-	Rectangular Barrette i) Along major axis ii) Along minor axis T-shape and H-shape i) Along web ii) Across web

4 Test results and Discussions

The experimental investigations on the model pile were carried out on model circular and barrette piles of various shapes. The load-settlement curves were plotted to determine the lateral capacities of the piles. The curves plotted in Fig 5 to Fig 9 shows the performance of circular and barrette pile subjected to lateral loads in medium dense cohesionless sand. As all load-displacement graphs are progressive and there is no clear failure point. Hence to calculate ultimate lateral capacity the criteria was taken as the load at which displacement is equal to 5 mm.

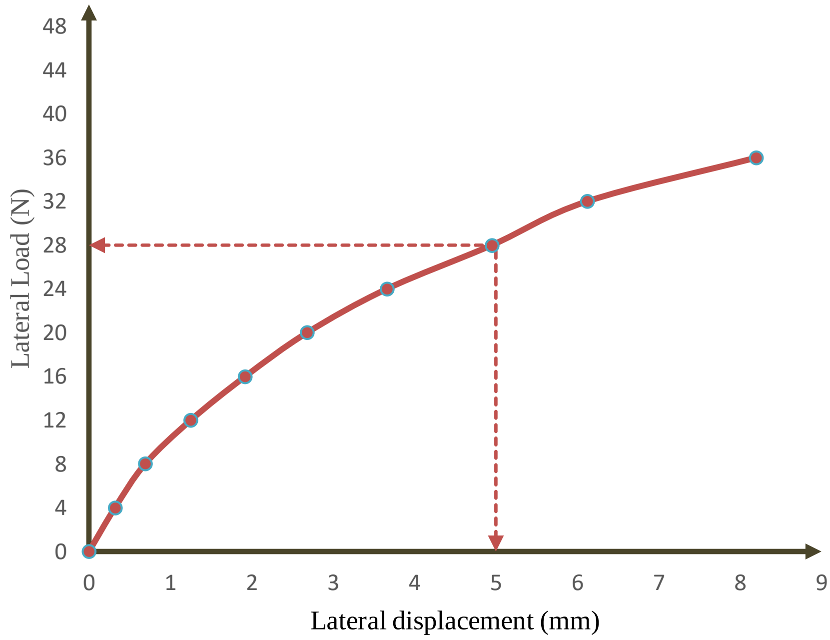


Fig. 5. Load-displacement curve for circular pile

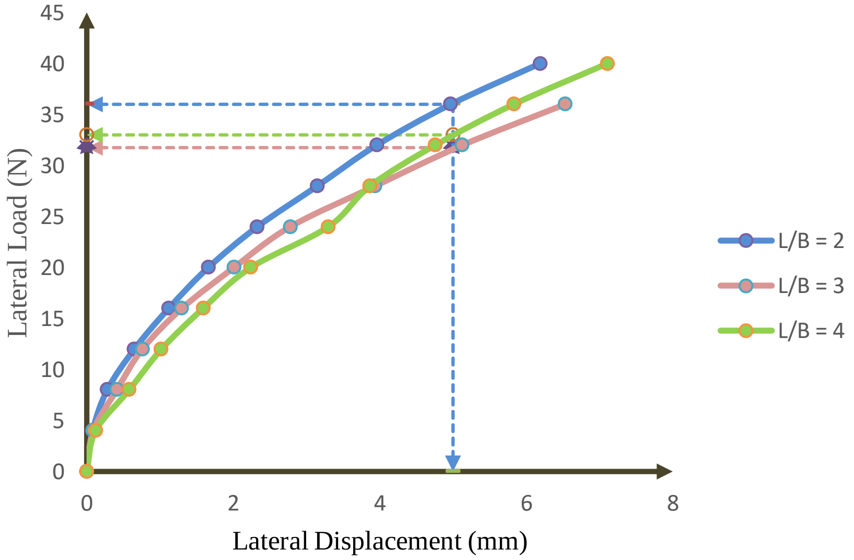


Fig. 6. Lateral Load vs lateral displacement Curves for Rectangular Barrette pile with different aspect ratios (Loading along the minor axis)

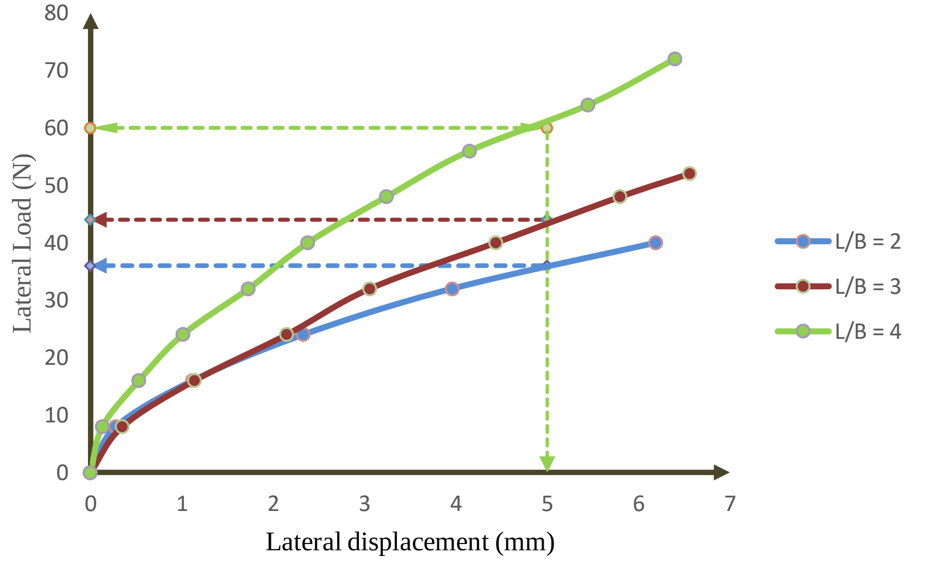


Fig.7. Lateral Load vs lateral displacement Curves for Rectangular Barrette pile with different aspect ratios (Loading along the major axis)

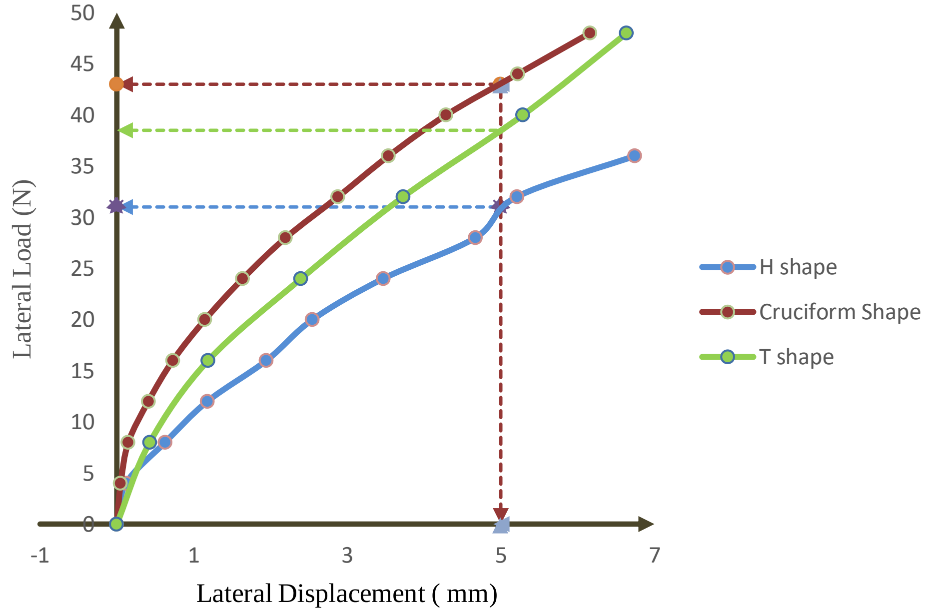


Fig. 8. Lateral Load vs lateral displacement Curves for Barrette piles of various shapes along web

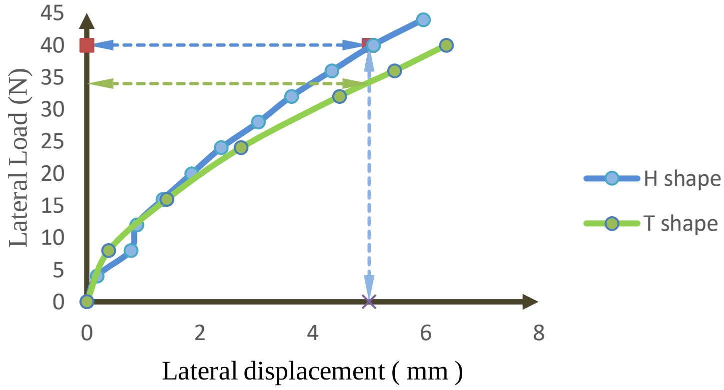


Fig.9. Lateral Load vs lateral displacement Curves for Barrette piles of various shapes Across the Web

The ultimate lateral capacities of the piles determined from the load-settlement curves are tabulated in Table 4 to 6.

Table 4. Ultimate lateral load capacity of conventional circular piles

Shape of Pile	Ultimate Bearing Capacity (N)
Circular	28

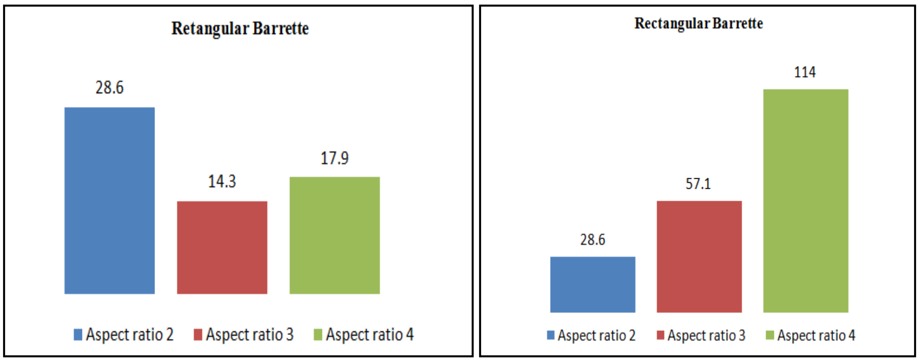
Table 5. Ultimate lateral load capacities of Rectangular Barrettes of different aspect ratio

Aspect ratio	Ultimate Lateral load capacity (N)	
	Along minor axis	Along major axis
2	36	36
3	32	44
4	33	60

Table 6. Ultimate lateral load capacities of barrette pile of various shapes

Shape of pile	Ultimate Safe Lateral Capacity (N)	
	Along web	Across web
T-shape	39	34
Cruciform shape	43	43
H-shape	31	40

The percentage increase in the ultimate lateral load capacities of rectangular barrettes of different aspect ratios, compared to the conventional circular pile is shown in Fig.10.

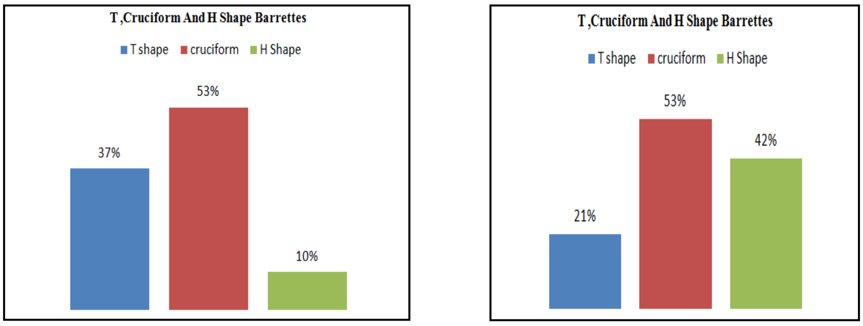


(a) (b)

Fig.10. Percentage increase in the ultimate lateral load capacities (a) Rectangular barrette pile (minor axis) (b) Rectangular barrette pile (major axis)

Thus, it can be seen that lateral load capacities of Barrette are much higher when the lateral load is applied along major axis. Also, the lateral load capacity increases with increase in the aspect ratio.

The percentage increase in the ultimate lateral load capacities of T-shape, Cruciform-shape, and H-shape barrettes, compared to the conventional circular pile is shown in Fig. 11.



(a) (b)

Fig.11. Percentage increase in the ultimate lateral load capacities (a) Cruciform-shape and H-shape barrettes (along with web) (b) Cruciform-shape and H-shape barrettes (across the web)

From the above results, it is observed that the ultimate lateral load capacities of barrettes of various shapes are higher as compared to that of the circular pile. Also, the lateral load capacities of the cruciform shape barrette are higher as compared to those of barrettes of other shapes.

5 Conclusions

The ultimate lateral load capacities of Barrette piles of various shapes in the sand were determined by performing laboratory model tests. Based on the results, the effect of various parameters influencing the performance was investigated. Within the framework of the present investigation, the following broad conclusions are drawn.

1. The ultimate lateral load capacities of Barrette Piles are higher as compared to those of circular pile of the same cross-sectional area.
2. The ultimate lateral resistance of the rectangular barrette along the major axis is greater than the minor axis.
3. The ultimate lateral resistance of the rectangular barrette increases with an increase in the aspect ratio of the pile when the load is applied along the major axis.
4. The ultimate lateral load capacity of rectangular shape (along major axis) with aspect ratio of 4 is much higher than other shapes of the barrette pile.
5. The lateral load capacities of the cruciform shape barrette are higher as compared to those of barrettes of other shapes.

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