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Performance of groups of barrettes subjected to vertical loading in different types of soils

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Abstract
Barrettes are non-displacement type, cast-in-place reinforced concrete pile of non-circular shape. Such piles can sustain axial loads and significant moments. In the present study, groups of circular and barrettes of different shapes resting in different types of soils were analysed by using the finite element computer program MIDAS GTS NX. The ultimate vertical capabilities of the piles were examined in relation to the pile's shape, slenderness ratio, aspect ratio of rectangular barrette piles, number of piles in the group, and soil type. The outcomes are compared in terms of improvement factor, which is defined as the ratio of ultimate vertical capacity of group of barrettes to that of group of circular piles. Results of the present study indicate that the group of barrettes exhibits greater ultimate vertical capacities as compared with group of piles of circular shape, having equal sectional area.

Keywords: Barrettes, ultimate vertical capacity, numerical analysis, improvement factor, MIDAS GTS NX

1. Introduction

Barrettes are bored; cast-in-place type of piles with shapes other than circular. These piles are constructed using diaphragm walling equipment in a deep trench of smaller widths that is excavated using polymer or bentonite slurry. These piles have high axial and lateral load capacities and are also suitable for most types of soil conditions. Typically, barrettes are rectangular piles, but a variety of other shapes like H, T, I, L and cruciform (+) shape may also be adopted. Although these piles serve the same purpose and have a similar design as that of traditional circular piles, they are more resistant to horizontal and vertical loads due to their higher specific surfaces per unit of cross-sectional area. The barrettes may be useful in the increasing need for tall constructions because they have a greater capacity than the circular pile. Additionally, building barrettes takes less time than building circular piles. Correctly positioning the barrettes can increase their bending moment resistance along the desired direction, especially in the case of lateral loading. Thus, Barrette foundations may be regarded as a cost-effective alternative to large diameter bored circular piles.

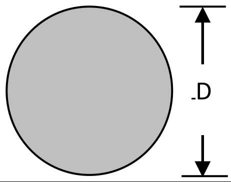
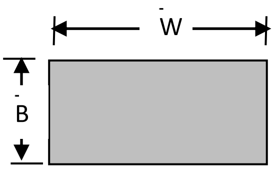
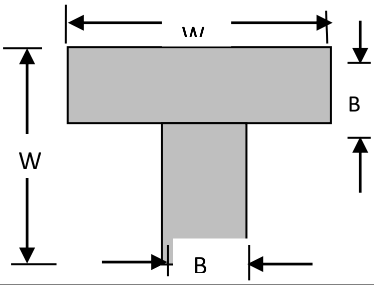
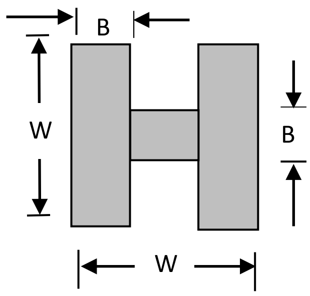
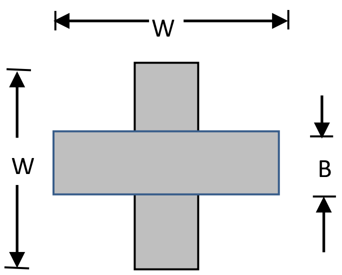
Analytical, numerical, experimental, and field studies related to barrettes have been reported in the literature. Ramaswamy S D *et al*. (1986) [1] presented the paper describing the construction and advantages of the Barrette foundation. A Z EI Wakil *et al*. (2012) [2] conducted experiments in a laboratory model setup and presented the results for the performance of small-scale rectangular barrettes which were laterally loaded in the sand. It was found that when the barrette was loaded in the direction of the major axis as distinct to the minor axis, their lateral resistance was higher. The lateral capacities of the barrettes were also significantly impacted by the relative sand density. Chu-EuHo *et al*. (1998) [3] evaluated the behaviour of a barrette under a high ultimate load. The barrette was tested in the highly instrumented test. W Ng Charles *et al*. (2000) [4] carried out field research on instrumented barrettes in Hong Kong. Barrettes were shown to be incredibly effective in resisting heavy vertical loads and large horizontal loads in the desired direction. L. M. Zhang *et al*. (2003) [5] explained the performance of barrettes of large-section, which were laterally loaded. The ultimate lateral capacity was found to be highest when the stress was along the longitudinal axis and lowest when it was along the perpendicular direction of the cross-section.

2. Methodology

In the present study, the finite element computer program MIDAS GTS NX was used to analyze the performance of groups of circular and barrettes of different shapes resting in different types of soils.

The effects of pile shape, slenderness ratio, aspect ratio of rectangular barrette piles, number of piles in the group, and soil type on the ultimate vertical capacity of the group of piles were examined. Two different slenderness ratios of pile *viz*., 5 and, 15 were considered to study the performance of short piles as well as long piles. Three different types of soils were considered *viz*., clayey soil, (c soil), sandy soil (ϕ soil), and c-ϕ soil. The aspect ratio of rectangular piles was varied as 1.4, 2.2, 3.15, and 4.9. The cross sectional areas of similar groups of barrettes and circular piles were kept the same to compare the performances of group of barrettes of different shapes with those of group of piles of circular shape. Table 1 provides the dimensions of the circular pile and various-shaped Barrettes foundation used for analyses in the current study.

Table 1: Shapes of Barrettes and their dimensions selected for numerical analyses

Sr. no	Cross section of the pile	Description	Dimension	
			Symbol	
1.		Circular	*D*	2.0
2		Rectangular W/B = 1.4, 2.2, 3.15 4.9	*W*	2.1, 2.62, 3.15 & 3.93
			B	1.5, 1.2, 1.0, & 0.8
3		T shape	*W*	2.35
			B	0.8
4		H shape	*W*	2.05
			B	0.65
5		Cross shape	*W*	2.36
			B	0.8

The properties of these soils are summarized in Table 2. Mohr-Columb Model was selected for all types of soils.

Table 2: Properties of the soils considered for analyses

Property	Clayey Soil	Sandy soil	c-ϕ soil
Undrained cohesion (kPa)	100	1	31
Friction angle	1	36	12
Young's Modulus (kPa)	40000	50000	50000
Poisson's Ratio (kN/m^3)	0.400	0.300	0.300
Unit Weight	18	20	18
Saturated Unit weight (kN/m^3)	20	21	20

Pile foundations and their caps were considered to be made of R.C.C. material, and treated as a linear elastic material. Hence model selected for them was the 'Elastic model'. Table 3 lists the material properties for the pile, barrettes, and caps chosen for the current investigation.

Table 3: Properties of Barrettes considered for analyses

Property assigned	Value
Material Model	Elastic
Young Modulus (MPa)	27386
Poisons Ratio	0.15
Unit Weight (kN/m$^{3)}$	24

In the first step, geometries of group of circular pile/barrettes, pile cap, and soil bed were developed according to the required dimensions. The spacing between the piles in the group was selected as three times the diameter or lateral dimension of the barrette. The width of soil mass was taken as 40B, where B is the pile diameter or pile breadth. The depth of soil mass was L+20B, in which L was the length of the pile. (Karthigeyan S. [7]). A typical group of barrettes along with pile cap and soil bed modeled in MIDAS GTX NS software is shown in Figure 1.

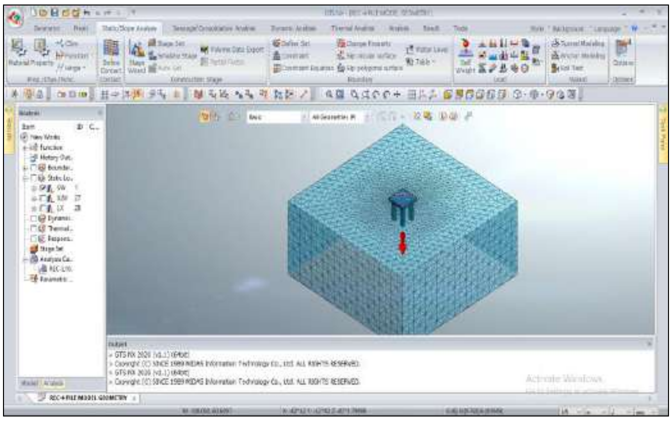


Fig 1: Group of barrettes along with pile cap and soil bed modeled in MIDAS GTX NS

3. Results and Discussions

To compare the performance of groups of barrettes of different shapes with similar groups of circular piles, subjected to vertical loading, an Improvement factor was defined as the ratio of ultimate vertical capacity of the group of barrettes to that of circular piles, as given by equation 1.

$$I_f = \frac{Q_u\,(\text{barrette group})}{Q_u\,(\text{circular pile group})} \quad (1)$$

Figures 2 to 4 show bar charts which illustrate the improvement factors for vertical loading on groups of short barrettes in clayey soil, sandy soil, and c-ϕ soil resp.

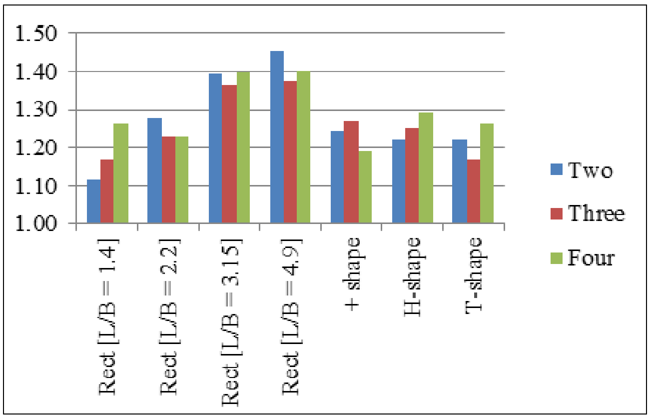


Fig 2: Improvement factors for groups of short barrettes in clayey soil

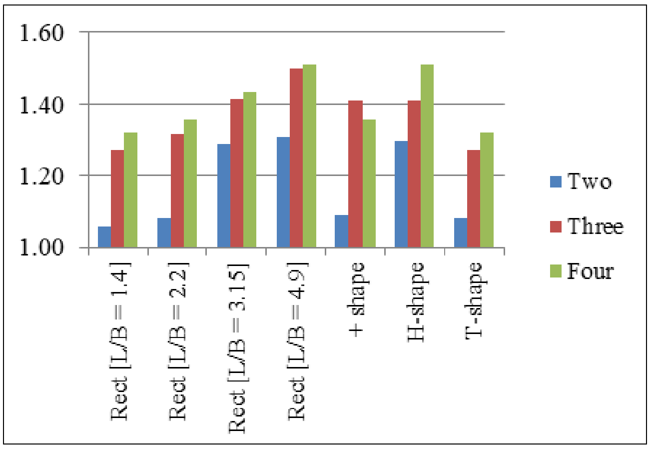


Fig 3: Improvement factors for groups of short barrettes in sandy soil

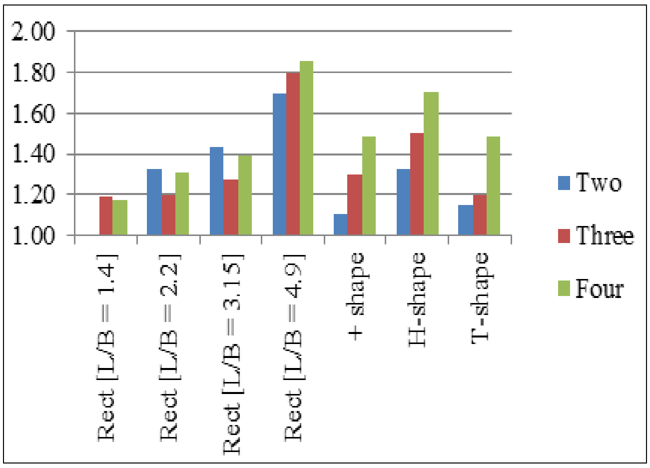


Fig 4: Improvement factors for groups of short barrettes in c-ϕ soil

4. The following points were noted related to performance of groups of short barrettes subjected to vertical loading

1. Improvement factors are in the range of 1.0 to 1.85,
2. Improvement factors are relatively higher in case of c-ϕ soil as compared to those in case of clayey and sandy soil,

3. Among the shapes of barrettes, other than rectangular, Improvement factors are higher in case of H-shape barrettes.

Improvement factors for vertical loading on groups of long barrettes in clayey soil, sandy soil, and c-ϕ soil are presented in the form of charts in Figures 5 to 7 resp.

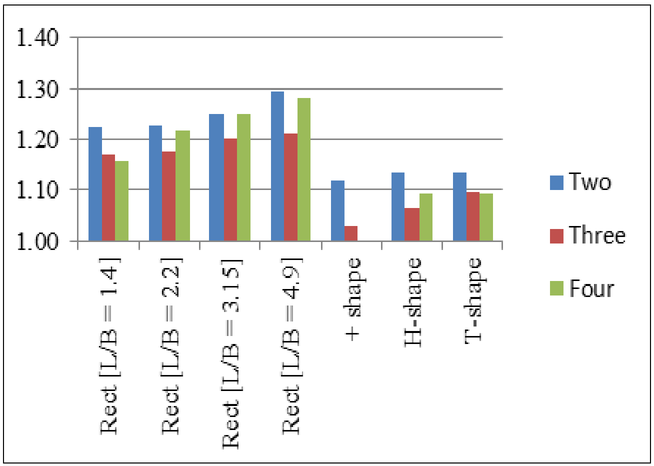


Fig 5: Improvement factors for groups of long barrettes in clayey soil

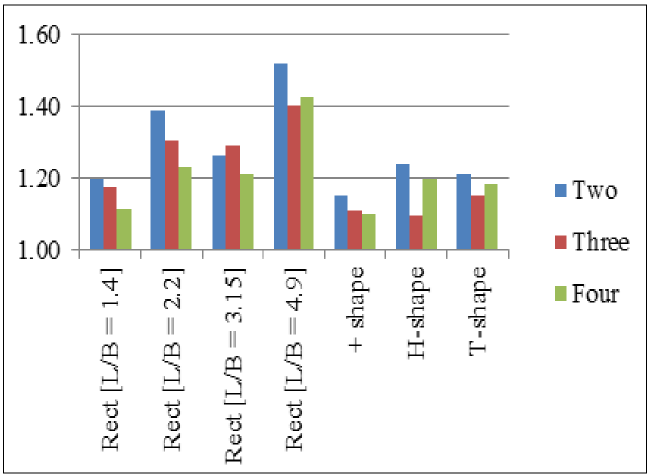


Fig 6: Improvement factors for groups of long barrettes in sandy soil

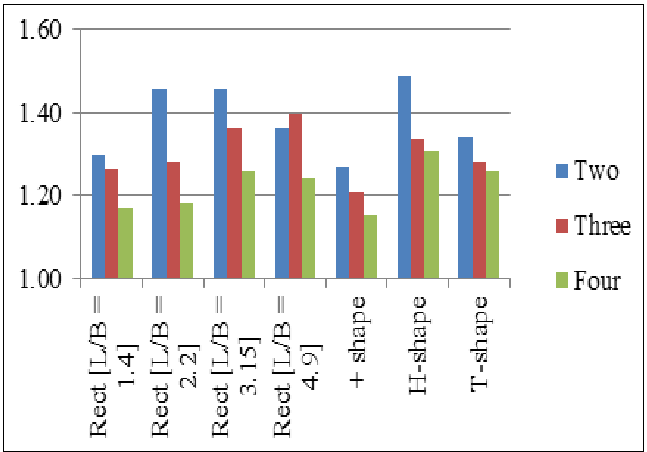


Fig 7: Improvement factors for groups of long barrettes in c-ϕ soil

5. The following points are noted related to performance of groups of long barrettes subjected to vertical loading

1. Improvement factors are in the range of 1.0 to 1.5,
2. In the case of rectangular barrettes, Improvement factors increases with the increases in the L/B ratio of barrettes, in all types of soils,
3. Improvement factors are higher in case of c-ϕ soil as compared to those in case of clayey and sandy soil,
4. Among the different shapes of barrettes, other than rectangular, Improvement factors are higher in case of H-shape barrettes.

6. Conclusions

From the results of numerical analyses performed on groups of barrettes of different shapes, following conclusions are made.

1. Ultimate vertical capacities of barrettes of different shapes are higher than those of group of pile of circular shape of similar cross sectional areas, to the extent of 85% for short piles and 50% in case of long piles.
2. Ultimate capacities of group of rectangular barrettes are higher as compared to groups of barrettes of other shapes.
3. Ultimate vertical capacity increases with the increase in the L/B ratio of rectangular barrettes, in all types of soils.
4. Group of barrettes are more effective in c-ϕ soil as compared to clayey and sandy soils.

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