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Behavior of laterally loaded small scale barrettes in sand

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Abstract This paper aims to investigate the response of laterally loaded rectangular cross sectional barrettes. Twenty-eight model tests for laterally loaded barrette were investigated to study the effect of sand relative density, aspect ratio of pile cross section, loading direction and load eccentricity. Based on this study, the lateral resistance of the barrette that loaded in the direction of major axis is higher than that loaded in the direction of minor axis. Sand relative density has significant effect on the lateral capacity of the barrettes. The ratio of the lateral capacity of the barrettes loaded in the direction of major axis compared to the barrettes loaded in the direction of minor axis is reduced as the sand relative density increases. Increasing the flexure stiffness of the barrette cross section causes a reduction in the lateral displacement of the barrette head. Increasing load eccentricity causes a significant reduction in the barrette lateral resistance.

1. Introduction

The lateral resistance of piles is governed by several factors, the most important factor is the ratio of the structural stiffness of the pile to the soil stiffness. The relative stiffness of the foundation element with respect to the soil controls the mode of failure and the manner in which the pile behaves under an applied lateral load. A barrette is a large cross section rectangular pile. Due to dependence of the flexural stiffness of the rectangular section on its orientation and the nonlinear behavior of the barrette materials, loading direction affects the lateral resistance of the barrette. Although some axial load tests have been performed in field to investigate the axial response of the barrettes Geotechnical Engineering Office [1]; Fellenius et al. [2]; Ng et al. [3], little study has been conducted to investigate the lateral response of barrettes. Due to the rectangular geometry, the lateral resistance of the barrettes depends on loading direction and may be controlled by the bending capacity of the barrette section, which may be different from responses of driven concrete piles and drilled shafts. Recently, a large-scale lateral load test program for deep foundations has been carried out in Hong Kong for the Kowloon – Canton Railway Corporation, Hong Kong, with the participation of the Hong Kong University of Science and Technology. Plumbridge et al. [4] and Ng et al. [5] have described the over-all test program and reported test results on single bored piles. The response

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of laterally loaded large-section barrettes based on the load tests, to simulate the response of the two test barrettes considering the nonlinear behavior of concrete and steel reinforcement, and to study the influence of loading direction on the lateral response of the barrettes. The lateral response of the barrettes is influenced by loading direction because of the dependence of the flexural stiffness of the rectangular barrettes on their orientation and the nonlinear behavior of their materials Zhang [6]. Extensive theoretical and experimental studies have been carried out by several investigators on laterally loaded piles to determine their ultimate lateral loads and displacements, under working loads. Matlock and Reese [7] define the relative rigidity of a laterally loaded pile in terms of the ratio of the flexural stiffness of the pile, EI, and the coefficient of lateral subgrade reaction, ks. Their method is applicable only if the deflection of piles is within the range of linear deformation of the soil. Vesic [8], Davisson and Gill [9], Broms [10], Banerjee and Davies [11] and Poulos and Davis [12] define and utilize a stiffness ratio, K_r, as

$$K_r = E_p I_p / E_s L^4 \tag{1}$$

where E_s is the deformation modulus of the soil, E_p the modulus of elasticity of the pile material, I_p the moment of inertia of pile cross-section and L the length of the pile. The pile usually behaves as a rigid one for K_r values greater than 10^{-2}. Kasch et al. [13] have proposed that embedded length to diameter ratio, L/d, of the pile also be used to assess the flexural behavior of the pile and concluded that in order to ensure rigid behavior, the L/d ratio should not exceed about 6. However, under some conditions, a foundation can have L/d ratio as high as 10 and still behave as a rigid one, but, for flexible behavior L/d should be in excess of 20. Based on the studies of Meyerhof et al. ([14,15]), the pile behavior is rigid even though L/d is as high as 16. From the above studies, it is felt that assessing the rigid behavior of the pile through relative stiffness factor, K_r, would be a better option. Failure of rigid or short shafts takes place when the lateral earth pressure resulting from lateral loading attains the limiting lateral resistance of the supporting soil along the full length of the member. The rigid pile is assumed to be infinitely stiff and the only motion allowed is pure rotation of the shaft as a rigid body about some point on the axis of the shaft for rigid body motion, the rotation of the shaft and the displacement at the ground line define the deformed position of the pile. From the extensive search it is found that little studies has been conducted to investigate the lateral response of the barrettes so this laboratory experimental study is performed to study the effect of cross section of the barrettes on their lateral resistance also the effect of sand relative density and direction of loading on the barrettes behavior were investigated.

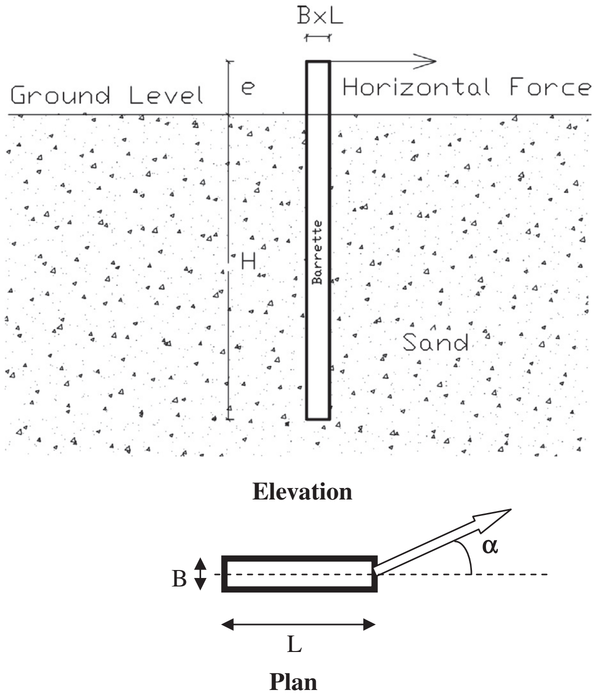
2. Testing equipment

To study the behavior of laterally loaded barrettes in sand, laboratory tests were conducted on a small scale model of three barrettes having cross section dimensions of $(B * L)$ equal to $50 * 50$ mm, $50 * 100$ mm, and $50 * 150$ mm. The barrettes models were machined from steel plates of thickness 3 mm to have a length of 710 mm, and side ratios L/B equal 1, 2, and 3. Twenty-eight laboratory experiments are conducted to study the behavior of laterally loaded barrettes. The model barrettes were laterally loaded; the lateral loads are applied using a frictionless pulley fixed to the soil bin via a steel wire connected to the top of the barrettes at one end and to a hanger at the other end. Standard weights are used for loading. Two-dial gauges – of accuracy 0.01 mm – were used to measure the barrettes lateral displacements. The dial gauges were attached horizontally on the top surface of the barrettes on the same loading level. The general layout of the equipment used in the present study is illustrated in Fig. 1. The lateral displacement of the barrettes was considered as the average of the two dial gauges readings. The soil bin is made out of two steel rings each of 300 mm height and 750 mm diameter. These rings were assembled to form a soil bin of total height 600 mm. The sides of the soil bin were strengthen using circular steel plates to prevent any lateral deformation of the side walls and to facilitate the erections of the steel rings using steel bolts. Also vertical steel ribs are added to each ring and welded to the boundary circular plates of each ring. The soil bin is placed on a rigid steel girder resting on the ground, accurately vertical. Spirit level was used to ensure vertical and horizontal levels of test setup. It is obvious that the dimensions of the soil bin are big enough to overcome the effects of the boundary conditions on the barrettes response, whereas the diameter of soil bin to the barrettes biggest side dimension is 5.0. It is worth mentioning that the barrettes length are 710 mm and the sand height is 600 mm, and the loading level is at the level of the barrettes head and the pulley diameter is 100 mm that's to say the wire is kept in a horizontal level between the barrettes and the pulley. To study the vertical eccentricity effect the loading steel wire was designed to be fixed at a height of 600 mm and 650 mm on the barrettes shafts. Finally it is worth mentioning that the barrettes were designed to be loaded in both directions, minor axis direction, and major axis direction. Considering the dimensions and material of the studied barrettes and the range of deformation modulus of sand which was given by Poulos [16], the studied barrettes are considered as rigid. Also considering the limitation of Meyerhof et al. ([14], [15]) the studied barrettes are rigid.

Figure 1 Complete set-up of testing procedures.

3. Experimental procedure

The barrette is vertically placed in the center of soil bin according to the testing program and the sand was formed in the soil bin in layers each of 50 mm thickness. To ensure homogeneity of sand formation a designed weight of sand, with an accuracy of 0.001 kN, was formed into a certain volume of the soil bin by compaction to give the specified relative density of 35%, 65%, and 90% according to a planned testing program shown in Table 1 and Fig. 2 shows the notations of the studied parameters. Compaction was carried out manually using a rammer weighing 40.0 N and of 200 mm diameter. The top surface of the formed sand was leveled using sharpened straight steel plate. The load was applied incrementally; each increment was kept constant till no significant change occurs in displacement, that is to say the difference between two successive readings is less than 0.01 mm per 5 min for three consecutive readings. The corresponding pile displacements were measured within an accuracy of 0.01 mm using the two-dial gauges. The sand used was medium size sand of minimum dry unit weight 15.6 kN/m^3, maximum dry unit weight of 18.2 kN/m^3, uniformity coefficient of 2.95, effective diameter 0.19 mm, and specific gravity 2.6.



Elevation

Plan

Figure 2 Notations for the studied parameters.

4. Test results and discussion

A total of 28 tests were carried out on laterally loaded barrettes constructed on sand deposit. The effect of aspect ratio of the barrette cross section, L/B, sand relative density, load direction, and load eccentricity on the lateral resistance were studied. The lateral force and displacement were obtained and discussed. The ultimate lateral capacity of vertical barrette was obtained from load displacement curves. The head lateral displacement (S) of the barrette is expressed in non-dimensional form in terms of pile width (B) as percentage ratio (S/B, %). The ultimate lateral capacity of the barrette is obtained from the load–displacement curve as the pronounced peaks, after which the barrette is failed. Wile in curves where no definite failure point occurs, the ultimate load is taken as the point where the slope of the load displacement curve first reached to zero or steady minimum value Vesic [17]. The measured ultimate loads for the barrettes constructed in loose, medium and dense sand for different studied parameters are given in Table 2. Typical variations of lateral force (P) with horizontal displacement, (S) of model barrette that constructed in medium sand for the three studied aspect ratios are shown in Fig. 3. In this series sand relative density, R_d 65%, embedment ratio, H/B and Load eccentricity, e/B were kept constant while the aspect ratios L/B have different values of 1, 2, and 3. This figure shows typical load vs. normalized displacement ratio (S/B) for the barrette that constructed in medium dense sand under lateral loading acting in the direction of minor axis of the barrette cross section $P_{\alpha 90}$. It is clear that, the ultimate lateral capacity of the barrette increases with the increase of the aspect ratio of the barrette cross section. At the same load intensity the lateral displacement is decrease as the aspect ratio is increased. The maximum value of lateral resistance is found to be at normalized displacement of 4.5%, 5.0%, and 9.0% for aspect ratios of 1, 2, and 3 respectively. It is also observed that the maximum normalized

Table 1 Model tests program.

Series	Constant parameters	Variable parameters
1	R_d = 35%, H/B = 12, e/B = 2, Load parallel to minor axis, α = 90°	L/B = 1, 2 and 3
2	R_d = 65%, H/B = 12, e/B = 2, Load parallel to minor axis, α = 90°	L/B = 1, 2 and 3
3	R_d = 90%, H/B = 12, e/B = 2, Load parallel to minor axis, α = 90°	L/B = 1, 2 and 3
4	R_d = 35%, H/B = 12, e/B = 2, Load parallel to major axis, α = 0°	L/B = 1, 2 and 3
5	R_d = 65%, H/B = 12, e/B = 2, Load parallel to major axis, α = 0°	L/B = 1, 2 and 3
6	R_d = 90%, H/B = 12, e/B = 2, Load parallel to major axis, α = 0°	L/B = 1, 2 and 3
7	R_d = 65%, H/B = 12, e/B = 2, L/B = 2	α = 0, 30°, 60° and 90°
8	R_d = 65%, H/B = 12, α = 0°, e/B = 0	L/B = 1, 2 and 3
9	R_d = 65%, H/B = 12, α = 0°, e/B = 1	L/B = 1, 2 and 3
10	R_d = 65%, H/B = 12, α = 90°, e/B = 0	L/B = 1, 2 and 3
11	R_d = 65%, H/B = 12, α = 90°, e/B = 1	L/B = 1, 2 and 3

R_d relative density of sand, H pile embedment depth, α is the inclination angle, B width of cross section of the pile, L length of pile cross section and e is load eccentricity.

Table 2 Ultimate lateral load for laterally loaded barrettes constructed in sand with different sand relative densities and variable aspect ratio.

Aspect ratio, (L/B)	Ultimate lateral load, N ($e/B = 2.00$ and $H/B = 12.00$)					
	Load in the direction of minor axis, $P_{\alpha 90}$			Load in the direction of major axis, $P_{\alpha 0}$		
	Loose sand $R_d = 35\%$	Medium sand $R_d = 65\%$	Dense sand $R_d = 90\%$	Loose sand $R_d = 35\%$	Medium sand $R_d = 65\%$	Dense sand $R_d = 90\%$
1	140	300	590	140	300	590
2	200	400	790	470	600	800
3	260	650	1100	640	900	1150

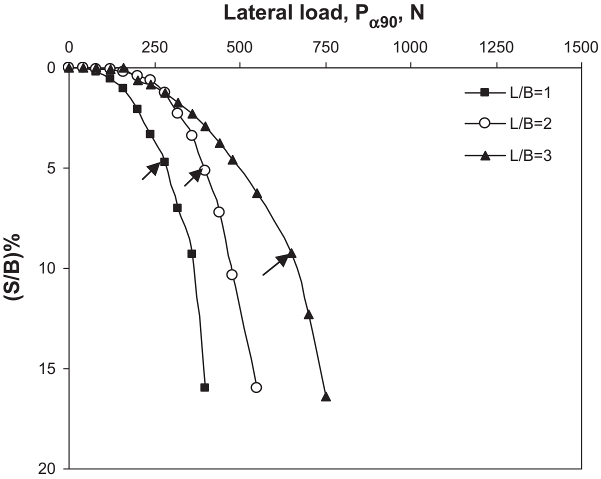


Figure 3 Variation of lateral load with horizontal displacement of barrette constructed in medium sand and lateral load in the direction of minor axis ($P_{\alpha 90}$).

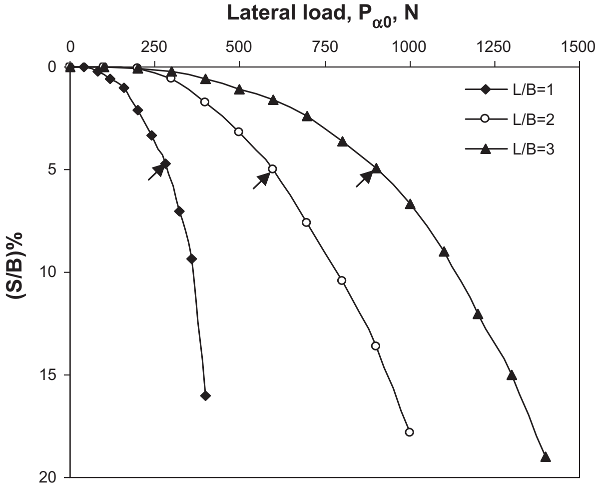


Figure 4 Variation of lateral load with horizontal displacement for barrette. constructed in medium sand and lateral load in the direction of major axis ($P_{\alpha 0}$).

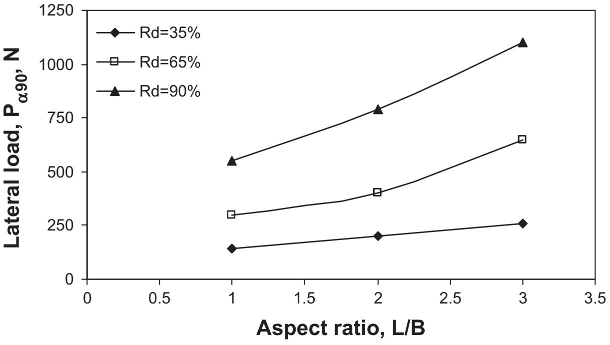


Figure 5 Variation of ultimate lateral load with aspect ration L/B for barrettes constructed in sand with different densities, and lateral load in the direction of minor axis.

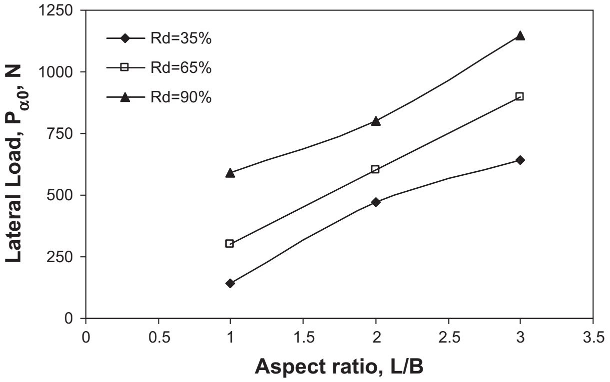


Figure 6 Variation of ultimate lateral load with aspect ration L/B for barrettes constructed in sand with different densities, and lateral load in the direction of major axis.

displacement up to the barrettes failure is increased as the aspect ratio increased; this trend is observed for all test results at different sand relative densities. For the same barrette lateral load, the lateral displacement is decreased significantly as the aspect ratio increases. For example, at lateral force of 400 N, the normalized lateral displacement is decreased from 16% for $L/B = 1$ to 5.00 and 3.00% for $L \cdot B = 2$ and 3 respectively, with displacement reduction 69% and 81% respectively. Fig. 4 shows the variations of lateral load ($P_{\alpha 0}$) with lateral displacement (S) that constructed in medium dense sand and the load in the direction of the major axis. The figure clearly indicates that changing the load direction parallel to the major axis causes significant increase in lateral resistance of the barrette. The figure also shows that the lateral displacement is decreased as the aspect ratio increased. For example, at lateral force of

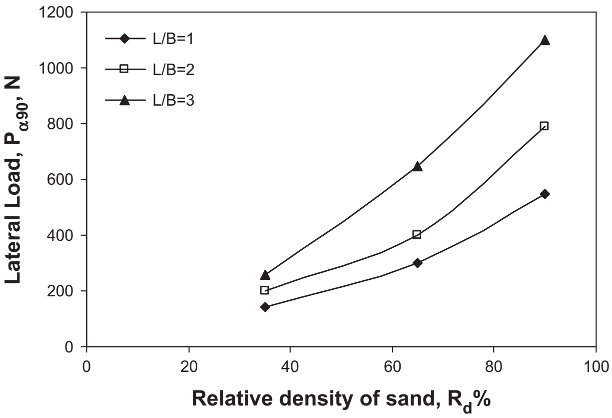


Figure 7 Variation of ultimate lateral load with sand relative density and lateral load in the direction of minor axis.

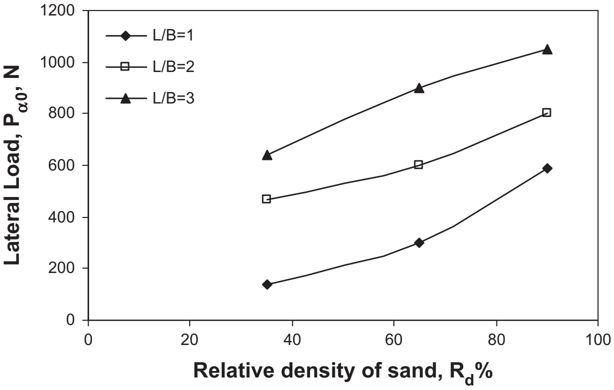


Figure 8 Variation of ultimate lateral load with sand relative density, Rd and lateral load in the direction of major axis.

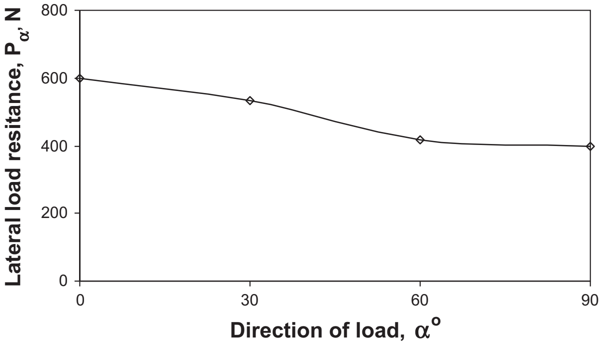


Figure 9 Variation of ultimate load capacity with loading direction, ($L/B = 2$, $e/B = 2$, $H/B = 12$ and $R_d = 65\%$).

400 N, the normalized lateral displacement decreased from 16% for $L/B = 1$ to 1.75 and 0.60% for $L \cdot B = 2$ and 3 respectively, with displacement reduction 89% and 96% respectively. Both figures confirm the significant increase in the lateral resistance of the barrettes with the increase of barrettes aspect ratio. The increase of the barrette resistance is large in the case of loading parallel to the major axis compared to the case of load in the direction of minor axis. The increase of the lateral resistance on changing the load direction can be attributed to the side friction and the increase of the flexural stiffness of the barrette section which has significant effect on the lateral resistance of the barrettes and also causes significant reduction of the lateral displacement of the barrette head.

4.1. Influence of the barrette cross sections

In order to study the effect of the barrette cross section on the lateral resistance Figs. 5 and 6 are constructed. The studied aspect ratios are 1, 2, and 3 for square barrette of section 50×50 mm and rectangular barrettes of section 50×100 mm, and 50×150 mm respectively. These three barrette shapes have constant embedment depth of 600 mm with load eccentricity of 100 mm. The ultimate lateral resistance with different aspect ratios of the three studied sand densities are shown in Fig. 5 for the case of load in the direction of minor axis and Fig. 6 for the case of load in the direction of major axis. These figures clearly demonstrate the significant effect of aspect ratio of the barrette on the lateral resistance. These figures demonstrate that the lateral resistance increase as the aspect ratio increase particularly for the barrette loaded in the direction of the major axis. For the same aspect ratio ($L/B = 2$), a gain in the lateral resistance for the barrette constructed in medium dense sand and loading in direction of minor axis compared to square section is 133%, relative to a gain of 200% for the barrette loading in the major axis. The percentage of increase in the lateral resistance with the increase of the sand relative density is more significant for the barrette loaded in the direction of major axis compared with the barrette loaded in the direction of the minor axis.

4.2. Influence of sand relative density

To investigate the effect of sand relative density and load direction on the lateral capacity of the barrtte Figs. 7 and 8 are

Table 3 Percentage of increase of lateral capacity of barrettes constructed in sand with different sand densities and variable aspect ratio of barrette.

Aspect ratio, (L/B)	% Of increase of lateral capacity for rectangular barrette/capacity of square barrette ($e/B = 2.00$ and $H/B = 12.00$)					
	Load in the direction of minor axis, $P_{\alpha 90}$			Load in the direction of major axis, $P_{\alpha 0}$		
	Loose sand $R_d = 35\%$	Medium sand $R_d = 65\%$	Dense sand $R_d = 90\%$	Loose sand $R_d = 35\%$	Medium sand $R_d = 65\%$	Dense sand $R_d = 90\%$
1	100	100	100	100	100	100
2	143	133	144	336	200	136
3	186	217	200	457	300	195

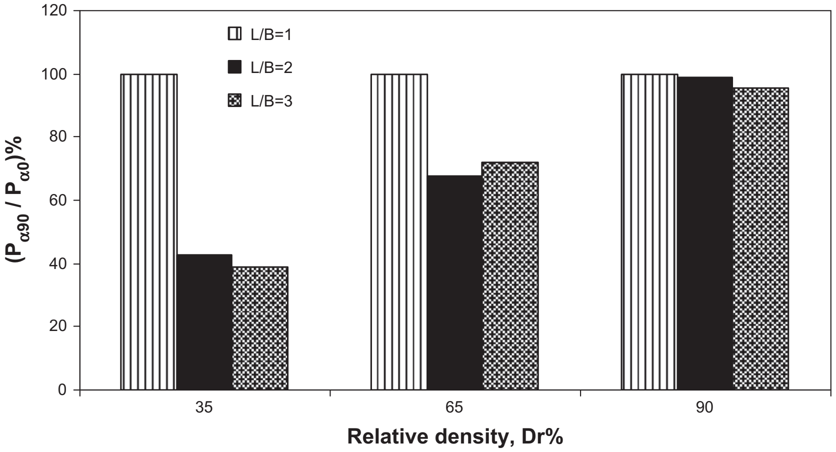
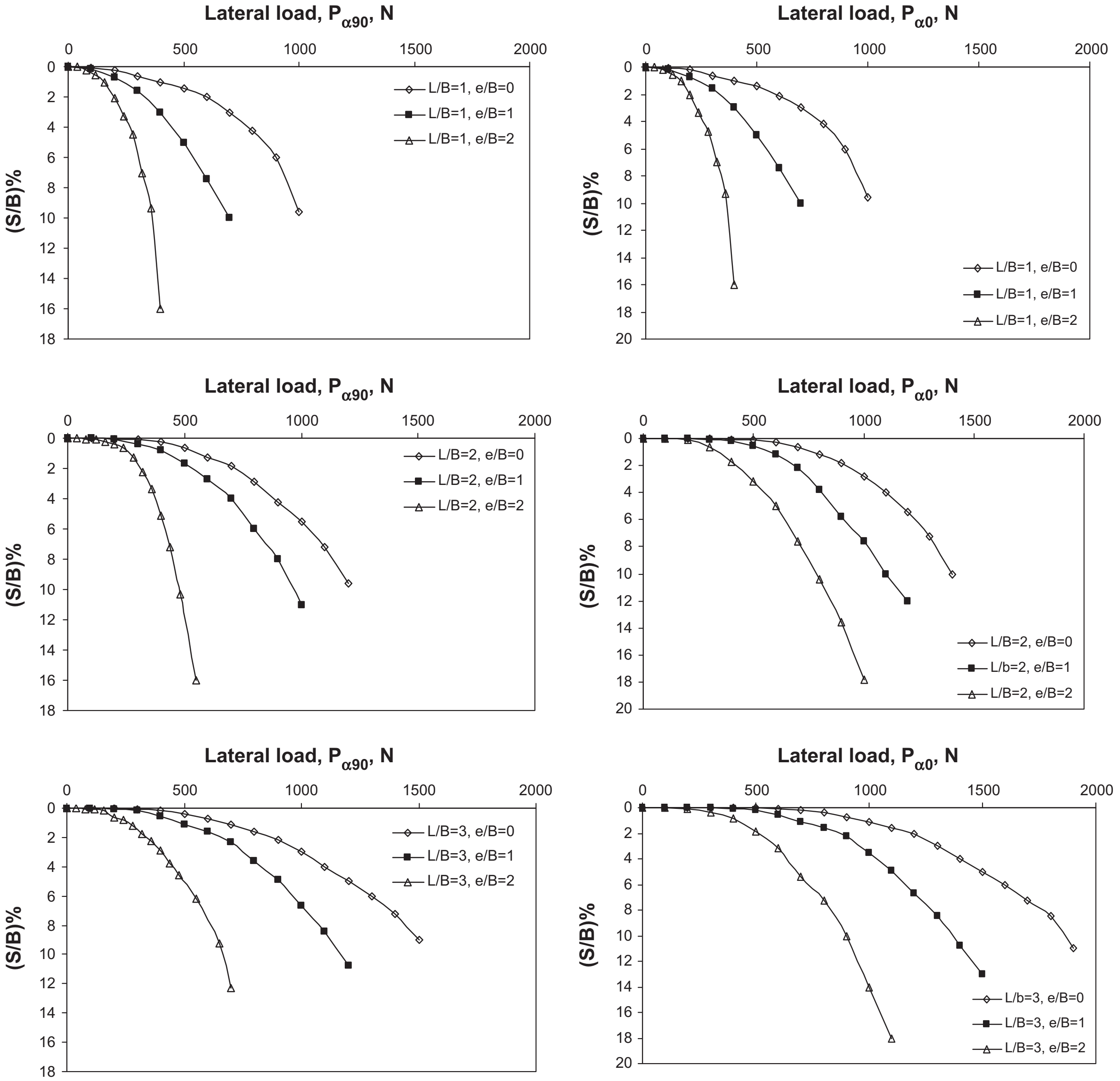


Figure 10 Variation of ultimate load capacity with loading direction, ($L/B = 2$, $e/B = 2$, $H/B = 12$ and $R_d = 35\%$, 65% and 90%).



(a) Load in the direction of minor axis **(b) Load in the direction of major axis**

Figure 11 Load vs. deflection, for barrettes with different aspect ratios ($e/B = 1$, 2 and 3, $H/B = 12$ and $R_d = 65\%$).

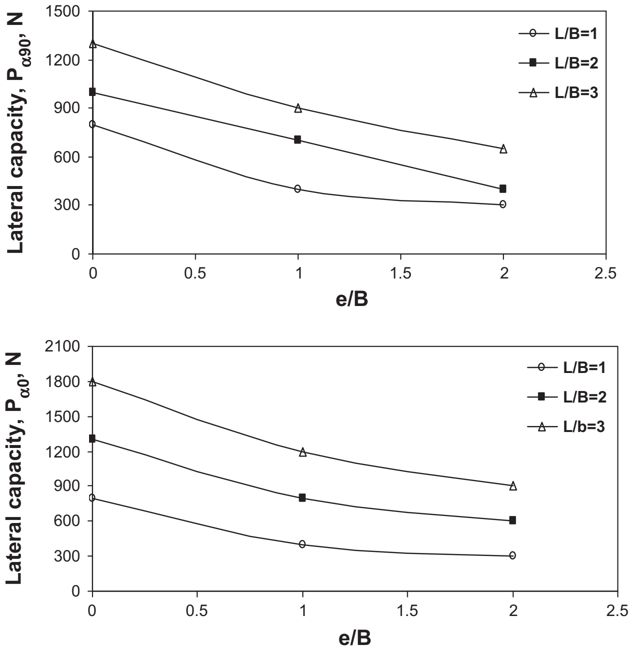


Figure 12 Lateral resistance vs. load eccentricity, for barrettes with different aspect ratios (L/B 1, 2, and 3, $H/B = 12$ and $R_d = 65\%$).

constructed, for the barrette loaded in the direction of minor axis and major axis respectively. Fig. 7 clearly shows that the increase of sand relative density resulted in little increase in lateral resistance in the loose condition while this increase is significant in medium and dense sand. Also the figure shows that the rate of increase in the barrette capacity increases as the aspect ratio of the barrette section increases. For example the rate of increase for loose sand, $L/B = 2.00$ and 3.00 is 43% and 85% compared with square barrette, which these values was 33% and 116% for medium dense sand and 44% and 100% for dense sand. Fig. 7 shows that the increase of sand density resulted in moderate increase in the lateral resistance of the barrette for the three studied aspect ratios. For example the rate of increase for loose sand, $L/B = 2.00$ and 3.00 is 235% and 357% compared to square barrette, which these values are 200% and 300% for medium dense sand and 35% and 77% for dense sand. These results it clearly indicates that the barrette lateral capacity on loading in the direction of major axis increases significantly for the barrette constructed in loose sand, the ratio of increase in the barrette resistance decreases as the sand relative density increases compared to loose condition. Table 3 illustrates the ratio of increase of the barrette capacity compared with the case of square barrette.

4.3. Influence of load direction

In order to study the effect of lateral load direction on the resistance of the barrette, series 7 is performed. In this series the aspect ratio is 2, embedment depth is 600 mm, load eccentricity is 100 mm and sand relative density is 65%. The ultimate lateral resistance with different load directions of this series is shown in Fig. 9. This figure clearly demonstrates the significant effect of the load direction on the lateral resistance of the barrette. This figure demonstrates that the lateral resistance of the barrette for the case of loading in the major axis direction, $P_{\alpha 0}$ is higher than that loaded in the direction of the minor axis, $P_{\alpha 90}$. Also Fig. 10 is plotted to compare the effect of lateral load direction on the lateral capacity of the barrette for the tested sand densities. This figure ensures that the structural stiffness of the barrette section in the direction of lateral load has major effect on the lateral resistance. The lateral resistance for the barrette tested in the direction of minor axis regarding to the major axis is about 66.7% for medium density sand, while this value is found to be 42.5% for loose sand and 98% for dense sand. From the obtained results it is concluded that the ratio between lateral resistance of the barrette tested in the direction of minor axis related to the capacity of the barrette loaded in the major direction is affected by the sand relative density and the barrette structural stiffness. from this figure it is concluded that the higher the sand relative density the lower the difference in the capacity of the barrette tested in both directions, the minor axis, and the major axis.

4.4. Influence of load eccentricity

In order to study the effect of lateral load eccentricity on the barrettes resistance, serieses 2, 5, 8, 9, 10, and 11 are performed. In these series the embedment depth is 600 mm, sand relative density is 65% and e/B is varied from 1, 2, and 3. The load deflection results for these seriese are shown in Fig. 11. This figure clearly demonstrates the significant effect of the load eccentricity on the barrettes lateral resistance. This figure shows that the lateral resistance of the barrette significantly increases with load eccentricity is decreased and reaches the maximum value at load eccentricity equals to zero. This observation is shown for the barrettes loaded in the directions of minor and major axes. Also it is clearly observed that the barrettes with no eccentricity have more resistance than the barrettes with load eccentricity. The barrette lateral displacement at failure load increases as the load eccentricity decreases. For the same relative displacement the lateral resistance increases as the load eccentricity is decreased for examples; for $L/B = 2$ and the load in the direction of minor axis at relative displacement (S/B) = 5%, the corresponding

Table 4 Ultimate lateral load for laterally loaded barrettes constructed in medium dense sand, with different load eccentricity and variable aspect ratio of barrette.

Aspect ratio, (L/B)	Ultimate lateral load, N ($R_d = 65\%$ and $H/B = 12.00$)					
	Load in the direction of minor axis, $P_{\alpha 90}$			Load in the direction of major axis, $P_{\alpha 0}$		
	$e/B = 0$	$e/B = 1$	$e/B = 2$	$e/B = 0$	$e/B = 1$	$e/B = 2$
1	800	400	300	800	400	300
2	1000	700	400	1300	800	600
3	1300	900	650	1800	1200	900

lateral load is 1100, 850, and 440 N for $e/B = 0$, 1, and 2 respectively. The barrette lost 22.73% and 60% from its lateral resistance as the load eccentricity (e/B) increased to 1 and 2 respectively. The obtained lateral resistance and corresponding eccentricity is plotted in Fig. 12. From this figure it is clear that the rate of increase in the lateral capacity of the barrette as the load eccentricity is decreased is moderate for e/B reduced from 2 to 1 while the rate of increase is significantly high as e/B is reduced from 1 to 0. This trend is shown for the barrette loading in both minor and major axis. The obtained ultimate lateral resistance for different load eccentricity is given in Table 4.

5. Scale effect

It is well known that due to scale effects and nature of soils especially granular soils, soils may not play the same role in the laboratory models as is in the prototype. These differences occur preliminary because of the differences in stress level between the model tests and the field tests Vesic [17], and Nazir and Nasr [18]. The stress level around the small scale model pile is much smaller than that in around the full scale piles. Despite the involvement of scale effects, the study not only can provide insight into the likely behavior of rectangular cross sectional pile that constructed in different sand densities, but also will provide a useful basic for further research using full-scale tests or centrifugal model tests and numerical studies leading to an increased understanding of rectangular cross sectional piles installed in sand subjected to lateral loads.

6. Conclusions

From the accomplished experimental study the following conclusions are obtained:

1. The lateral resistance of the barrette loaded in the direction of major axis is higher than that the barrette that loaded in the direction of minor axis.
2. Sand relative density has significant effect on the lateral capacity of the barrettes. That's to say the higher the relative density of sand the higher the lateral capacity of the barrette.
3. The ratio of the lateral capacity of the barrette that loaded in direction of major axis regarding the barrette loaded in the direction of minor axis is reduces as the sand relative density increases.
4. Increasing the flexure stiffness of the barrette cross section in the direction of lateral load causes a reduction of lateral displacement of the barrette head.
5. Increasing load eccentricity causes a significant reduction in the barrette lateral resistance.
6. The maximum lateral resistance for the barrette is attained at zero load eccentricity.

References

[1] Geotechnical Engineering Office GEO. Pile design and construction GEO publication no. 1/96, Hong Kong; 1996.
[2] Fellenius BH, Altaee A, Kulesza R, Hayes J. O-cell testing and FE analysis of 28-m-deep barrette in Manila, Philippines. J Geotech Geoenviron Eng 1999;125(7):566–75.
[3] Ng CWW, Rigby DB, Ng SWL, Lei GH. Field studies of well-instrumented barrette in Hong Kong. J Geotech Geoenviron Eng 2000;126(1):60–73.
[4] Plumbridge GD, Sze JWC, Tham TTF. Full scale lateral load tests on bored piles and a barrette. In: Proc, 19th annual seminar of the geotech division. Hong Kong Institution of Engineers, Causeway Bay, Hong Kong; 2000. P. 211–20.
[5] Ng CWW, Zhang LM, Nip CN. Response of laterally loaded large-diameter bored pile groups. J Geotech Geoenviron Eng 2001;127(8):642–57.
[6] Zhang LM. Behavior of laterally loaded large-section barrettes. J Geotech Geoenviron Eng 2003;129(7):639–48.
[7] Matlock H, Reese LC. Generalized solutions for laterally loaded piles. J Soil Mech Found Div ASCE 1960;86(5):63–91.
[8] Vesic AB. Bending of beams resting on isotropic elastic solid. J Eng Mech Div, ASCE 1961;87(2):35–53.
[9] Davisson MT, Gill HL. Laterally loaded piles in a layered soil system. J Soil Mech Found Div, ASCE 1963;89(3):63–94.
[10] Broms BB. Lateral resistance of piles in cohesive soils. J Soil Mech Found Div, ASCE 1964;90(2):27–63.
[11] Banerjee PK, Davies TG. The behavior of axially and latterly loaded single piles embedded in non-homogeneous soils. Geotechnique 1978;28(3):309–26.
[12] Poulos HG, Davis EH. Pile foundation analysis and design. New York: Wiley; 1980.
[13] Kasch VR, Coyle HM, Bartoskewitz RE, Sarver WG. Design of drilled shaft to support precast panel retaining walls. Research report no. 211.1, Texas Transportation Institute, Texas A&M University, College Station, Tex; 1977.
[14] Meyerhof GG, Mathur SK, Valsangkar AJ. Lateral resistance and deflection of rigid wall and piles in layered soils. Can Geotech J 1981;18:159–70.
[15] Meyerhof GG, Sastry VVRN. Bearing capacity of rigid piles under eccentric and inclined loads. Can Geotech J 1985;22:267–76.
[16] Poulos HG. Behavior of laterally loaded piles: II-Pile groups. J Soil Mech Found Div ASCE 1971;97(SMS):733–51.
[17] Vesic AS. Analysis of ultimate loads of shallow foundations. J Soil Mech Found Div 1973;94(SM3):363–86.
[18] Ashraf K. Nazir and Ahmed Nasr Pullout capacity of batter pile in Sand. J Adv Res, Cairo in press.

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