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Effect of Embedment and Spacing Ratios on the Response of Lateral Load of Single and Group Piles

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K E Y W O R D S

lateral load, group pile, embedment ratio

A B S T R A C T

This paper displays an experimental work of three-scale model tests of single pile and nine–scale model tests of group pile (1x2) with spacing to diameter (S/D) ratios (2,4, and 6) respectively. The pile models inserted in the medium-dense dry sand with a relative density of 60% and different length to diameter (L/D) ratios (15, 25, and 30) were subjected to the lateral load with a rate of 2.5 mm/min. The test results present the effect of the change of the ratio of (L/D) and (S/D) on lateral displacements at the head of the pile. For single and group piles when the embedment ratio (L/D) increases, the ultimate lateral load increases also for group piles. When the (S/D) ratio increases, the ultimate lateral load increases. However, for (L/D) equal to 20, this increment is not linear with spacing increment, where a slight increment is observed of the relatively close pile and vice versa. While for other (L/D) ratios the increment of pile load is increased linearly with spacing increase.

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1. INTRODUCTION

Several transmission towers, tall chimneys, high-rise buildings, offshore structures, retaining structured, bridges, quay, and harbor structures are supported by piles [1,2]. These buildings not only tolerate axial loads but also are succumb to large lateral loads such as earthquakes Slope failure, liquefaction, ship impact, and vehement winds [3].

The pile tends to deflect or bend when subjected to lateral forces and moments. The deflection of the pile causes strains in the soil mass. To satisfy equilibrium, the soil must provide reactions along the length of the pile to balance the applied loads and moments. The lateral load led to larger displacements and bending moments of piles which can cause serviceability problems and distributed damage to the piles.

Therefore, the lateral loading capacity of piles is very essential to design for the construction of deep foundations [4]. Many approaches have been submitted to analyze the lateral loading capacity, such as the Broms method [5], Brinch Hansen method [6], the p-y curve approach [7,8], the elastic method [9], and the strain wedge method [10,11].

Usually, pile foundations are liable to the axial load or lateral load or a combination of them, laterally loaded piles behavior is one of the major issues concerned with the soil-structure interaction. [12]

Lateral load capacity is contingent on many stuff of soil and piles foundation feature, where the pile head deflection rests on the type of soil, pile stiffness, pile length, pile installation, loading condition, pile configuration in a pile group, pile spacing, and head condition which is how the pile is linked to the structure and pile cap. [13,14]

This research attends the consequence from twelve scale-model tests done in medium-dense dry sand to locate the effects of embedment ratio (L/D) ratio on single and group pile and the effect of spacing between piles (S/D) ratio on the group pile (2x1).

2. Experimental Work

I. Index Properties of Soil

The soil which is dealt within this research is cohesionless soil (sand) raising from Karbala city in Iraq. A large number of tests are executed according to the standard specifications to explain and recognize both the mechanical and physical properties of the used sand as shown in Table 1. As stated by the unified soil classification system, the soil used is poorly graded sand (SP). [15]

TABLE I: Properties of the sand used in the experimental models.

Test	Result value	Specifications
Active sizes: D_{10}, D_{30}, D_{50}, D_{60} [mm]	0.18, 0.3, 0.4, 0.46	ASTM D 422 and ASTMD 2487 (2010) [16]
Coefficient of uniformity [Cu]	2.5	ASTM D 422 and ASTMD 2487 (2010) [16]
Coefficient of curvature [Cc]	1.087	ASTM D 422 and ASTMD 2487 (2010) [16]
Specific gravity [Gs]	2.67	ASTM D 854 (2010) [17]
Maximum dry unit weight, [kN/m^3]	17.54	ASTM D 4254 - (2006) [18]
Minimum dry unit weight, [kN/m^3]	15.2	ASTM D 4253 - (2006) [19]
Maximum void ratio	0.49	…………
Minimum void ratio	0.72	…………
Relative density [RD]	60	…………
Natural Dry unit weight [γ_dkN/m^3]	16.52	…………
void ratio (e)	0.585	…………
Friction angle, degree	38	ASTM D3080 -11 [20]

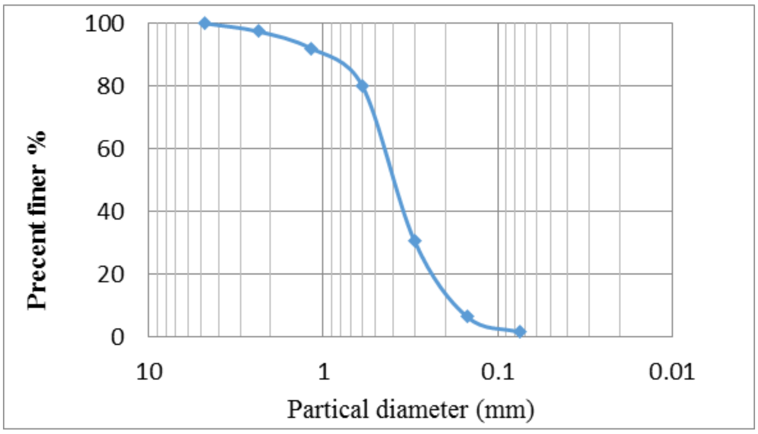


Figure 1: Grain size distribution for the used soil.

II. Pile model and container

The pile model employed in this research is a square hollow aluminum pile with closed ends, with 20 mm outer diameter, 18 mm inner diameter, and the thickness of the wall was equal to (1mm). The Pile models are manufactured with three different ratios of length to diameter (L/D) (20, 25, and 30). So, they have three embedded lengths(400, 500, and 600) mm.

The experimental system consists of a rectangular test box having a width of 750 mm, a height of 740 mm, and a depth of 250 mm. The base and two sides of the box were constructed of a 6 mm thick steel plate and one side is made from wood. In contrast, the front side of the box is a Perspex sheet with 18mm thickness that acted as a viewing window for displacements measurement as presented in Figure (2).

Figure 2: Front view of the experimental box

III. The Pile Instillation and Dial Gage

The first step to prepare the model is to install the pile vertically, then the soil is prepared with a specific density. For pile installation, a guide section with a 10 mm steel section has a dimension of 40 mm in width and 860 mm in length is used. The benefit of the steel section is to ensure that the pile model (single or group) is vertically installed and fixed at the top of the box. Also, to fix the pile on the Perspex sheet, grease along the pile shaft is used to ensure that the sand does not enter between the pile and the sheet, in this way, the pile is fixed in the middle of the box as shown in Figure (3).

After the model preparation with specific relative density (60%) was finished and the top surface layer is leveled, a dial gauge is applied with 0.01 mm thoroughness to count the lateral displacements of the pile cap during the test period (single pile and pile group load tests). The gage was stationary using a holder of magnetic stand base which is concentration of the load cell at the other side of the pile cap.

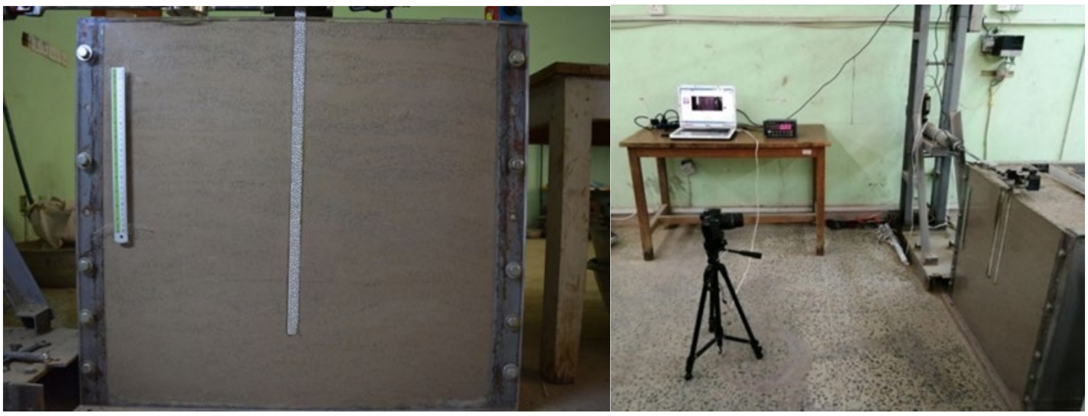


Figure 3: Completed testing model

3. THE SYSTEM OF HORIZONTAL MOTION

The lateral loading system as clarifies in Figure (4) consists of the electrically controlled horizontal hydraulic jack and screw steel shaft joined with each other that exerts a horizontal load applied on the load cell from one side while the other side of the load cell connected with a steel shaft which works as same as a penetration cone to enforce a point load on the pile cap. For the object of reading the load that is applied from the hydraulic jack, a load cell must be linked to a weighing indicator. It is worth mentioning that the test is ended when the lateral displacement reaches approximately twice the pile width.

The horizontal jack apparatus be composed of a cylinder, control device, and electric jack, the control device is utilized to alter the frequency value. This apparatus is collected and manufactured by Elway (2017) [21]. The jack holder was designed to move the horizontal jack down and up along the steel structure as present in Figure (5). The frequency value used in this study is 0.5Hz, which equal to the speed of 2.5 mm/min.

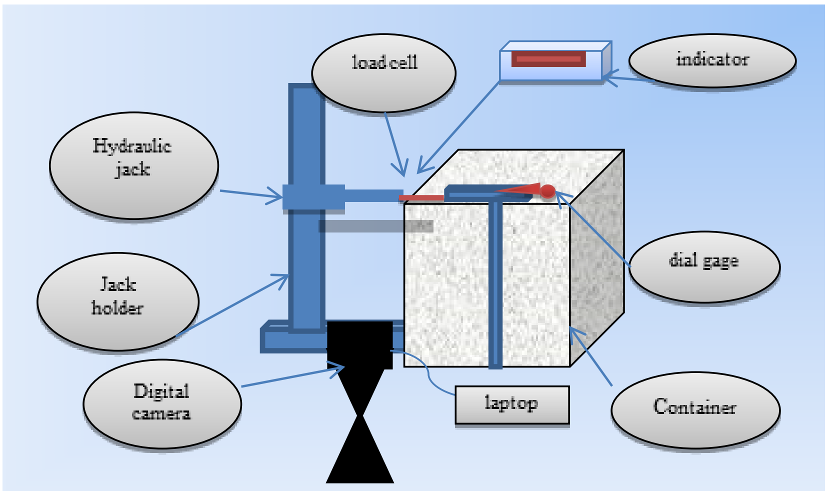


Figure 4: System of lateral loading diagram.

Figure 5: Horizontal movement device used in the test.

4. Model Test Results

Physical simulation is used to investigate specific cases of prototype behavior and to verify theoretical and/or empirical hypotheses. Most physical models would be built with smaller scales than the prototype because it is desired to obtain information about anticipated response patterns more quickly and with greater control over model specifics than would be possible with the prototype [22].

Three model tests of single piles and nine models test for pile groups (1×2) with different spacing (2D, 4D, and 6D). The test results present the effect of changing the ratios of (L/D) and (S/D) on lateral displacements at the head of the pile. The analyses are carried out to produce more understanding of the behavior of piles embedded in medium-dense dry sand at progressively moving load at the pile head.

I. The effect of embedded ratio (L/D) on the load- deflection curve of a single pile

Figure (6) shows the relationship between lateral load and lateral displacement produced for a single pile. These values present the measurement at the pile head. In single piles, when (L/D) ratio increased the values of lateral load increased and this may be referred to as the increase in the soil resistance thrust along the pile to resist the applied lateral load.

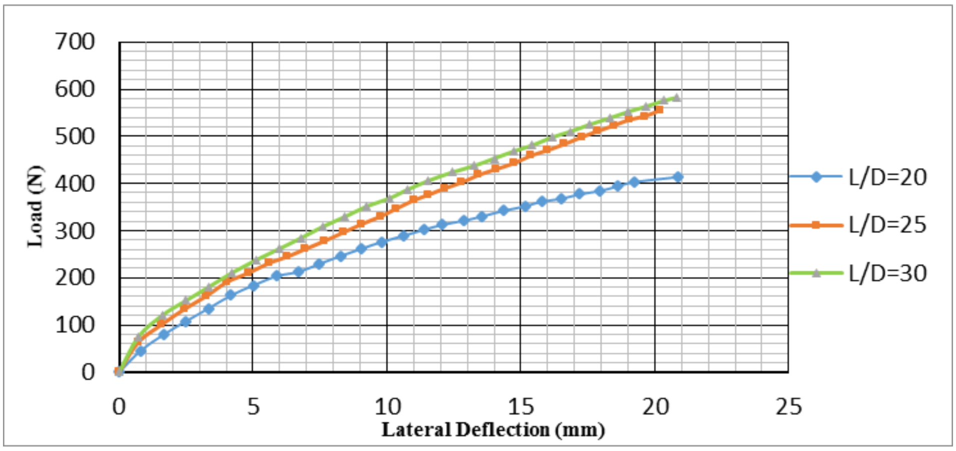
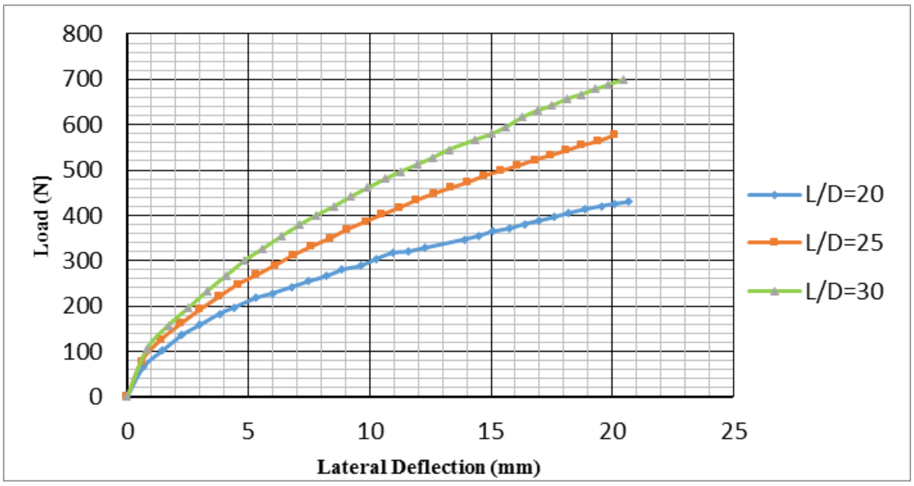


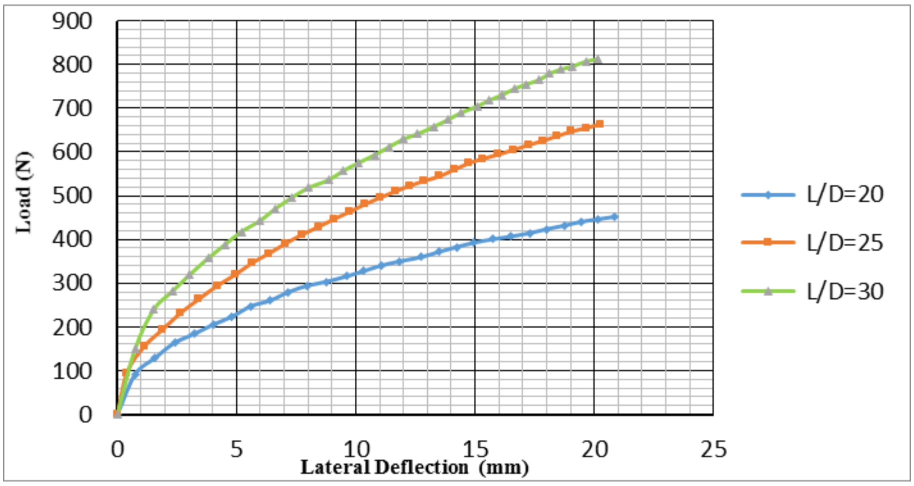
Figure 6: Relationship between lateral load-deflection for single pile

II. The effect of embedded ratio (L/D) on the load- deflection curve of group pile (1X2)

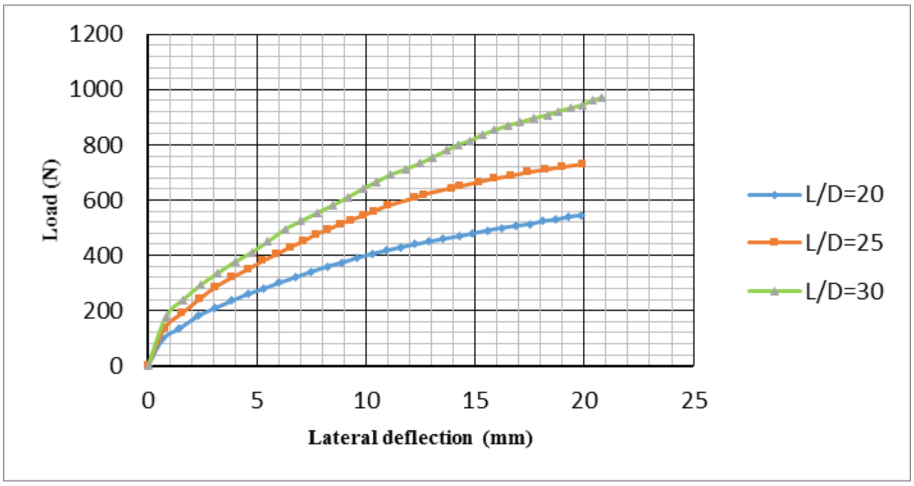
Figure (7) shows the lateral load and lateral displacement curves produced for group piles of different (S/D) ratios. In group piles, when (L/D) ratio increased the values of lateral load increased and this may due to an increase in soil resistance thrust along the pile which in turn resists the applied lateral load. However, lateral pile resistance is not linear with (L/D) increment, where a slight increment is observed between a single pile of (L/D) =25 and (L/D) =30 compared to the increment between (L/D) =20 and (L/D)=25.



(a): Relationship between lateral load-deflection for group pile of different (L/D) with S/D =2



(b): Relationship between lateral load-deflection for group pile of different (L/D) with S/D =4



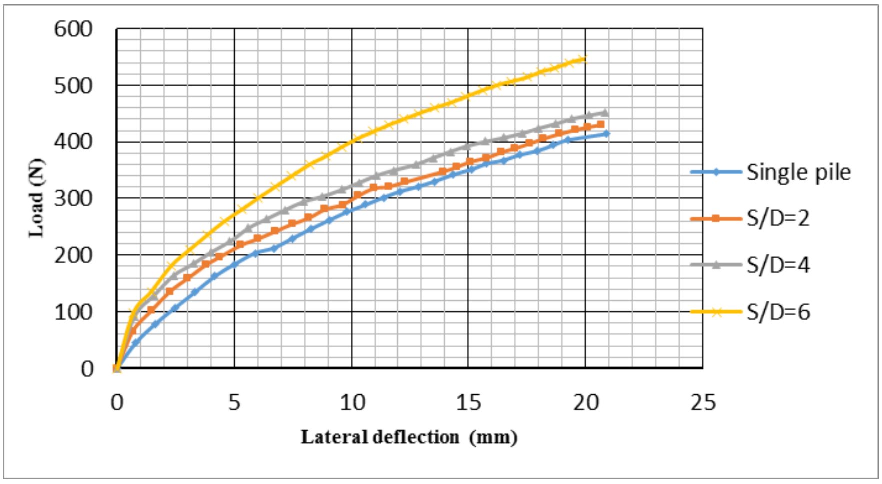
(c): Relationship between lateral load-deflection for group pile of different (L/D) with S/D =6

Figure 7: Relationship between lateral load-deflection for group pile of different (L/D) ratio with different ratio S/D

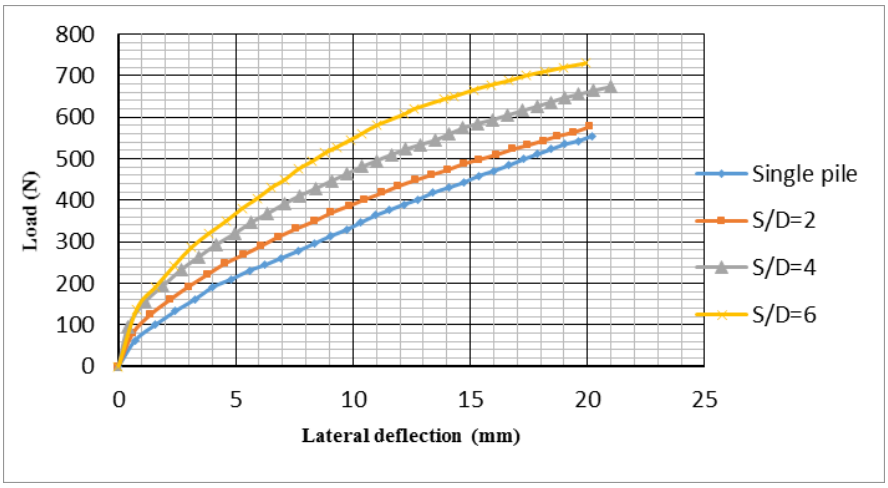
This behavior may be referred to the fact that the increase in the length of the pile is no longer effective under the same loading and soil conditions so that the thrust of lateral soil resistance against applied lateral loads did not increase at the same rate that occurred between embedment ratios of 20 and 25. This result agreed with findings of [23-24].

The effect of (S/D) for group pile on the load- deflection curve

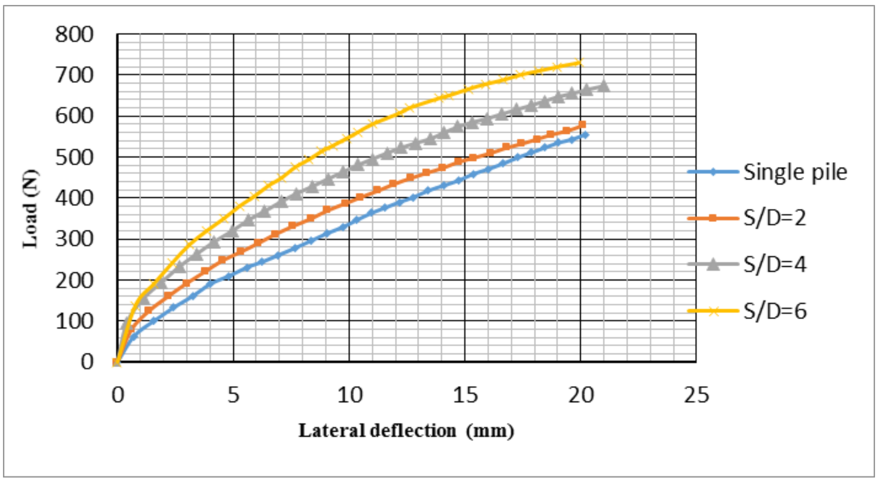
The effect of pile interaction (represented by distance) is investigated in this series. From Figure (8), it's clear that when (S/D) increases the lateral load resistance increases for any displacement value. However, for (L/D) equal to 20, this increment is not linear with spacing increment where a slight increment is observed of the relatively close pile and vice versa. While for other (L/D) ratios the increment of pile load is increased linearly with spacing increase.



(a): Relationship between lateral load-deflection for group pile of different (S/D) with L/D =20



(b): Relationship between lateral load-deflection for group pile of different (S/D) with L/D =25



(c): Relationship between lateral load-deflection for group pile of different (S/D) with L/D =30

Figure 8: Relationship between lateral load-deflection for group pile of different (S/D) with different L/D ratio

Accordingly, in close piles, the group pile may act as one unit in which the soil resistance between any two adjacent piles may overlap and behave as one unit. In contrast, for large spacing, the overlapping between soil resistances of any adjacent piles is decreased and hence the pile is far from act as a unit, hence, the thrust of soil resistance increase producing more resistance to lateral load.

5. Conclusions

The conclusions obtained from testing of 12 models of piles embedded in medium-dense dry sand under lateral loading can be listed as follows:

1. For a single pile when the embedment ratio (L/D) increased, the ultimate lateral load is also increased. However, lateral pile resistance is not linear with (L/D) increment, where a slight increment is observed between the single pile of (L/D) =25 and (L/D) =30 compared to the increment between (L/D) =20 and (L/D) =25.
2. For group pile when (L/D) ratio increased the values of lateral load increased due to an increase in the soil resistance thrust along the pile shaft which in turn resists the applied lateral load. This trend is observed for all (S/D) ratios.
3. When (S/D) increases the lateral load, resistance increases for any displacement value. However, for (L/D) equal to 20 this increment is not linear with spacing increment, where a slight increment is observed of the relatively close pile and vice versa. While for other (L/D) ratio the increment of pile load is increased linearly with spacing increase. It is believed that in close piles the group pile may act as one unit in which the soil resistance between any two adjacent piles may overlap and behave as one unit. In contrast, for large spacing, the overlapping between soil resistances of any adjacent piles is decreased and hence the pile is far from act as a unit, hence, the thrust of soil resistance increased producing more resistance to the lateral load.

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