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Reducing Settlement Using Piled Raft for Neighboring Foundations in Port-Said

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ABSTRACT

The problems of building settlements in Port-Said area have been a great concern in recent years. Damages occur in buildings due to urban development that requires high rise structures to accommodate these extensions. Raft has been used for many new buildings in Port-Said. Soft to firm clay layers extends down to depths reaching 60 m under the ground surface. This paper studies the effect of constructing new building beside an existing one. Piled raft has been studied as settlement reducer and thus to be used as a foundation system in the new building. The typical soil stratification and properties in Port-Said zone are considered in this study. Parametric study is carried out to examine influence of new piled raft variables on the existing building. It has proved that the use of piled raft reduces considerably settlement under the existing building.

KEYWORDS: Raft, piled raft, soil-structure interaction, foundation, settlement.

1. INTRODUCTION

Port-Said lies on the eastern side of the Nile Delta at the north end of the Suez Canal on the Mediterranean Sea.

Most dry land in Port-Said has been reclaimed except for a narrow beach which separated Lake Manzala from the sea. This narrow beach was subdivided into several zones and was studied by Golder Associates (1979). The study investigated clearly the soil layering and stratification down to 60m below the ground surface. The investigation showed that Port-Said area contains clay layers starting from about 12 m under the ground surface to down to 50 m. The same clay layers are also found in the old area of the city. Natural soil deposits having extended clay layers causes settlement problems as observed in Port-Said area. Raft foundations are used to reduce settlement problems observed under many buildings in Port-Said. Thus, it is necessary to study another suitable foundation system such as piled raft.

Analyzing piled raft is a complex task because of the three-dimensional nature of the problem. Main capabilities that must be considered in the analysis are; interaction between all piles, raft and soil elements; accounting for the actual loading and geometry of pile foundations; representing a realistic nonlinear soil model in the analysis.

Considering all these factors require great experience and effort. Analysis of piled raft foundations is illustrated in literatures [2] to [15]. Accounting for the above mentioned factors, the proposed piled raft on Port-Said has been analyzed by modules of compressibility method for elastic raft on layered subsoil model.

Parameters studied in the parametric study are chosen to cover most of the possible variables that affect behavior of piled raft.

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This paper illustrates the effect of using piled raft as a foundation system in the new building B_R to reduce differential settlement of the existing building B_L. To achieve this task, typical soil stratification and properties that exist in Port- Said are considered in the analysis.

A parametric study is carried out to assess the effect of the different foundation parameters and get optimal foundation dimensions. Results of this research would form a base for piled raft design guidelines in Port-Said, where piled raft never been used in this area.

2. MATHEMATICAL MODELING

Numerical study of this research is carried out by commercial program *ELPLA* [8], which can analyze piled raft and raft using different subsoil models. In the analysis, the raft is analyzed by the finite element method.

Piled raft is treated as a rigid member having a uniform settlement on its nodes. Soil is modeled as a three dimensional continuum medium. Nonlinear analysis of pile foundation is taken into account using hyperbolic function. Theoretical bases of soil models and methods in *ELPLA* [8] are well documented by EL Gendy et al. (2006), EL Gendy (2007 a, b).

3. SOIL PROPERTIES

The study presented in this paper is carried accounting for the soil data in reclaimed zones as source data. This source data has been based upon the extensive geotechnical study performed by Golder Associates (1979). According to several investigated cases down to 60 m under the ground surface for 6 zones in Port-Said as shown in Figure (1), surface soil conditions are relatively uniform but in some places the ground surface is underlain by fill. The whole areas have a thin layer of very soft surface clay with an average thickness of 0.2 m in the northern part of the zones to 2 m thick in the south. Below the surface clay layer there is compact dense fine sand with an average thickness of about 7m, sand grades downward through a transition zone into firm clay to 12 m. A thick clay layer extends to an average depth of about 50m below the ground surface, resting on basal deposits of hard clay and dense sand. In this paper soil data of zone 2, which are similar to the most of those exist in Port-Said, are considered. Zone 2 lies south the city. It contains the water treatment station, few apartment buildings, agricultural and industrial development areas. Figure (2) shows a main soil profile of Port-Said area. Figure (3) shows some photos of building damages resulting from adjacent constructions in Port-Said.

3.1. Modulus of Compressibility

Analysis of foundation using continuum model requires the modulus of compressibility of clay *Es* as a main soil parameter. Considering the available water content for clay layers from Golder Associates [1], these variables can be represented in general equations related to the depth. Reda [12] has determined the modulus of compressibility for each zone and verified it. It can be approximated it by the following linear relation:

$$E_s = E_{so}\left(1 + 0.06\,z\right) \qquad (1)$$

Where:
E_s : Modulus of compressibility, (MN/m^2).
E_{so}: Initial modulus of compressibility,
E_{so}=2 (MN/m^2) and
z :Depth measured from the clay surface, m.

3.2 Groundwater

Groundwater in Port-Said lies within 2m from the ground surface. In this study the groundwater level is assumed to lie directly below the raft, where foundation level is considered at 1.9m.

3.3 Typical Soil Profile and Soil Properties

According to the soil stratification in zone 2, typical soil profile and soil properties used in the analysis are shown in Table 1.

4. PARAMETRIC STUDY

Piled raft is used as a settlement reducer. Thus, it is considered as a foundation system for the new building B_R.

4.1 Raft –Raft Interaction [R-R]

For the purpose of comparison between results obtained from raft-piled raft interaction and those of raft-raft interaction, parametric study is carried out firstly for raft-raft system, which studies the interaction between an existing building on a raft foundation and the construction of a new neighboring building on raft foundation also.

Considering the two buildings B_L and B_R are constructed on two rafts. Geometry and loads of the two rafts used in the analysis are shown in Figure (4).

Choosing rafts dimensions and load geometries depend on the typical residential building in Port-Said. Ranges of parametric study variables for raft-raft interaction analyses are listed in Table 2. For raft-raft analysis and raft-piled raft analysis, results are only obtained for foundation of dimensions 20×20 m^2 and the new building B_R loaded by 120 kN/m^2, while the existing building B_L was loaded by 50 kN/m^2. Then, generalization factors are obtained for the other cases.

4.2 Material Properties

Raft and piled raft have the following material parameters:
Young's modulus E_b = 3.4 * 10^7 (kN/m^2)
Poisson's ratio ν_b = 0.2 and
Unit weight γ_b = 0

While piles have the following material parameters:
Young's modulus E_b = 2.35 * 10^7 (kN/m^2) and
Unit weight γ_b = 0

4.3. Results of Analysis

4.3.1. Settlement

The settlement effect is expressed as a dimensionless settlement ratio rsc, which given by: rsc= Sc/Smax. Where, Sc is the calculated settlement of the existing building (cm) and Smax is the maximum allowable settlement according to ECP (1995), which equals to 15 cm.

Figures (5) to (8) show settlement ratio distribution along the common central axis of the two neighboring buildings. Raft thickness of the existing building B_L equals 0.5 m. Thickness of the new raft B_R is variable to study its effect on settlement ratio of the existing building B_L. Thickness *T* of the new raft B_R ranged from 0.8m to 1.5m. From these figures it can be observed that: increasing the raft thickness *T* of the new building B_R slightly decreases the differential settlement of the existing building B_L. Moreover, differential settlements of the existing building B_L are inversely proportional to distance *D* between the existing raft and the new one. Angular distortion of the existing building B_L is ranged from 0.678% to 0.26% for distances *D* equal 0.2 and 6m, respectively.

4.3.2 Differential Settlement

Figure (9) shows the calculated differential settlements between points *b* and *g* at the existing building B_L as a dimensionless angular distortion ratio rα, rα = αo/ αmax. αo equals the calculated differential settlement of existing building B_L and αmax is the maximum allowable differential settlement according to ECP (1995), which equals 1/500.

It can *be* observed that; increasing the raft thickness *T* of the new building B_R slightly decreases the angular distortion ratio of the existing building B_L. The angular distortion ratio decreases from 1.875 to 1.7, when the thickness *T* ranged from 0.8m to 1.5m at *D* equals 0.2m.

The separation distance *D* is inversely proportional to the angular distortion ratio of the existing building B_L. The angular distortion ratio decreases from 1.7 to 0.65 for distances *D* ranged between 0.2m to 6m at *T* equals 1.5m, respectively. From the above settlement figures, it is observed that; constructing a new building beside the existing one has a great effect and may be exceed the allowable settlement. Only, if the distance between the two buildings becomes greater than 6m, the settlement will be in the safe side.

4.3.3 Contact Pressure

Figure (10) shows the contact pressure distribution along the common central axis of the two neighboring buildings with raft thickness T of the new building B_R. It can be observed from this figure that: construction of the new building B_R reduces the contact pressure of the existing building B_L at the edges. At point b which located at the far edge of the existing building B_L the reduction ratio is equal to 56%, while at point g which located at the edge of the existing building B_L near the new building B_R this ratio is equal to 33.8% for D equals 0.2m and T equals 1.5m. Increasing the distance D between the two buildings B_L and B_R increases contact pressure at the far edge of the new building B_R.

4.3.4. Moment

Figure (11) shows the calculated moment distribution along the common central axis of the two neighboring buildings. The figure shows that; the moment at the centre of the existing building B_L only has positive sign thus, the main reinforcements are located at the bottom of the existing building B_L. Due to construction of the new building B_R, the moment at the raft of the existing building B_L reverses its sign into a negative sign.

Damages then could occur at the top of the existing building B_L foundation. It could be concluded that not only the additional settlement due to constructing the new building B_R causes damages for the existing one but also a reversed moment is generated as well. Increasing the separation distance D between the two buildings decreases the induced additional negative moment of the existing building B_L.

At D equals 6m, the bending moment of the existing building B_L matches with moment of the existing building B_L prior constructing the new building B_R indicating no effect of construction in the existing one.

4.4. Raft - Piled Raft Interaction

This section presents the case of constructing the new building B_R on piled raft where the existing building B_L is resting on a raft [R-PR] system. Geometry and loads of the existing building B_L and three different models of piled raft with three different pile spacing are considered in the analysis as shown in Figure (12). It should be noted that the piles used under the new building raft are friction piles constructed through and ending on the clay layer.

4.4.1 Ranges of Parametric Study Variables

Parametric study is carried out covering a wide range of foundation variables such as: pile spacing S, pile diameter d, pile length L, piled raft size $A \times B$ and the applied load q.

The effect of using piled raft as a foundation system of the new building B_R on the existing building B_L in Port-Said typical soil stratification, under various conditions and parameters are examined. Ranges of the numerical parameters are listed in Table 3.

Case studies are carried out to study effect of constructing the piled raft B_R on the existing building B_L.

Figures (13) through (21) are presented to describe the effect of each variable on the settlement, differential settlement, contact pressure and bending moments of the existing building B_L (raft foundation).

4.4.2 Effect of Pile Length L

Figure (13) shows the relation between the pile length L in the piled raft B_R and settlement ratio rsc of the existing building B_L. The figure shows that the influence of pile length L in settlement reduction of the existing building B_L starts at a pile length of 8m. Settlements may also decrease when pile length equals 8m. The reason is that the top surface of clay layers begins at a depth of about 8m. A practical piled raft used in settlement reduction in Port-Said is considered when pile length reaches 24m.

This length can reduce settlement of the existing building B_L to about 21% of the calculated settlements for the case of raft-raft [R-R] system.

From Figure (14) it is noted that, increasing the pile length L decreases the angular distortion ratio rα of the existing building B_L. Optimal pile length L ranges from 16 to 24m, where the reduction in the angular distortion ratio rα of the existing building B_L ranges from 1 to 0.355, respectively.

Figure (15) shows the relation between the contact pressure of the existing building B_L and the pile length L of piled raft B_R. The figure shows that, increasing the pile length L decreases the contact pressure of the existing building B_L and using of pile length L equals 8m is not effective.

Figure (16) shows the bending moment distribution along the common central axis of the existing building B_L and piled raft B_R. from this figure it can be observed that; construction of the new building B_R causes a negative moment that appears at the top of the existing building B_L.

This negative moment may causes damages on the top of the existing building B_L foundations due to insufficient steel area. Increasing of the pile length L decreases amount of negative moment that appears on the top of the existing building B_L until it disappears at a pile length L equals 24m.

4.4.3. Effect of Pile Diameter d

Figure (17) shows effect of pile diameter d in piled raft B_R on settlement ratio rsc of the existing building B_L. It illustrates that increasing the pile diameter d did not affect the settlement of the existing building B_L. In addition, the increasing the pile diameter d did not also affect the contact pressure and bending moment of the existing building B_L.

4.4.4. Effect of Pile Spacing *S*

Figure (18) shows the effect of the pile spacing ratio S/d where S is the pile spacing (m) and d is the pile diameter (m), on the settlement ratio rsc of the existing building B_L. From this figure it is noted that decreasing pile spacing ratio S/d decreases the computed settlement ratio of the existing building B_L.

It is suggested that the suitable pile spacing ranges from 2 to 3m. Results also shows that pile spacing slightly affects the contact pressure and bending moment at the raft foundation of the existing building B_L.

4.4.5. Effect of Distance *D*

Figure (19) shows the relation between the distance D, which is the distance between the two buildings and the angular distortion ratio rα of the existing building B_L. The distance D is inversely proportional to angular distortion ratio rα of the existing building B_L. At L equals to16m, d equals to 0.5m, the value of rα decrease from 1 to 0.4 for D equals to 0.2, 6m, respectively.

4.5. Generalization Factors

The analysis is performed on model building which has the same size for the existing building B_L and piled raft B_R of 20x20m^2. Uniform load on the existing building B_L equals 50kN/m^2 and for the piled raft B_R the load is equal to120kN/m^2. The diagram shown in Figure (20) presents generalization factors for loads of piled raft B_R, while Figure (21) illustrates the generalization factors for dimensions for the existing building B_L and piled raft B_R.

Generalization factors are carried out for models of 10x10m^2 and 15x15m^2 for both raft and piled raft under uniform pressure of 120, 180 and 240kN/m^2 for piled raft.

Values of settlements at specified nodes a, d, f and g, differential settlements and bending moments of the existing building B_L are presented. The corresponding value in the diagrams is multiplied by the appropriate estimated generalization factor.

5. COMPARISON BETWEEN ALL SYSTEMS

Mohamedien et al (2013) carried out a parametric study to examine the efficiency of constructing R.C. wall adjacent to an existing building to reduce the differential settlement of it. A comparison between R.C. wall and piled raft as settlement reducers was carried out in this paper using the results of [16].

Figure (22) shows comparison between all the systems used to reduce the differential settlement of the existing building B_L when the two buildings are located at nearly the same foundation level equals 1.9m and distance between the two buildings D equals 0.2m. The two buildings have the same raft size 20x20m^2, and load of the existing building B_L equals 50kN/m^2. The new building B_R is loaded by a uniform pressure of 120 kN/m^2. The differential settlement shows as a relative angular rotation of the existing building B_L.

Raft-raft interaction [R-R] is proposed as a reference used for relative angular rotation of 100%. It illustrates that: using R.C. wall without anchor between the two buildings [R-W-R] of depths equal to 6,9 and 12m reduces relative angular rotation of the existing building B_L to 95, 78 and 59%, respectively. While, using anchored R.C. wall [R-AW-R] of depths equal to 6, 9, 12 and 15m reduces relative angular rotation of the existing building B_L to 60, 51, 48 and 46%. Then, anchored wall has been preferred to reduce relative angular rotation of the existing building B_L. The less wall depth is, the less the cost of construction is. Wall thickness does not affect performance of anchored R.C. wall as illustrated. [R-AW-R] system is more efficient than [R-W-R] system.

Using of piled raft as a construction system of the new building B_R [R-PR] is illustrated. From the figure it can observe that, optimal piled raft system is pile length 24 m, pile diameter 0.5m and pile spacing ranged from 2-3 m.

Optimal piled raft system reduces relative angular rotation of the existing building B_L to 21%.

Solution of using piled raft is suitable as a system for the new building B_R than using of the R.C wall between the two buildings. Cost of construction of the two systems could be very important to select the optimal system which could be used beneath the existing building B_L.

Also, taking the high cost of piled raft into consideration and that cost of pile casting depending on the soil condition, its diameter, lengths, driven or bored, machine or manmade and number of piles, all should be considered.

6. CONCLUSIONS

A parametric study is carried out to examine the efficiency of piled raft as a foundation system for a new building constructed adjacent to an existing one.

Comparison between different systems of settlement reducers has been illustrated. These systems are: Raft-Raft [R-R], Raft-Wall-Raft [R-W-R], Raft-Anchored Wall-Raft [R-AW-R] and Raft-Piled Raft [R-PR]. Using R.C. wall without anchor between the two buildings [R-W-R] with depths equal to 6, 9 and 12m, and with thickness 0.4m reduces the relative angular rotation of the existing building to 95, 78 and 59%, respectively.

Using anchored wall [R-AW-R] with the same thickness and with depths 6,9,12 and 15m reduces the relative angular rotation of the existing building to 60, 51, 48 and 46%, respectively. Piled raft is a suitable foundation system in Port- Said area compared with Raft-Raft [R-R], Raft-Wall-Raft [R-W-R] and Raft-Anchored Wall-Raft [R-AW-R] systems. Different parameters of piled raft such as pile length, pile diameter, pile spacing, loading, raft dimensions and distance between the two buildings have been considered. Optimal piled raft dimensions can be used in Port-Said for the new building are those having 24m pile length, 0.5m pile diameter and 2-3m pile spacing. Optimal piled raft reduces the computed relative angular rotation of the existing building about 21% of the Raft-raft foundation system.

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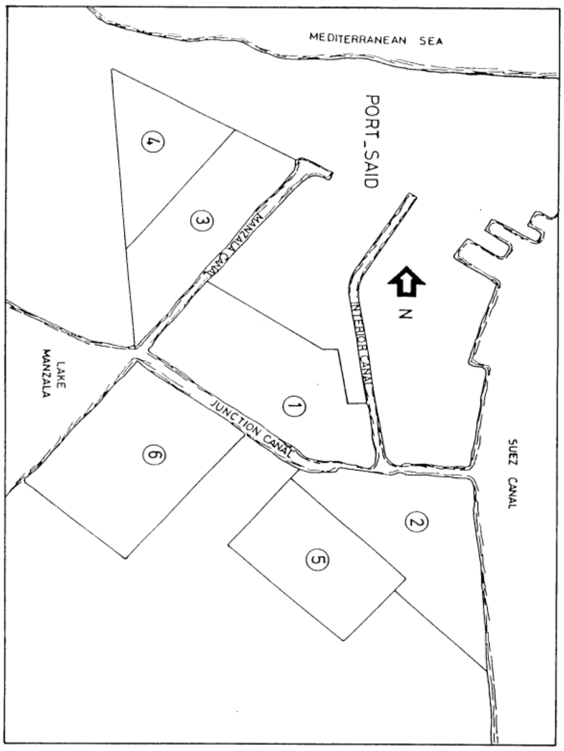


Figure 1: Port-Said zones

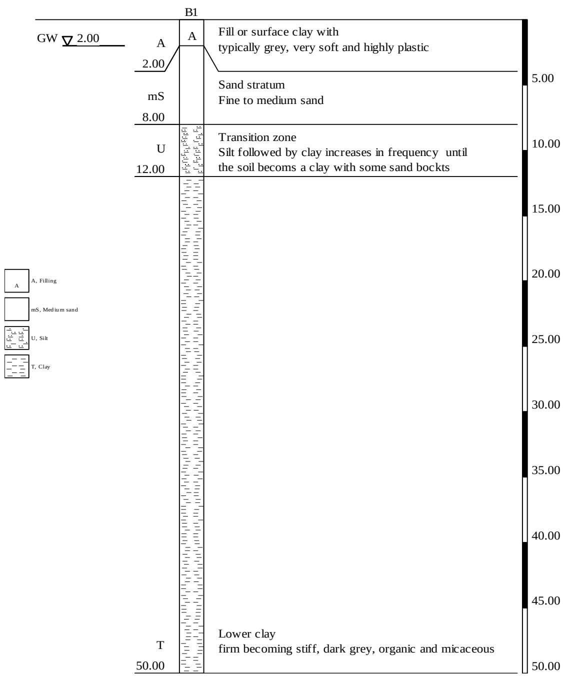


Figure 2: Main soil profile of Port-Said

Figure 3: Damages resulting from adjacent construction

Table 1.Typical soil parameters

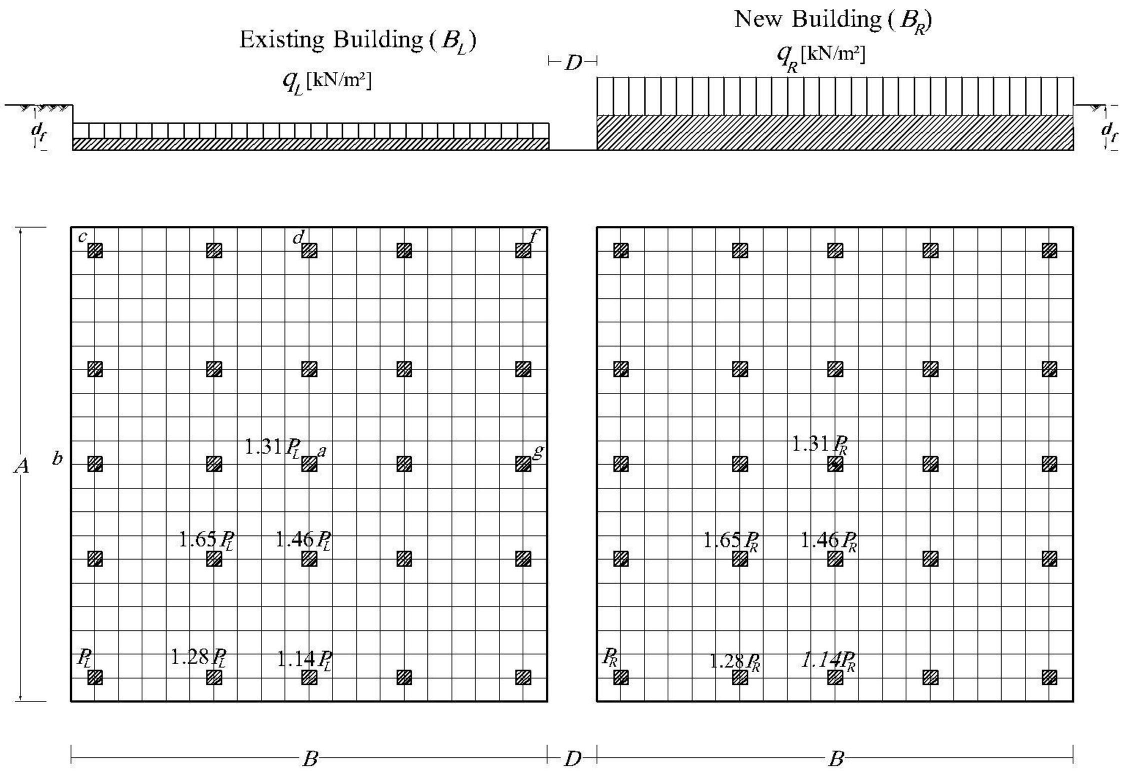
Layer No.	Type of soil	Depth under the ground Surface z (m)	Modulus of Compressibility Es (kN/m^2)	Undrained cohesion c_u (kN/m^2)	*Poisson's* ratio of the soil ν_s (-)	Unit weight of the soil γ_s (kN/m^3)
1	Fill or surface clay	1.9	1750	-	0.3 for sand 0.45 for clay	γ_s =18
2	Sand	8.3	60000	-		γ_{sub}=8
3	Silt	12.0	6500	-		γ_{sub}=8
4	Clay	41.5	Eq. 1	Eq. 2		γ_{sub}=8

Table 2. Ranges of variables for the new raft

Name of variables	Range
Raft thickness of the new building T ,(m)	0.8, 1.0, 1.2, 1.5
Distance between two buildings D,(m)	0.2-2.0-4.0-6.0
Foundation size $A\times B$, (m^2)	10×10, 15×15, 20×20
Applied load for the new building q, (kN/m^2)	120, 180, 240

Table 3. Ranges of variables for the piled raft

Name of variables	Range
Pile length L, (m)	8, 16, 24
Pile diameter d, (m)	0.4 , 0.5, 0.6
Pile spacing S. (m)	2, 3, 4
Foundation size $A\times B$, (m^2)	10×10, 15×15, 20×20
Applied load q ,(kN/m^2)	120, 180, 240



Distance between the two buildings (D) = 0.2,2,4,6 [m]

q_L = 50 [kN/m²] q_R = 120,180,240 [kN/m²]

P_L =614.44 [kN] P_R =1474.65 [kN]

Figure 4: Rafts geometry and loads for buildings B_R and B_L

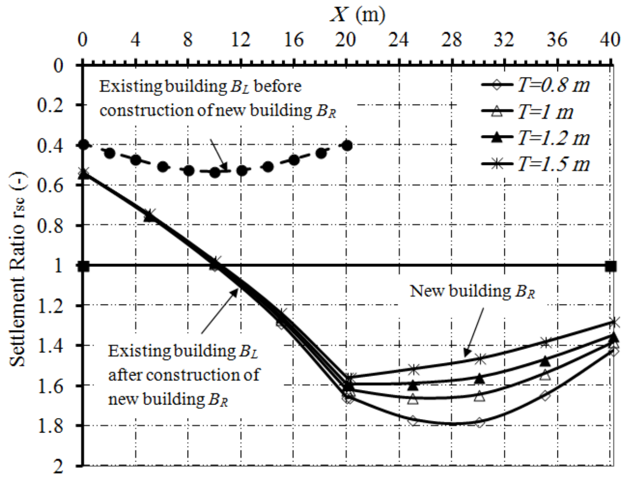


Figure 5: Settlement ratio of two buildings, *D* =0.2m

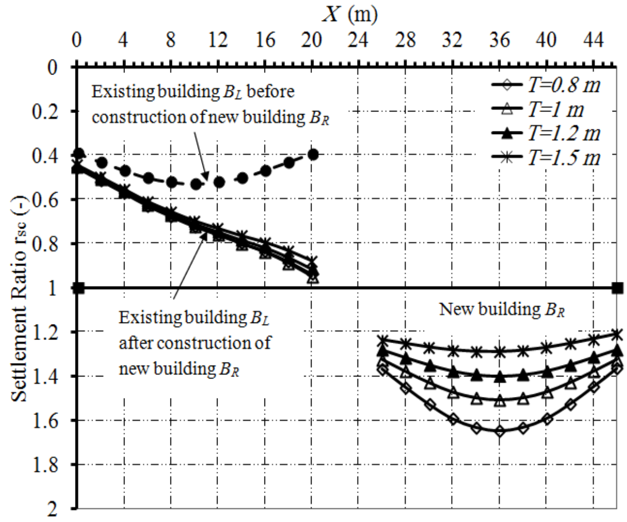


Figure 8: Settlement ratio of two buildings, *D* =6m

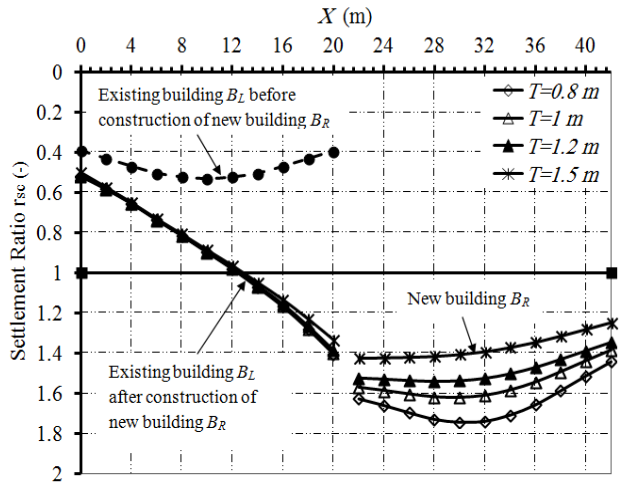


Figure 6: Settlement ratio of two buildings, *D* =2m

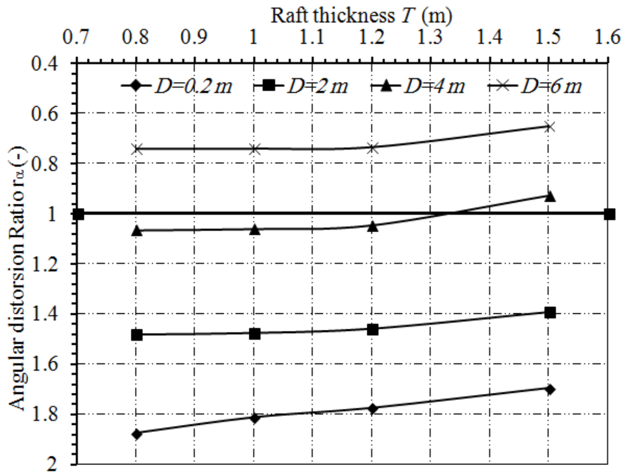


Figure 9: Angular distortion ratio rα of the existing building B_L at different values of *D*

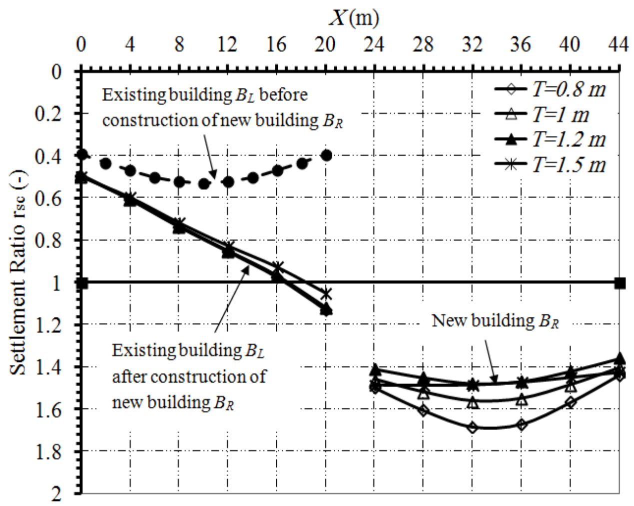


Figure 7: Settlement ratio of two buildings, *D* =4m

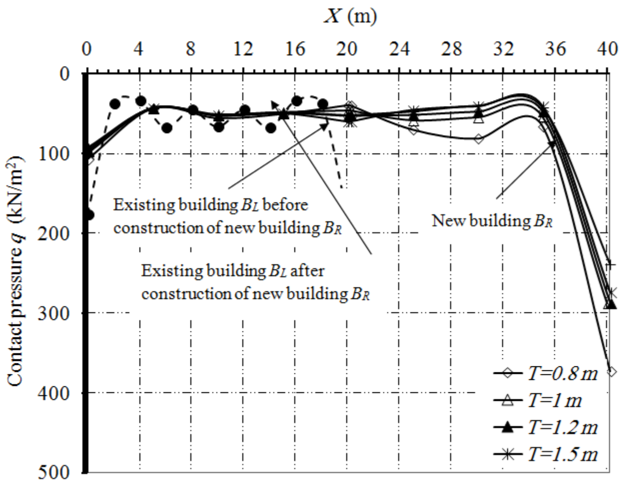


Figure 10: Contact pressure of two buildings, *D*=0.2m

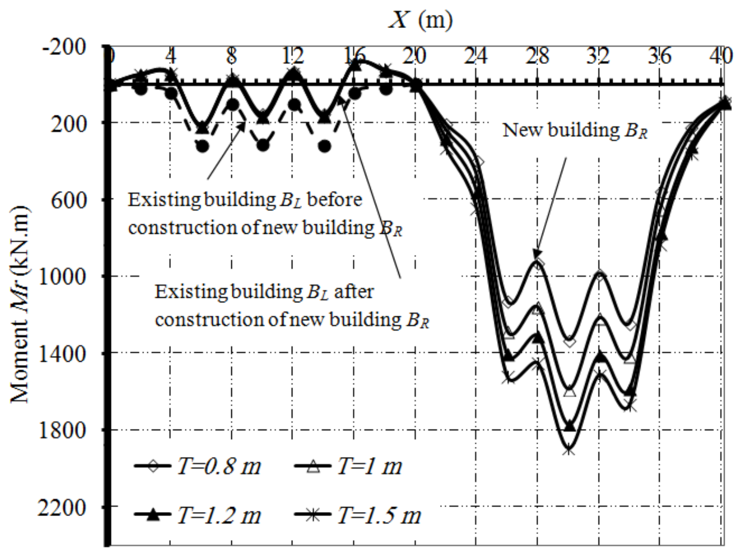


Figure 11: Bending moment of two buildings, *D*=0.2m

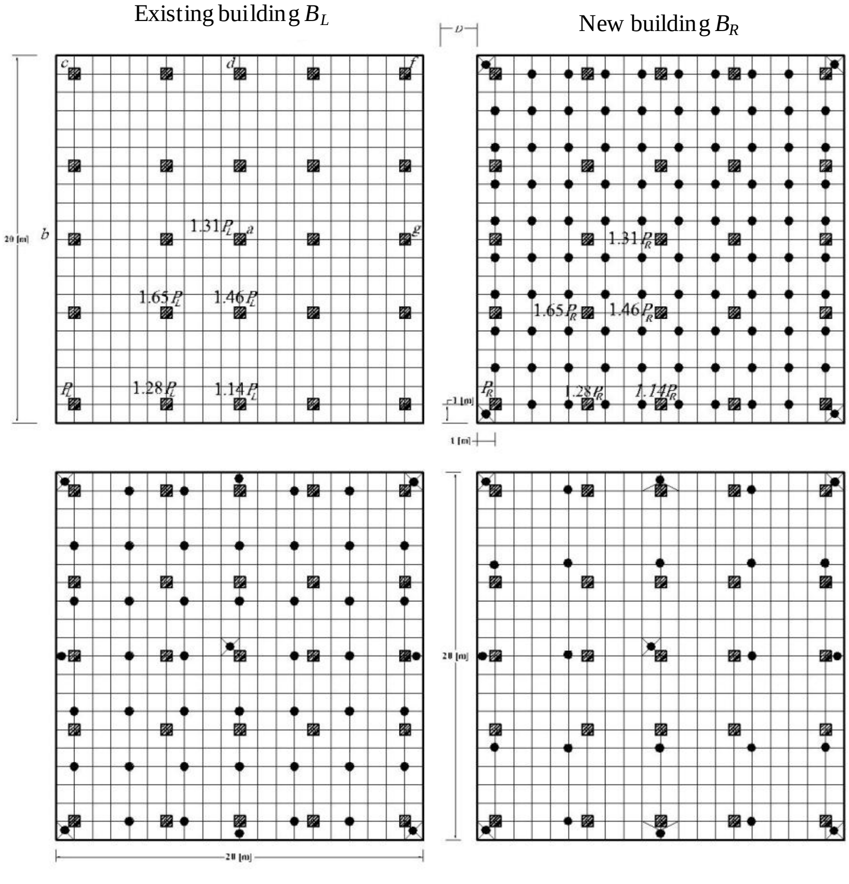


Figure 12: Raft and piled raft models

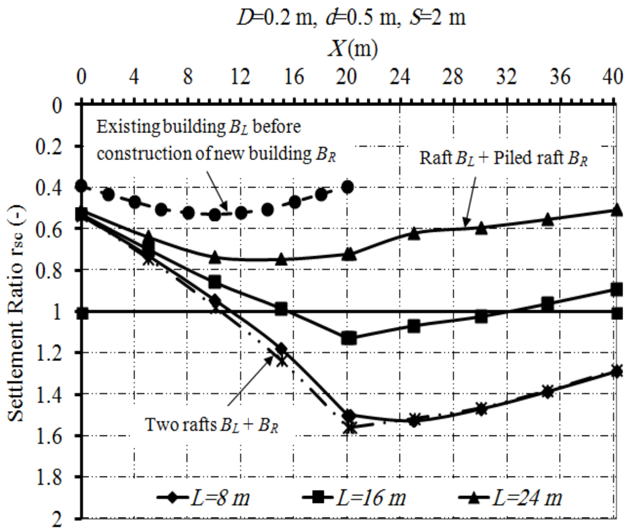


Figure 13: Effect of pile length L on settlement ratio rsc of the existing building B_L

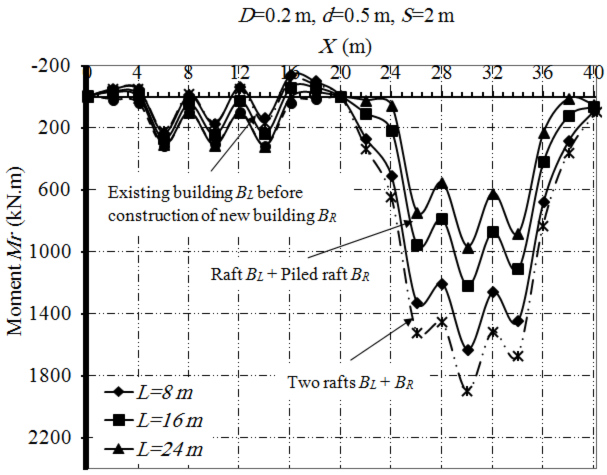


Figure 16: Effect of pile length L on moment Mr of the existing building B_L

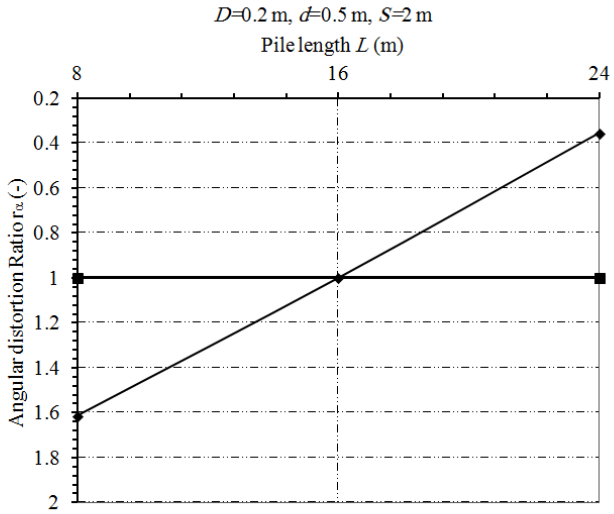


Figure 14: Effect of pile length L on angular distortion ratio rα

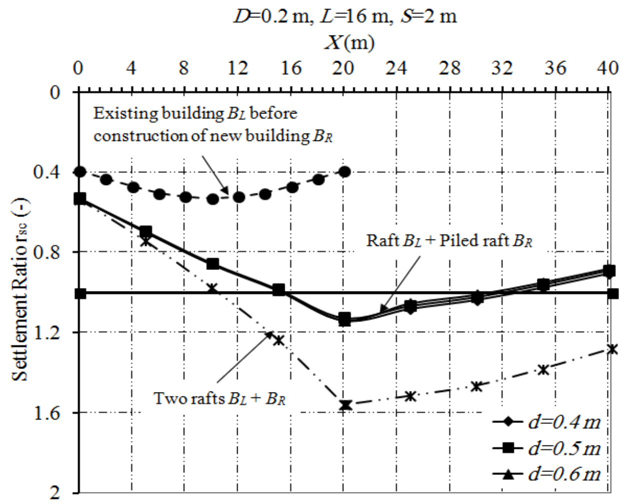


Figure 17: Effect of pile diameter d on settlement ratio rsc of the existing building B_L

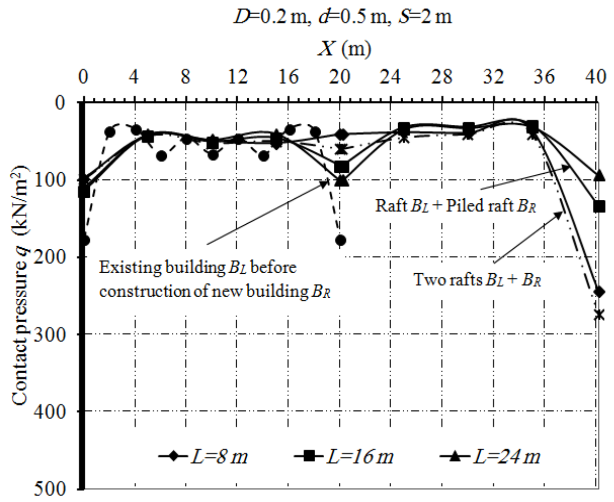


Figure 15: Effect of pile length L on contact pressure q of the existing building B_L

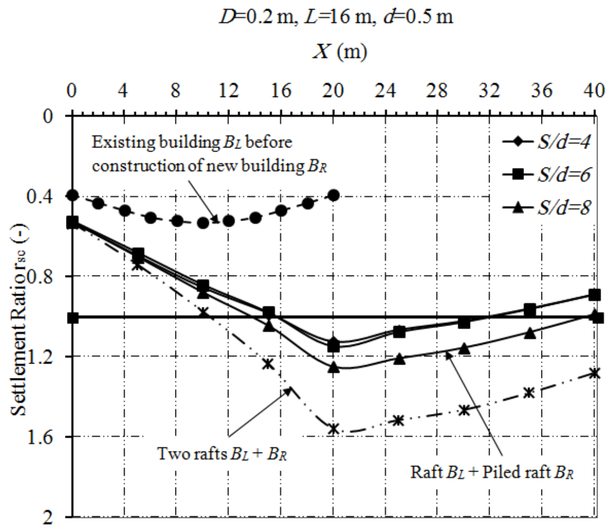


Figure 18: Effect of pile spacing ratio S/d on the settlement ratio rsc of the existing building B_L

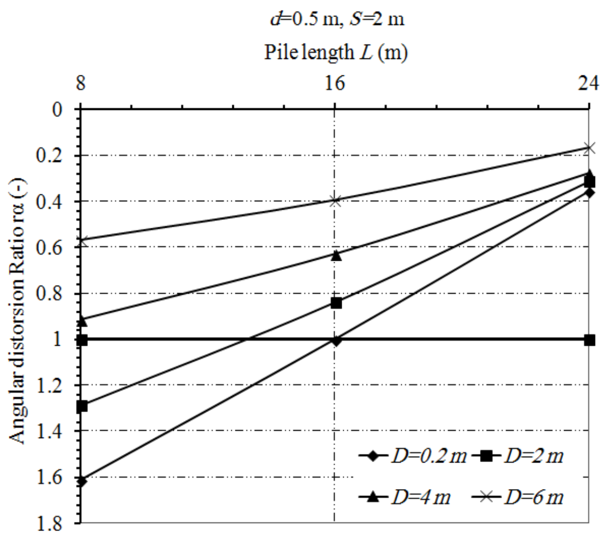


Figure 19: Effect of distance between the two buildings *D* on angular distortion ratio rα

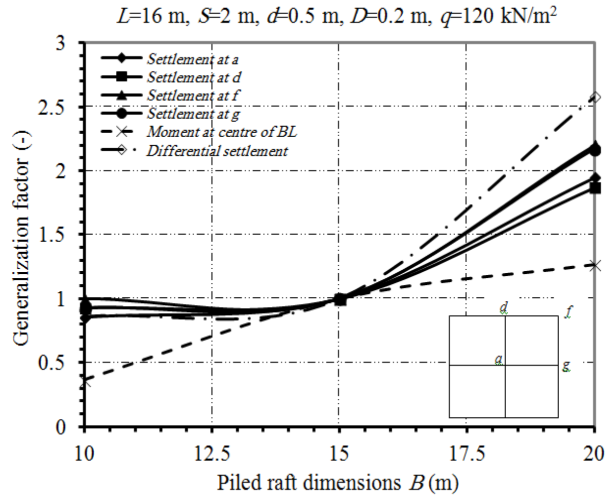


Figure 21 Generalization factors for piled raft dimensions

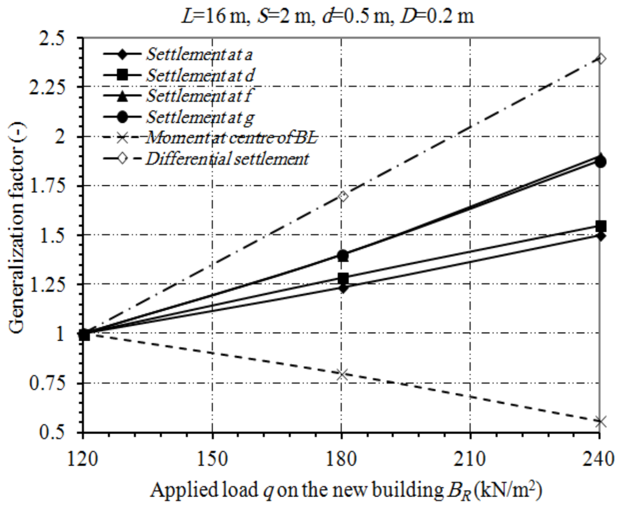


Figure 20: Generalization factors for piled raft loads

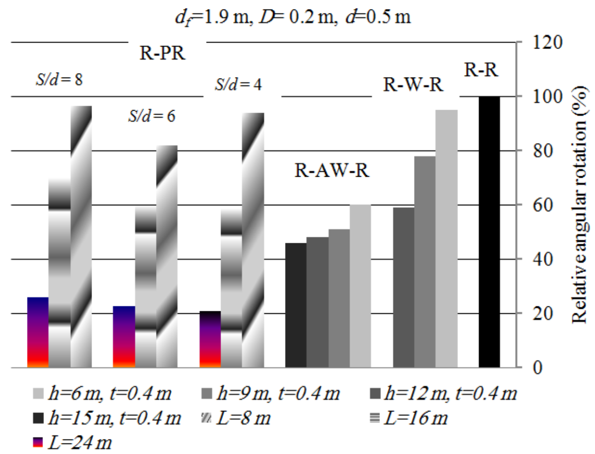


Figure 22: Relative angular relation (%) between alternatives for different settlement reducers