



## Reducing Settlement Using Retaining Walls for Neighboring Foundations in Port-Said

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### ABSTRACT

The problems of settlement in Port-Said area have been a great concern in recent years. Damages occur in buildings due to urban development that requires constructing high rise buildings to accommodate the growing population. Raft foundations have been used for new buildings in Port-Said. This is mainly due to the presence of soft clay layers, which extends to depths that may reach 60m under the ground surface. This paper studies effect of constructing a new building beside an existing one. Constructing of a retaining wall between the two buildings is studied as settlement reducer for the existing one. Typical soil stratification and properties in Port-Said are considered in a numerical study to achieve this task. A parametric study is also carried out to examine influence of constructing such retaining wall, and study the effect of its variables on the existing building. Results revealed that constructing a retaining wall between the existing building and the new one reduces the settlement under the existing building. The study also presents guidelines and diagrams for proposed properties of such retaining walls that may be used in Port-Said.

**KEYWORDS:** Retaining walls, foundations, differential settlement, anchored wall.

### 1. INTRODUCTION

Port-Said lies in 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 separates Lake *Manzala* from the sea. This narrow beach was subdivided into several zones and was studied by *Golder Associates* (1979). It was well investigated in several points down to 60m under the ground surface. The investigation showed that Port-Said area contains clay layers starting from about 12m under the ground surface down to 50m. This clay layers is also found in the old area from the city.

Naturally, soils that have clay layers extended to deep depths causes settlement problems as observed in Port-Said area. Although, raft foundations are used; settlement problems in Port-Said have largely been observed in many buildings. This necessitates studying another suitable foundation system such as piled raft for example.

This paper illustrates the effect of construction of a retaining wall between new building and an existing one.

The effect of constructing a new building beside an existing one starts from excavation and extends till completing the construction of the new building.

Installation of a retaining wall beside the existing building is necessary before excavation for the new one.

As early as in 1969 Peck (1969) published graphs to estimate the surface settlements caused by excavations, which is based on numerous projects mostly from Chicago around that time. The projects are usually temporary constructions with several wall types, such as

Berliner walls and sheet pile walls. The work by Peck was extended by Goldberg (1976) to include more wall types

*Pappin et al* (1985) presented different numerical methods for analyzing the behavior of flexible retaining walls. *Vaziri* (1994) presented a computer program for analyzing the behavior of flexible retaining walls. This program is efficient, versatile and easy to use and provides a powerful tool for complete design of earth retaining structures. *US Army Corps of Engineers* (1994) introduced an engineering manual for design of sheet pile walls. This manual provides information on foundation exploration and testing procedures, analysis techniques, allowable criteria, design procedures, and construction consideration for the selection, design, and installation of sheet pile walls. The guidance is based on the present state of the technology for sheet pile-soil-structure interaction behavior. *Gue and Tan* (1998) illustrated that the success of the design and construction of a deep excavation begins from well planned and closely supervised investigation works including field and laboratory testing. *Russo et al* (2008) studied new construction projects in congested urban settings that commonly require demolition of an existing structure and deep excavation to accommodate several levels of below-grade parking or occupied space associated with the new building. The prediction and monitoring of building response to adjacent construction activities is necessary to minimize building damage resulting from subsurface movement and ground borne construction vibrations. *Liu and Liu* (2008) applied the numerical simulation analysis method to carry out a comparative simulation for the changing of adjacent buildings settlement deformation along with the foundation pit

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excavation depth and the compared the analysis results with the actual monitoring data.

*Reda* (2009) represents several cases in Port-Said, in which new buildings have settlement problems and caused considerable damages for surrounding existing buildings. It is concluded that the damages that occurred are related to the type of Port-Said clay, which is defined as normally consolidated clay. In such case, new heavy buildings caused considerable consolidation settlements to the underlying clay layers within the surrounding area.

This consolidation settlement is considered as an additional settlement for the existing light structures. *Korff* (2009) studied the deformations and damages to buildings adjacent to deep excavations in soft soils.

*Vatovec et al* (2010) presented an article on planning and managing building response to adjacent construction.

*Zhang et al* (2012) presented a spatial analysis for the effect of deformations of retaining structures and adjacent buildings with finite element analysis based on *M-C (Mohr -Coulomb)* soil model.

This paper focuses on the problem of differential settlement expected for an existing building  $B_L$  due to constructing a new building  $B_R$  beside it in Port-Said using retaining wall between them as a settlement reducer. To achieve this task, typical soil stratification and properties in Port-Said zone are considered. Then, a parametric study is carried out to examine the properties of the proposed retaining wall.

## 2. MATHEMATICAL MODELING

The numerical study of this research is carried out by the commercial program *PLAXIS v8.2* (2006), which can analyze retaining walls and foundations using different subsoil models. In the analysis, the retaining wall is analyzed by the finite element method. The retaining wall is modeled as a beam element with three degrees of freedom per node. Two translational degrees of freedom ( $u_x, u_y$ ) and one rotational degree of freedom (rotation in the  $x$ - $y$  plane:  $\phi_z$ ). 5-node beam elements are used with the 15-node soil elements. The beam elements are based on *Mindlin's* beam theory. Soil element was modeled as 15-node plain strain, elasto-plastic, triangular elements with 12 integration points.

The behavior of the soil is modeled as 2D elastic-plastic *Mohr-Coulomb* Model that involves five input parameters, i.e.  $E_s$  (modulus of compressibility) and  $\nu$  (Poisson's ratio) for soil elasticity;  $\phi$  (angle of internal friction) and  $c$  (unit cohesion of soil) for soil plasticity and  $\psi$  as an angle of dilatancy. When using 15-node soil elements, the corresponding interface elements are defined by five pairs of nodes. Zero thickness interface elements are used to model the soil-wall interface. The finite element mesh used in the analysis is shown in Figure (2).

## 3. SOIL PROPERTIES

The study in this paper is carried out taking into account the soil data in the reclaimed zones as source data. This source data is based upon the extensive geotechnical study performed by *Golder Associates*

(1979). According to several investigated points down to 60m under the ground surface for 6 zones in Port-Said as shown in figure (1), the 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 0.2m in the northern part of the zones to 2m in the south. Below the surface clay there is compact dense fine sand with an average thickness of about 7m, the sand grades downward through a transition zone into firm clay to 12m. The clay extends to an average depth of about 50m below the ground surface, the clay resting on basal deposits of hard clay and dense sand. In this paper the soil data of zone 2, which are similar to most of those in Port-Said, are considered. Zone 2 lies south the city. It contains the water treatment station, few apartment buildings, agricultural and industrial development zones. The main soil profile in Port-Said shows in Figure (2).

### 3.1. Modules of Compressibility

Analysis of foundation using continuum model requires the modules of compressibility of the clay  $E_s$  as a main soil settlement 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* [10] had determined the modulus of compressibility for each zone and verified it. It can be approximated it by the following linear relation:

$$E_s = E_{so}(1 + 0.06z) \quad (1)$$

Where:

$E_s$  : Modulus of compressibility, (MN/m<sup>2</sup>),

$E_{so}$  : Initial modulus of compressibility,  $E_{so}=2$  (MN/m<sup>2</sup>)  
and

$z$  : Depth measured from the clay surface, (m).

### 3.2. Groundwater

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

### 3.3. Soil Profile and Soil Properties

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

## 4. RAFT-WALL-RAFT INTERACTION

Existing building  $B_L$  has been constructed on raft subjected to uniform load equals to 50kN/ m<sup>2</sup>, raft size is considered 20x20m<sup>2</sup> and raft thickness is taken equal to 0.5m. The two buildings  $B_L$  and  $B_R$  have been constructed at a foundation level equals to  $d_f= 1.9$ m, and rest on the soil layers illustrated in Table 1. New building  $B_R$  is to be constructed on raft having size of 20x20m<sup>2</sup> and thickness  $T$  equals to 1.5m. R.C. wall is constructed to support excavation side and to decrease the differential settlement of the existing building  $B_L$ , [R-W-R] system.

Differential settlements of the existing building  $B_L$  is represented as relative angular rotation  $\theta$  %. Relative

angular rotation equals to  $\theta \% = \theta_i / \theta_o \times 100$  where  $\theta_i$  is differential settlement of the existing building  $B_L$  when R.C. wall is constructed and  $\theta_o$  is the differential settlement of the existing building  $B_L$  due to construction of the new building  $B_R$  and without R.C. wall. Many factors affecting results of the present study is shown in Figure (3); these factors are called parameters of the current study such as:

- Wall depth,  $h$ ,
- Distance  $X$  of the wall from the existing building  $B_L$ ,
- Distance  $D$  between the two buildings  $B_L$  and  $B_R$ ,
- Construction level,  $d_f$  and
- Wall thickness,  $t$ .

Finite element distribution for R.C. wall and two buildings  $B_L$  and  $B_R$  is shown in Figure (4).

Table 2 shows the values of the studied parameters.

Table 3 shows the values of wall and rafts properties used in the analysis.

## 5. RESULTS OF ANALYSIS

The two buildings are analyzed in two cases. Case (1) Two buildings located at the same foundation level  $d_f$  which equals to 1.9 and 4m. Case (2) Two buildings located at different foundation levels.

### 5.1 Two Buildings Located at The Same Foundation Level.

#### 5.1.1. Effect of wall depth $h$

Figure (5) shows the effect of wall depth  $h$  on the relative angular rotation  $\theta$  of the existing building  $B_L$ . In this curve  $x$ -axis shows the wall depth  $h$ , while  $y$ -axis shows the relative angular rotation  $\theta$  of the existing building  $B_L$ . The figure shows that, the wall depth significantly affects the relative angular rotation  $\theta$  of the existing building  $B_L$ . The influence of wall depth in settlement reduction starts for a wall depth more than 6m.

The relative angular rotation  $\theta$  of the existing building  $B_L$  decreases from 78% to 59% with increasing the wall depth from 9 to 12m, respectively at a separation distance between the two buildings,  $D$  equals to 0.2m. Each increase in the wall depth by 1m decreases the relative angular rotation  $\theta$  by 5%. The top surface of clay layers begins at a depth of about 8m.

#### 5.1.2. Effect of distance $X$

Figure (6) shows the effect of distance  $X$  of the wall from the existing building  $B_L$  on the relative angular rotation  $\theta$ .

The figure shows that the distance  $X$  is directly proportional to relative angular rotation  $\theta$  of the existing building  $B_L$ . At  $D=2m$ ,  $h=12m$  increasing  $X$  from 0.2 to 2m increases  $\theta$  from 52 to 57%. Also, for  $D=4m$ ,  $h=12m$  increasing  $X$  from 0.2 to 4m increases  $\theta$  from 49 to 56.3% and for  $D=6m$ ,  $h=12m$  increasing the distance  $X$  from 0.2 to 6m increases  $\theta$  from 45 to 55%. Wall has been preferred to be located beneath the existing building  $B_L$  to minimize additional settlements that occur due to construction of the new building  $B_R$ .

#### 5.1.3. Effect of distance $D$

Figure (7) shows the relation between distance  $D$  between the two buildings and the relative angular rotation  $\theta$  of the existing building  $B_L$ . The figure illustrates that the distance  $D$  is inversely proportional to the relative angular rotation  $\theta$  of the existing building  $B_L$ .

At  $h=12m$ ,  $t=0.4m$  and  $X=0.2m$ , the relative angular rotation decreases from 59 to 45% for  $D=0.2, 6m$ , respectively. Distance  $D$  has little effect on the relative angular rotation due to construction of the R.C wall between the two buildings.

#### 5.1.4. Effect of foundation level $d_f$

Figure (8) shows the relation between the wall depth  $h$  and the relative angular rotation  $\theta$  of the existing building  $B_L$  at foundation levels equal to 1.9 and 4m, respectively.

Increasing foundation level  $d_f$  slightly decreases the relative angular rotation  $\theta$ . At  $D=0.2m$  and  $h=12m$ , the relative angular rotation  $\theta$  decreases from 59 to 55% at foundation levels 1.9 and 4m, respectively. Increasing foundation level  $d_f$  has no effect on the relative angular rotation  $\theta$  of the existing building  $B_L$ . Stress at different levels of the two buildings remains the same.

#### 5.1.5. Effect of wall thickness $t$

Figure (9) shows the effect of wall thickness  $t$  on the relative angular rotation  $\theta$  of the existing building  $B_L$  at different wall depths. The figure shows that, increasing the wall thickness  $t$  slightly decreases the relative angular rotation  $\theta$ . For wall depth equals to 12m, the relative angular rotation  $\theta$  decreases from 59 to 53% for wall thicknesses equal to 0.4, 0.6m, respectively. Wall depth has greater effect than wall thickness on the relative angular rotation  $\theta$ .

#### 5.1.6. Effect of Wall Anchorage [R-AW-R]

Effect of using wall with ground anchor at 2m below the foundation level on the relative angular rotation  $\theta$  of the existing building  $B_L$  is demonstrated in the, [R-AW-R] system. The wall thickness is 0.4m and connected with ground anchor 10m length, aligned at angle  $20^\circ$  from the wall and having stiffness  $EA$  equals  $6 \times 10^5$  kN is used, as shown in Figure (10).

Figures (11) and (12) shows the relation between wall depth  $h$  and relative angular rotation  $\theta$  of the existing building  $B_L$  at foundation levels of 1.9 and 4m, respectively. The figures show that using wall of depths equal to 6 and 15m with ground anchors reduce the relative angular rotation  $\theta$  by 60 and 46%, respectively.

For foundation level equals to 4m, the relative angular rotation  $\theta$  reduced to 45% and 36% for wall depths equal to 6 and 15m, respectively.

Accordingly, using ground anchor reduces the wall deformations and consequently the differential settlements. Figures (13) through (15) show the effect of anchorage on the relative angular rotation  $\theta$  of the existing building  $B_L$  for different values of distances  $D$ .

These figures show that increasing the distance  $D$  decreases the difference between the two values of the relative angular rotation  $\theta$  of the existing building  $B_L$ . The two values of the relative angular rotation are due to using R.C wall without ground anchor and the second

one due to using R.C. wall with ground anchor. At  $h=12\text{m}$ ,  $t=0.4\text{m}$  and  $X=1\text{m}$ , the difference between the two values of the relative angular rotation  $\theta=32, 26$  and  $16.6\%$ , for  $D=2, 4$  and  $6\text{m}$ , respectively. Increase the distance  $D$  decreases the effect of the new building  $B_R$  on the existing building  $B_L$ , which causes additional settlement for the existing building  $B_L$ . The wall depth slightly affects the relative angular rotation  $\theta$  of the existing building  $B_L$  when anchored R.C. walls are used for all values of the distance  $D$ .

Figure (16) shows the contact pressure distribution along the common central axis of the two rafts. The figure shows that; the contact pressure distribution of the existing building  $B_L$  only at edges is greater than that in the middle. Construction of the new building  $B_R$  reduces the contact pressure of the existing building  $B_L$  at the edges. At wall depth equals  $12\text{m}$  without ground anchor and at a wall depth equals  $6\text{m}$  with ground anchor, the contact pressure of the existing building  $B_L$  increases at the edges and decreases at the middle. Then, increasing the wall depth or using wall with ground anchor makes the contact pressure of the existing building  $B_L$  matches with the contact pressure prior constructing of the new building  $B_R$ , indicating no effect of construction in the existing one.

## 5.2. Case of Two Buildings Located at Different Foundation Levels

New building  $B_R$  is constructed at level  $3\text{m}$  below the foundation level of the existing building  $B_L$  as illustrated in Figure (17). The effect of constructing the new building  $B_R$  at different foundation levels is illustrated in Figure (18). Construction of the new building  $B_R$  at different foundation levels increases the relative angular rotation  $\theta$  of the existing building  $B_L$ . The increase in ratios equals to  $10$  and  $14\%$ , for wall depths equal to  $9$  and  $12\text{m}$ , respectively. The increase in the relative angular rotation of the existing building  $B_L$  is due to stress changes that occurs at different foundation levels. Using wall depths less than  $9\text{m}$  does not reduce the relative angular rotation  $\theta$  of the existing building  $B_L$ . Accordingly, anchored R.C wall is preferred to be used in such case.

### 5.2.1. Effect of wall Anchorage at different construction Level

The effect of using anchored wall is illustrated in Figure (20).

Anchor stiffness is  $6 \times 10^5 \text{ kN}$ , its length= $10\text{m}$  and located at a distance equals to  $3\text{m}$  from ground level as shown in Figure (19).

Figure (20) shows that the effect of wall anchorage is very important in reducing the relative angular rotation  $\theta$  of the existing building  $B_L$ , when the foundation levels of the two buildings are different. Decreasing ratios equal to  $25$  and  $18\%$  for wall depths equal to  $9$  and  $12\text{m}$ , respectively.

## 6. EFFECT OF USING R.C. WALL

Figure (21) and other Figures included in this paper show comparison between all systems which have been used and the relative angular rotation of the existing

building  $B_L$ . Two buildings have been located at the same foundation level equals to  $1.9\text{m}$  and the distance between the two buildings equals to  $0.2\text{m}$ . Two buildings have the same raft size  $20 \times 20\text{m}^2$ , load of the existing building  $B_L$  equals to  $50\text{kN/m}^2$ . The new building  $B_R$  is loaded by  $120\text{kN/m}^2$ . Raft-raft interaction [R-R] is proposed as a reference used for relative angular rotation of [100%].

This figure illustrates that, using R.C. wall without anchor between the two buildings [R-W-R] of depths equal to  $6, 9$  and  $12\text{m}$  reduces the relative angular rotation of the existing building  $B_L$  to  $95, 78$  and  $59\%$ , respectively. On the other hand, using anchored R.C. wall [R-AW-R] of depths equal to  $6, 9, 12$  and  $15\text{m}$  reduces the relative angular rotation of the existing building  $B_L$  to  $60, 51, 48$  and  $46\%$ . Thus, anchored walls are preferred to reduce the relative angular rotation of the existing building  $B_L$ . The smaller the wall depth is, the less the cost of construction. Wall thickness does not greatly affect the performance of the anchored R.C. wall as illustrated. Thus, [R-AW-R] system is more efficient than [R-W-R] system.

## 7. CONCLUSIONS

A parametric study is carried out to examine the efficiency of constructing R.C. walls adjacent to an existing building to reduce the differential settlements.

Different parameters of the R.C. wall such as; wall depth, distance of the wall from the existing building, distance between the two buildings and wall thickness are considered in the analysis. The study aims at minimizing the relative angular rotation of the existing building to get optimum dimensions of R.C. wall. The wall depth is the main parameter that affects the relative angular rotation of the existing building. Wall depth is inversely proportional to the relative angular rotation of the existing building. Wall thickness slightly affects the relative angular rotation of the existing building. Optimum dimensions of R.C. wall in Port-Said for ordinary adjacent structures are; for R.C. wall without ground anchor  $12\text{m}$  wall depth,  $0.4\text{m}$  wall thickness and  $0.2\text{m}$  distance of the wall from the existing building, when the two buildings are located nearly at the same foundation level.

Optimum dimensions of the R.C. wall reduce the relative angular rotation to about  $59\%$ . Using anchored R.C. wall with depth of  $9\text{m}$  reduces the relative angular rotation to about  $51\%$ . Anchored wall depth slightly affects slightly the relative angular rotation of the existing building.

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**Table 1. Soil parameters**

L ayer No.	Type of soil	Depth under the ground Surface z (m)	Modulus of Compressibility $E_s$ (kN/m <sup>2</sup> )	Undrained cohesion $c_u$ (kN/m <sup>2</sup> )	Poisson's ratio of the soil $\nu_s$ (-)	Unit weight of the soil $\gamma_s$ (kN/m <sup>3</sup> )
1	Fill or surface clay	1.9	1750	-	0.3 for sand	$\gamma_s = 18$
2	Sand	8.3	60000	-		$\gamma_{sub} = 8$
3	Silt	12.0	6500	-		$\gamma_{sub} = 8$
4	Clay	41.5	Eq. 1	Eq. 2	0.45 for clay	$\gamma_{sub} = 8$

Where,  $EA$ : Normal stiffness of wall, (kN/m),  
 $EI$ : Flexural rigidity of wall, (kN/m<sup>2</sup>/m),

$M_P$ : The ultimate bending moment on wall, (kN.m),  
 $w$ : The weight of wall, (kN/m<sup>2</sup>) and  $\nu$ : Poisson's ratio.

**Table 2. Examined Parameters**

Name of variables	Range
Wall depth $h$ (m)	6, 9, 12, 15
Distance $X$ of the R.C wall from the existing building $B_L$ (m)	0.2, 1, 2, 3, 4, 5, 6
Distance $D$ between the two buildings (m)	0.2, 2, 4, 6
Foundation level $d_f$ (m)	1.9, 4
Wall thickness $t$ (m)	0.4, 0.5, 0.6

**Table 3. Wall and Rafts Properties**

Element type	Wall	Raft $B_L$	Raft $B_R$
Thickness (m)	$t = 0.4$	$T = 0.5$	$T = 1.5$
$EA$ (kN/m)	$8 \times 10^6$	$1 \times 10^7$	$4 \times 10^7$
$EI$ (kN/m <sup>2</sup> /m)	$1.1 \times 10^5$	$2.1 \times 10^5$	$1.3 \times 10^7$
$M_P$ (kN.m)	287	-	-
$w$ (kN/m <sup>2</sup> )	10	0	0
$\nu$ (-)	0.2	0.2	0.2
Material model	Elasto-plastic	Elastic	Elastic

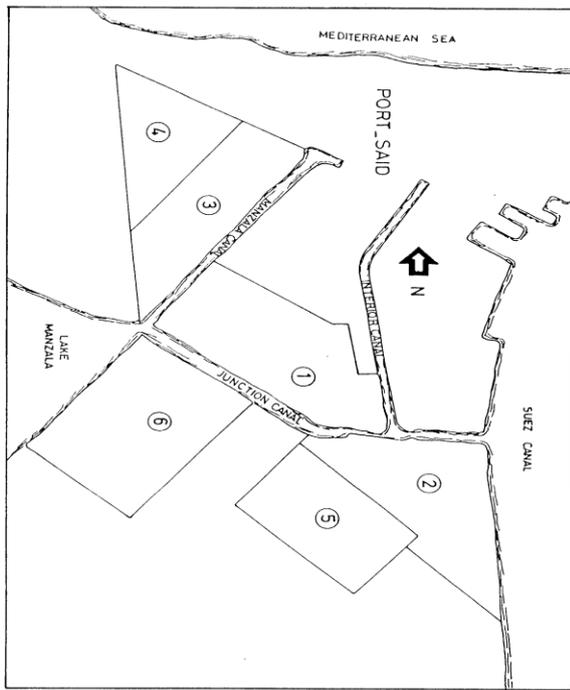


Figure 1: Port-Said zones

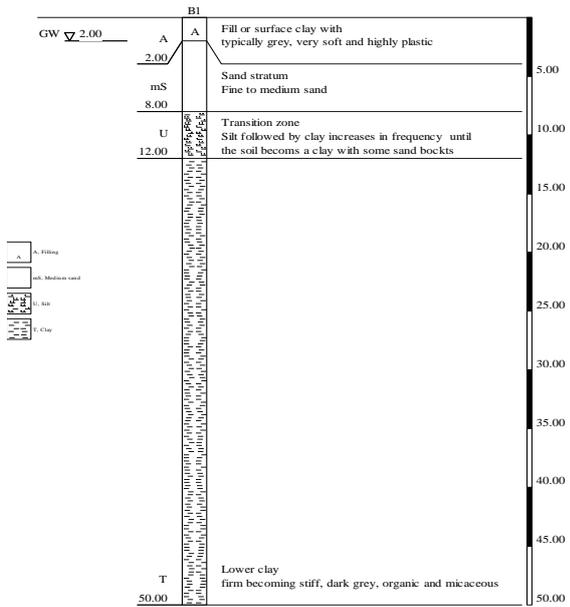


Figure 2: Main soil profile in Port-Said

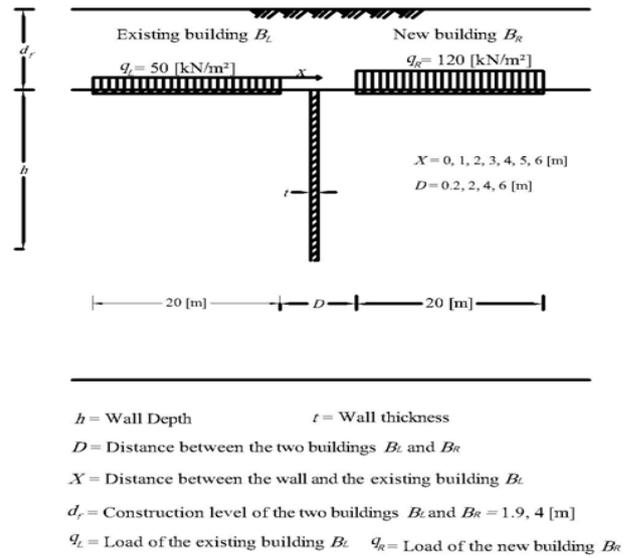


Figure 3: Parameters of the study

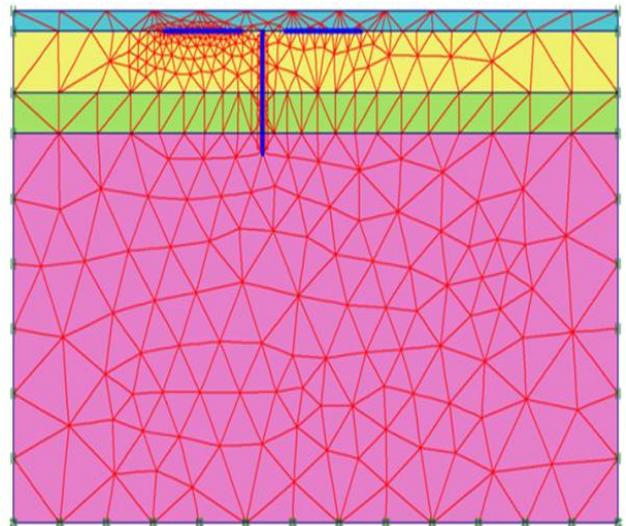


Figure 4: Finite element mesh in PLAXIS

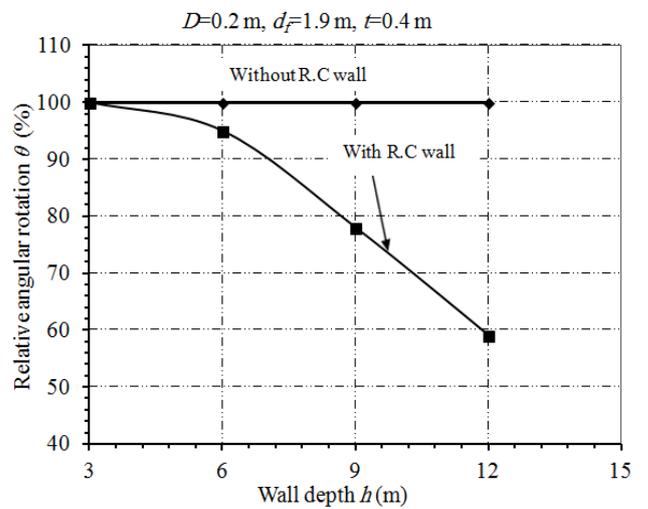


Figure 5: Effect of wall depth  $h$

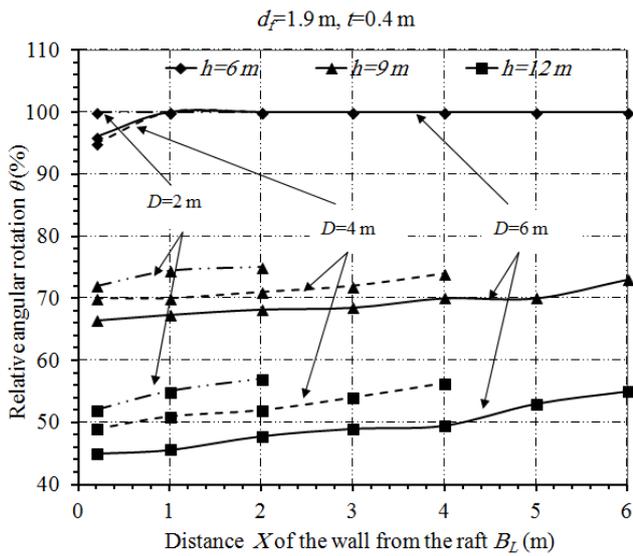


Figure 6: Effect of distance  $X$

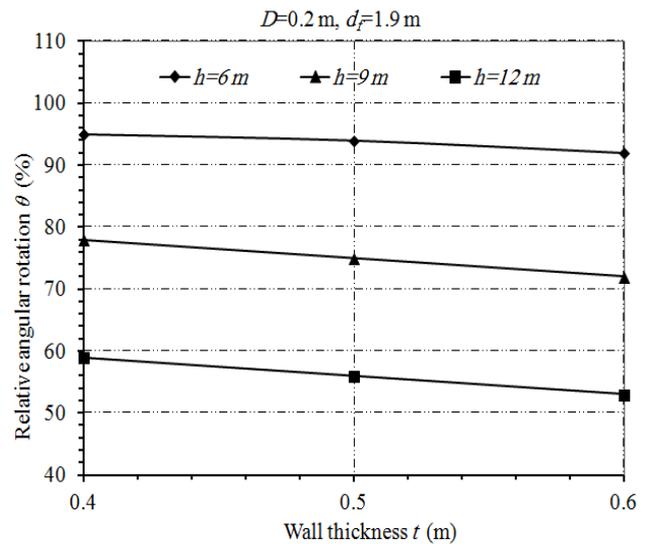


Figure 9: Effect of wall thickness  $t$

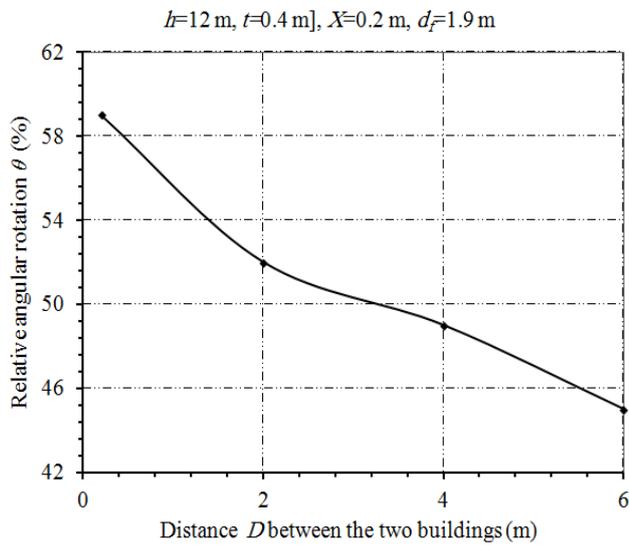


Figure 7 Effect of distance  $D$  between the two buildings

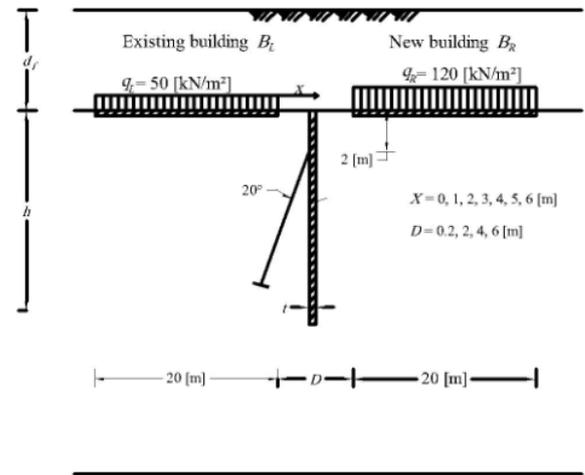


Figure 10: Effect of wall anchorage on the relative angular rotation  $\theta$

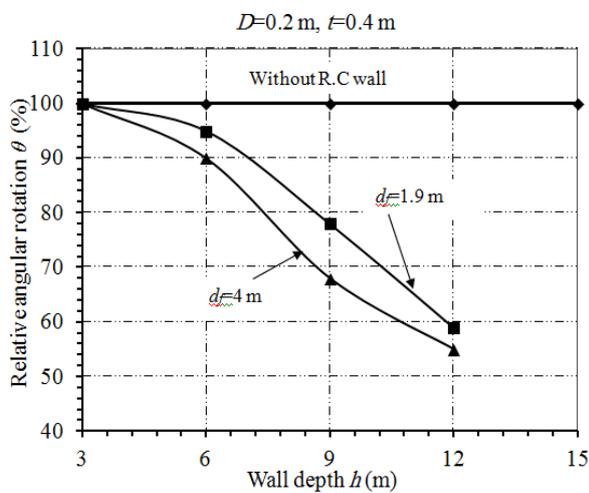


Figure 8: Effect of foundation level  $d_f$

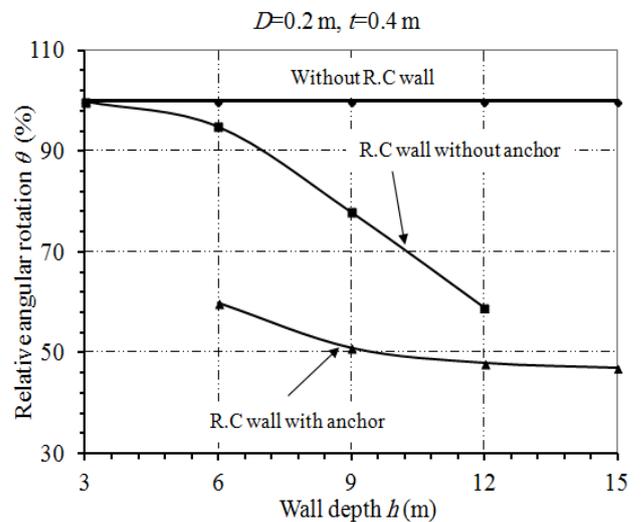


Figure 11: Effect of wall anchorage on the relative angular rotation  $\theta$  at  $d_f = 1.9$  m

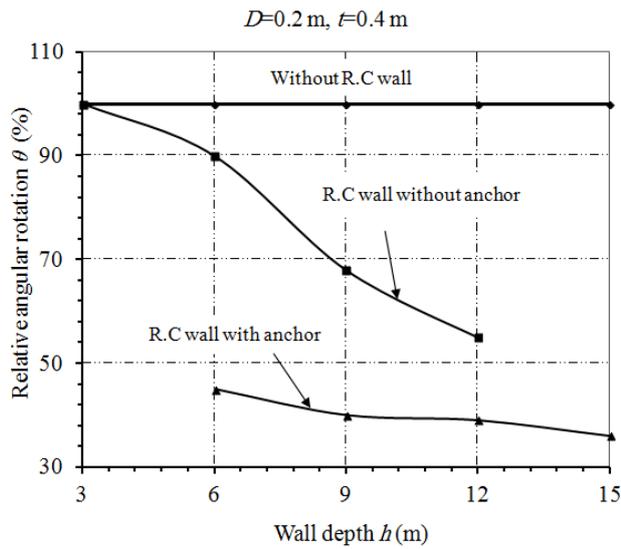


Figure 12: Effect of wall anchorage on the relative angular rotation  $\theta$  at  $d_f=4$  m

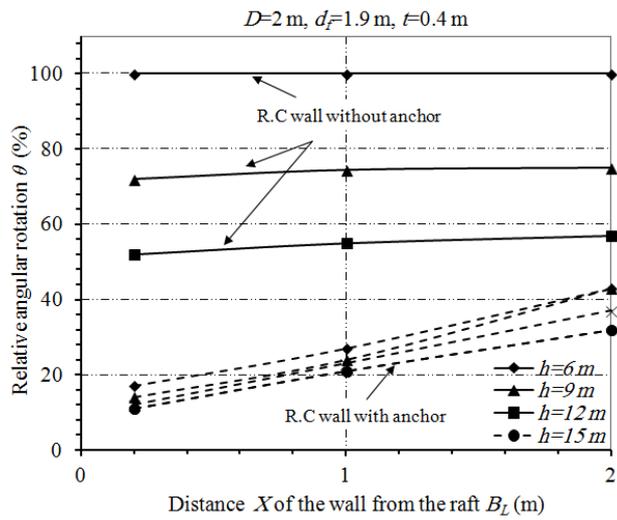


Figure 13: Effect of wall anchorage,  $D=2$  m

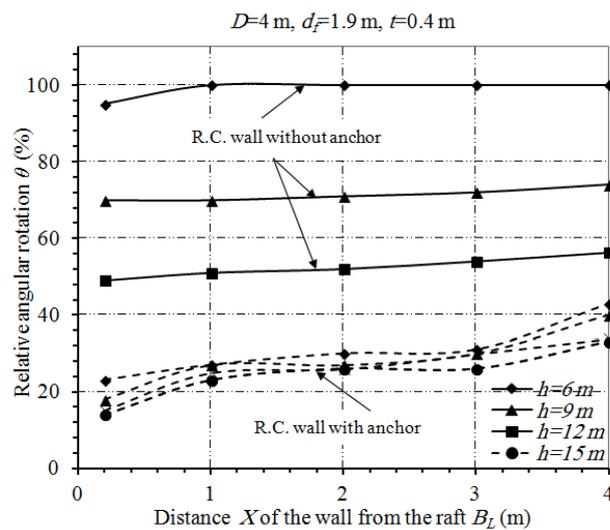


Figure 14: Effect of wall anchorage,  $D=4$  m

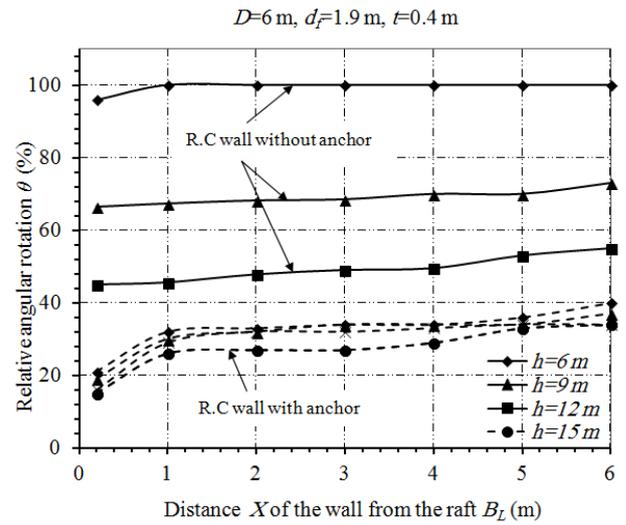


Figure 15: Effect of wall anchorage,  $D=6$  m

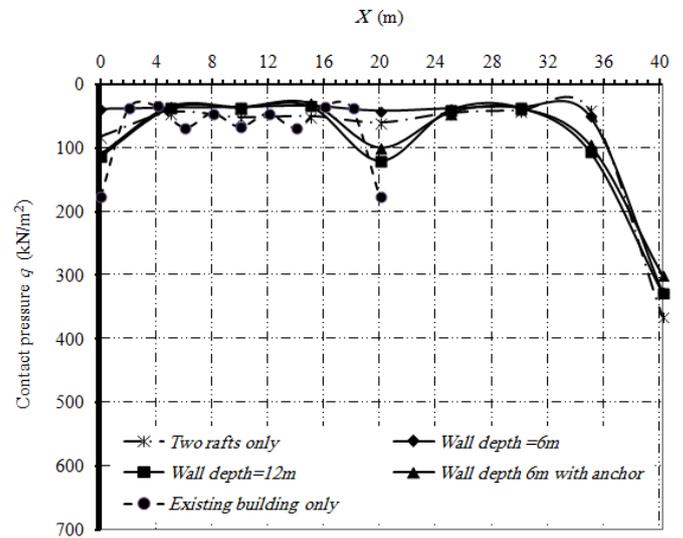


Figure 16: contact pressure distribution

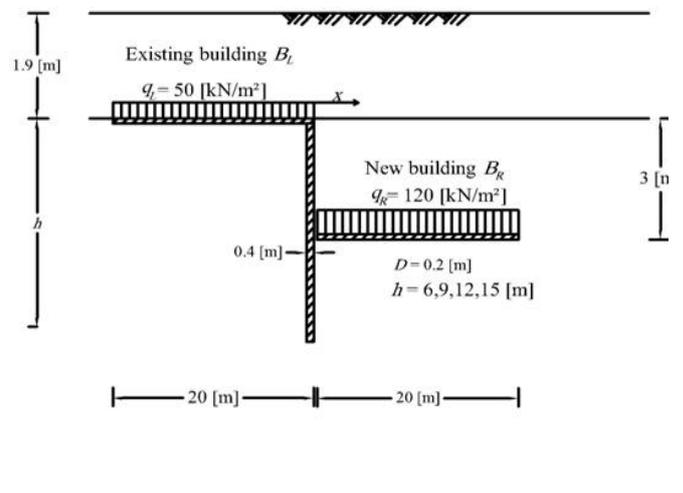


Figure 17: New building  $B_R$  located at different foundations levels

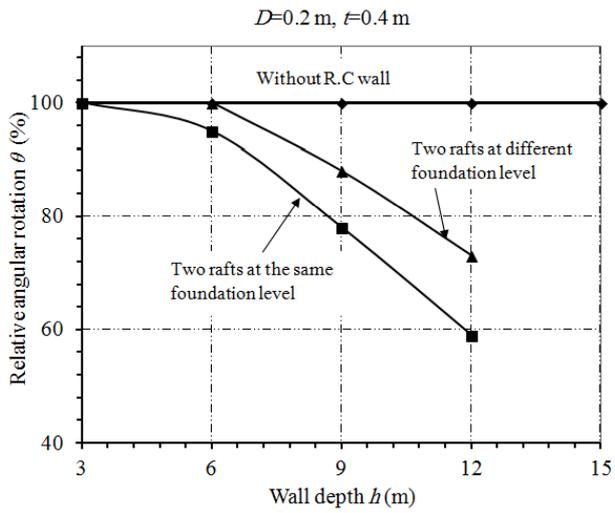


Figure 18: Effect of different foundations levels

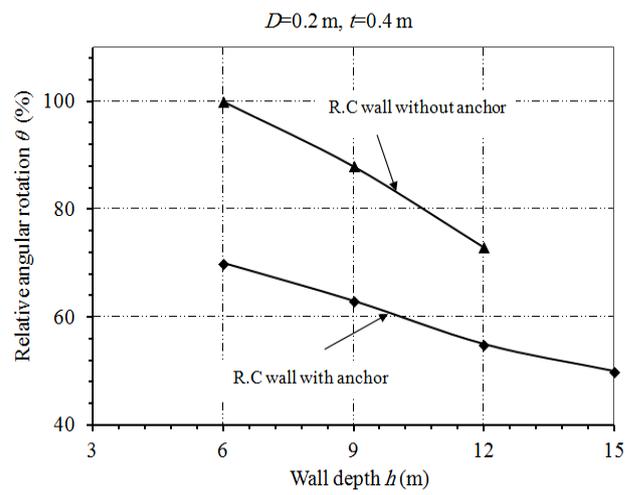


Figure 20: Effect of wall anchorage on the relative angular rotation

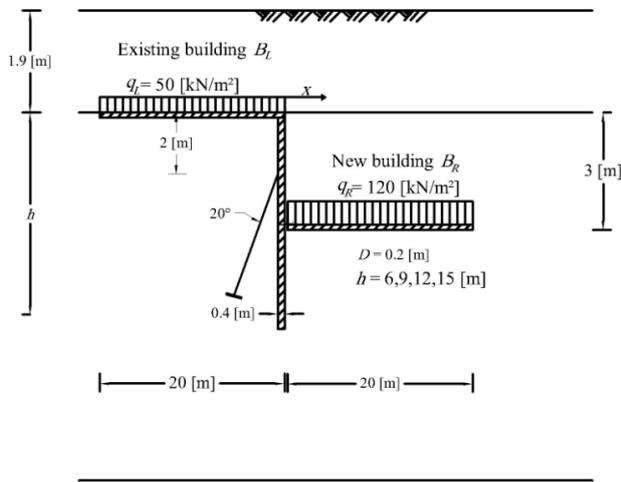


Figure 19: New building  $B_R$  located at different foundation levels

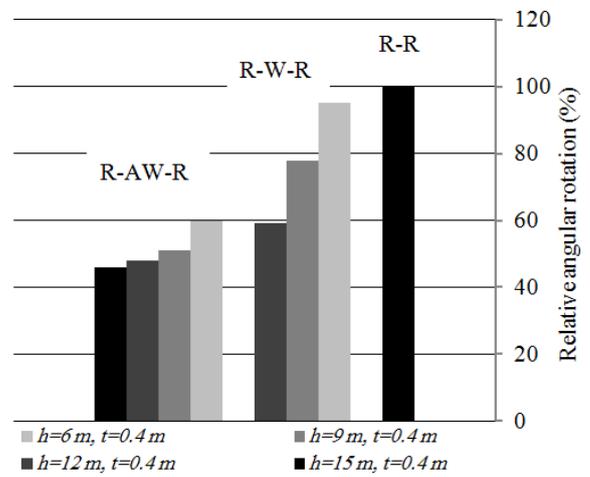


Fig 21: Relative angular relation (%) of the existing building  $B_L$