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Evaluation of Ground Movement Induced by Braced Excavation Using Finite Element Analysis Verified by Case History

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المخلص العربي:
يقدم البحث دراسة نظرية لحركة التربة المجاورة للحفر العميق حيث أن حركة التربة الناجمه عن الحفر العميق أصبحت من اهم معاملات التصميم التي يجب اخذها في الإعتبار وبالأحري في الأماكن التي يوجد بها مباني مجاورة للحفر ولذلك لابد من تقدير قيمة الحركة الناجمه من الحفر بدقة حتي لاتؤثر علي المنشاءات المجاورة حيث أن معظم الأكواد والمواصفات الموجودة تأخد في الإعتبار معاملات الأمان ضد الأنهيار بالقص أو المنشاء الساند ولاكن لا تاخذ في الإعتبار الحركة الأرضية الناتجة من الحفر ولذلك إستلزم الأمر دراسة قيمة الحركة الأرضية بإستخدام برامج التحليل العددي مع تأكيد وبرهنة الحل بحالة دراسة حتي نتأكد من طريقه النمذجة الصحيحة. وتم عمل الدراسة إستخدام برامج التحليل العددي (Plaxis v8.6) مع تأكيد وبرهنة النتائج بحالة دراسة موقعية ذات بيانات كاملة وقياسات موثقة.

Abstract:
Underground construction has become a common practice worldwide; induced ground movements are a major a criterion for most underground construction projects in urban areas because these can cause damage in adjacent structures. So that, accurate predictions for surface ground movement is important design issue in the analysis and design of excavation support systems. All of codes of practice are based on the design criteria is to satisfy factor of safety to prevent the collapse of the system and around soil. It implies that the surface ground movement is a secondary concern, although large number of buildings and utilities is sensitive to small movements induced by excavation which may lead to cracks on adjacent buildings and damages. The objective of this paper is to study the effect of system rigidity on the ground movement adjacent to deep excavation using finite element analysis. System rigidity includes wall penetration depth, wall rigidity and horizontal spacing between struts.

Keywords: Deep excavation, Ground movement, and Plaxis.

1 Introduction
Performance and design of deep excavation are related to both stability and deformation that should be within the acceptable limits. The design can be performed either using finite element method or classical methods. The design of the retaining structure is depending on calculating the earth pressure which is based on soil-side support interaction using manuals or computerized methods. The behavior of deep excavations side support system is governed by the ground conditions such as soil properties and the in-situ conditions. Some of these factors are difficult to access or quantify. Thus, it is difficult to consider all the relevant parameters in a detailed analysis for the deformation of deep excavations. The complexity and the number of these parameters lead to the use of models and techniques, able to reasonably consider the impact of such parameters. Excavation support systems are temporary or permanent structures that have a fundamental influence on the safety, quality, speed, and profitability of construction projects that required deep excavation. They are used to minimize the excavation area, to keep the sides of deep excavations stable, and to ensure that movements will not cause damage to neighboring structures or to utilities in the surrounding ground.

2 Case Study, Luk, T. F. (2001)

The selected case study is considered tieback excavation with contiguous caissons bored pile wall in multilayered soils overlying moderately to slightly weathered rock. This project site is located in center of Guangzhou city, China. The excavation zone is approximately rectangular in shape with dimension of (90 x 62.40 m2) in plan as shown in figure 1. The excavation site was done in the period of 1999-2000 to construct a structure a 38-story with 3-levels of basements. The final excavation depth is 12.00 m.

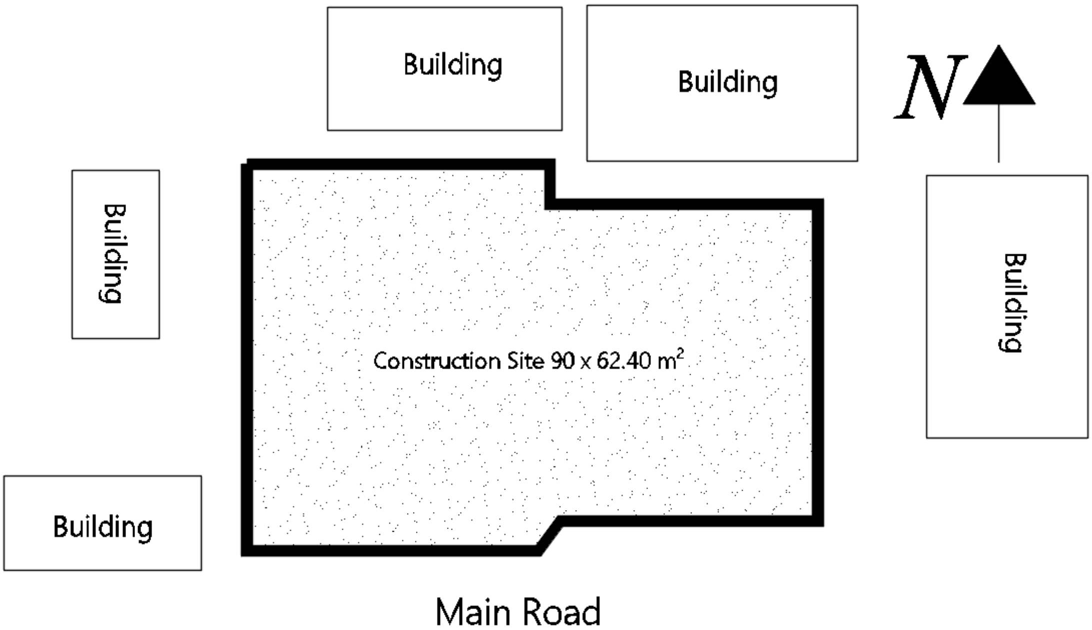

Figure 1: Site layout plan and dimensions, Luk, T. F. (2001).

The retaining structure was made up of a series of 1200 mm caisson bored piles at 1.5m center to center with one row of tieback anchors at 1.5m spacing. Bottom-up method was adopted for basement construction. The pressure grouted tiebacks were inclined 30 degrees with the horizontal. The design load was 690kN and lock-off load usually ranges between 75% to 100% of the anchor design load.

2.1 Soil conditions

According to the subsurface investigations, the soil profile of the investigation site as shown in figure 2. consists of four main soil layers. There is a 0.80 m to 2.00 m thick artificial fill layer. This layer is heterogeneous and its particles from fine to coarse-grained materials, the average SPT-N value of this layer is approximately 4 blows/ft. Underneath the fill layer there is A plastic silty clay layer with thickness varied from 4.0 m to 10.00 m with average SPT-N values ranging from (8 - 12) blows/ft. Below the plastic silty clay, there is a hard plastic silty clay layer with thickness varied from 10.00 m to 13.50 m along the investigation site, the average SPT-N values of this layer are varied from (20 - 27) blows/ft. After that there is a Highly Weathered Siltstone layer was founded with average SPT-N value approximately 69 blows/ft, and all soil borings are terminated within this layer. The groundwater table located at depth 1.5m below the ground surface. Because the groundwater flow rate was rather small, dewatering performed using sump pumps inside the construction site during excavation.

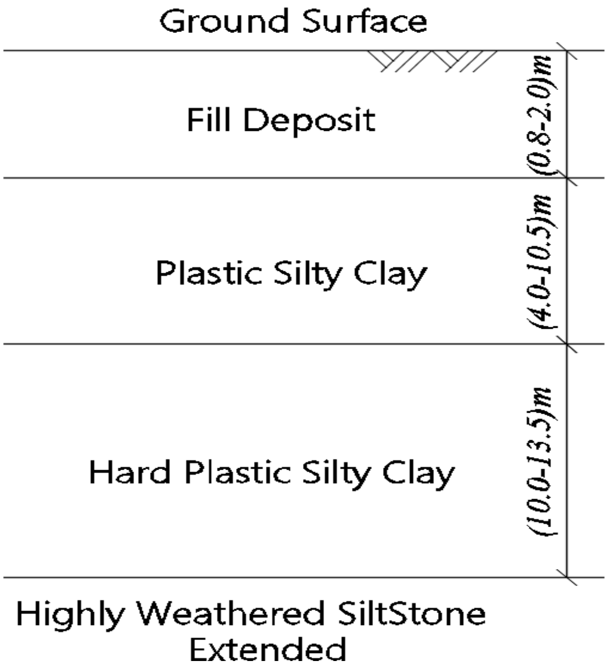

Figure 2: Soil Layers Profile, Luk, T. F. (2001).

2.2 Soil Parameters

Soil parameters used in the design of earth retaining system are presented in table 1, it collected from site investigation, laboratory tests and, field measurements.

Table 1: Soil Parameters Used in the Design of Earth Retaining System.

Soil description	**Layer thickness (m)**	**Density γ (kN/m^3)**	**Cohesion Cu (kN/m^2)**	**Friction Φ**	**Young's modulus E (kN/m2)**	**Poisson ratio**
Fill deposit	0.80	19	10	15	11080	0.30
Plastic silty clay	10.90	18	30	22	22160	0.30
Hard plastic silty clay (1)	4.00	19	40	26	55400	0.30
Hard plastic silty clay (2)	7.30	20	60	28	74790	0.30
Highly weathered rock	Extended	20	70	28	200000	0.30

2.3 Construction Procedure

The construction Procedure is schematically shown in figure 3. A reinforced caisson bored piles wall 1200 mm diameter, at 1.50 m center to center spacing and length of 17.50 m was used as a retaining structure along the perimeter the excavation site. The excavation pattern was performed in two stages.

In 1st excavation stage, the site was excavated to a depth of (-5.00 m), which located in the second layer of the soil profile “Plastic Silty Clay” As presented in figure 3, First row of tie back anchors was installed at a depth (-3.30) with length 39.0 m divide to 31.30 m free length and 7.50 m bonded length, and average horizontal spacing 1.50 m between them.
In 2nd excavation stage of the site, was excavated to a depth of (-12.00 m) the final excavation depth, that located in the third layer of the soil profile “Hard Plastic Silty Clay” As presented in figure 3.

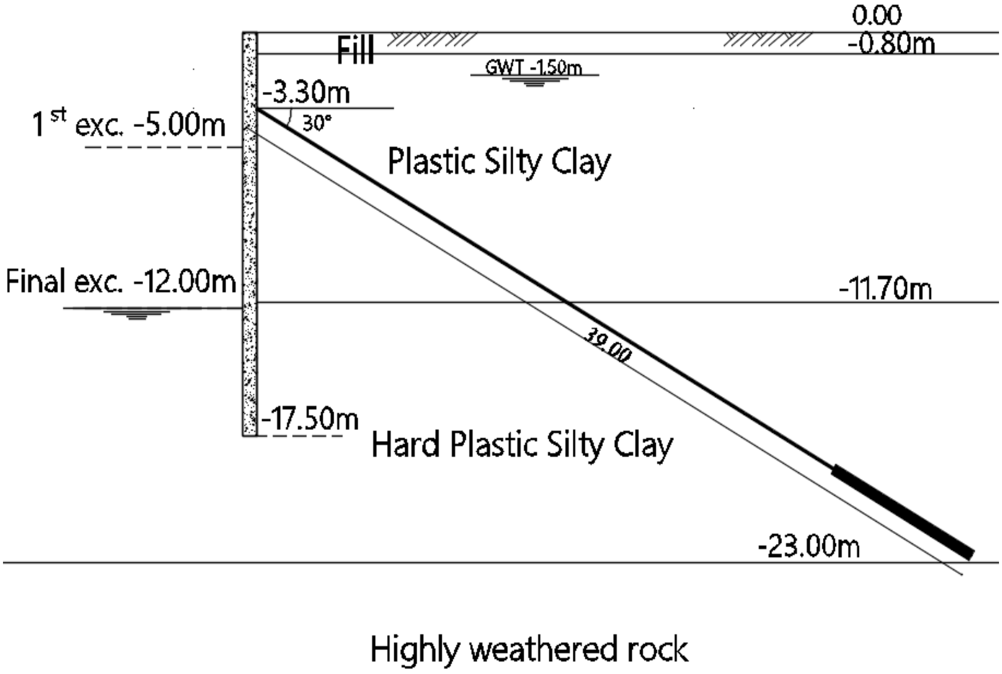

Figure 3: Typical cross section for selected case, 1 row of tie backs, excavation procedure and supporting system, Luk, T. F. (2001).

2.4 Instrumentation and Monitoring

In order to monitor horizontal displacements that may occur on the earth retaining wall during foundation excavation and to evaluate whether displacements are under the allowable limits or not, a total number of 8.00 inclinometers were installed around the retaining system. As shown in figure 4, the inclinometers were installed prior to foundation excavation and optical reflectors were placed on the cap beams to verify inclinometer readings. Also, for observing the vertical ground movement that may occur on the buildings adjacent to excavation during foundation excavation and to evaluate whether vertical movement is under the allowable limits or not, a total number of 23.00 settlement points were installed around the retaining system and beside the surrounding structures as shown in figure 4. In addition to measure the actual load on the ground anchor, a total number of 6.00 load cells were used as shown in figure 4, to control the excavation procedure and to evaluate whether the actual load on the ground anchors within the acceptable level or not, and not to exceed the design load. And for measuring the change in ground water a total number of 6.00 standpipe piezometer was installed around excavation zone.

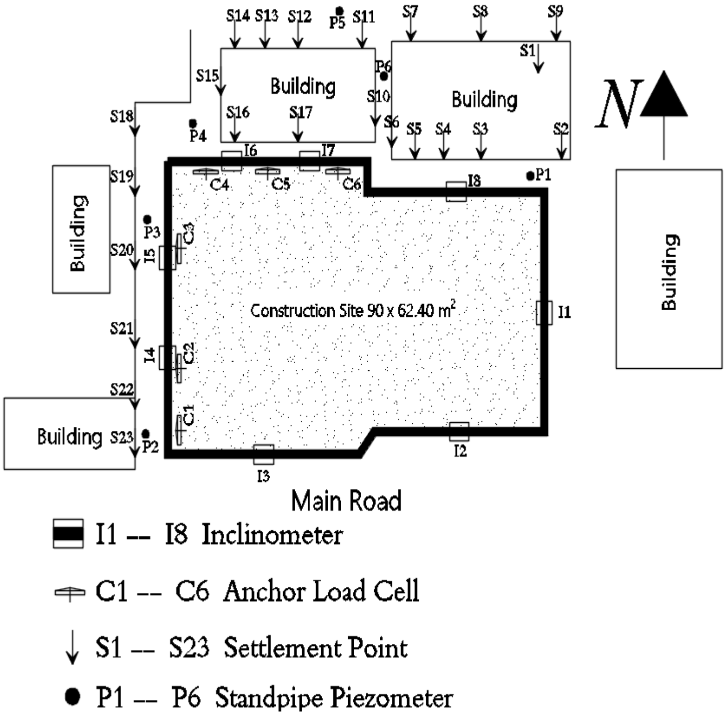

Figure 4: Site layout and monitoring plan, Luk, T. F. (2001).

2.5 Excavation Performance

The movements of the wall, the ground, and the adjacent buildings were monitored during construction using standard monitoring devices. Inclinometer readings, were collected and graphically represented in chart shown in figure 5 for the North side section, this figure describes relationship between field displacement (mm) for the final excavation stages (2nd stage -12.00 m excavation) and the excavated depth (m). figure 5 shows settlement points monitoring field readings for final excavation stage (2nd stage -12.00 m excavation), Presented as a Relationship between vertical ground movement (mm) and Horizontal distance from wall (m).

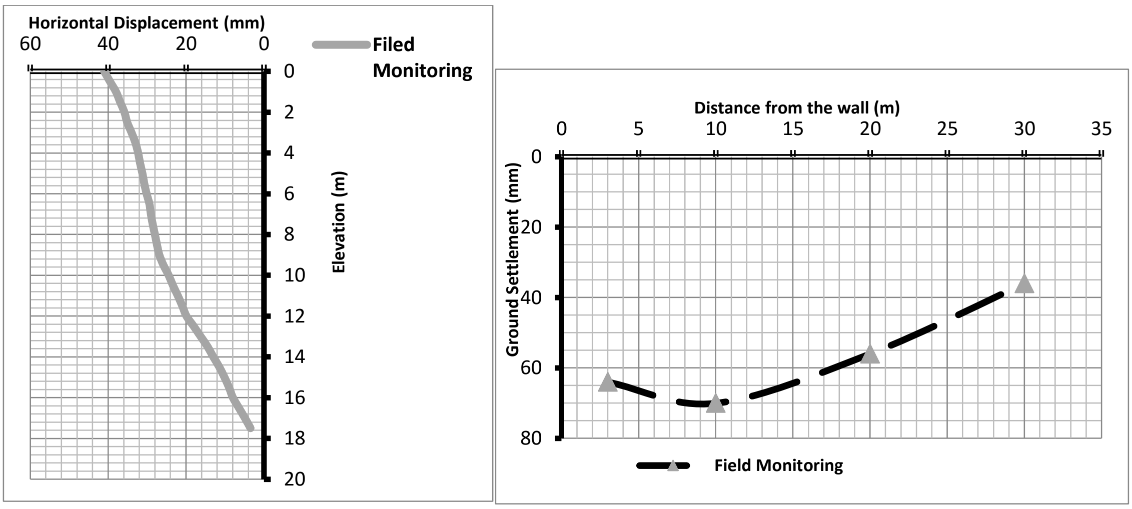

Figure 5: Monitoring Field Readings for final excavation stage (2nd stage 12.00 m excavation), Presented as a Relationship between Horizontal Displacement, Vertical Displacement and Excavated Depth, North Side Section, Luk, T. F. (2001).

3 Finite element modelling

Figure 6 shows the finite element mesh generated to model the case study. The different soil layers were modeled using the fifteen node triangular elements. This element integration type was (12-point gauss).

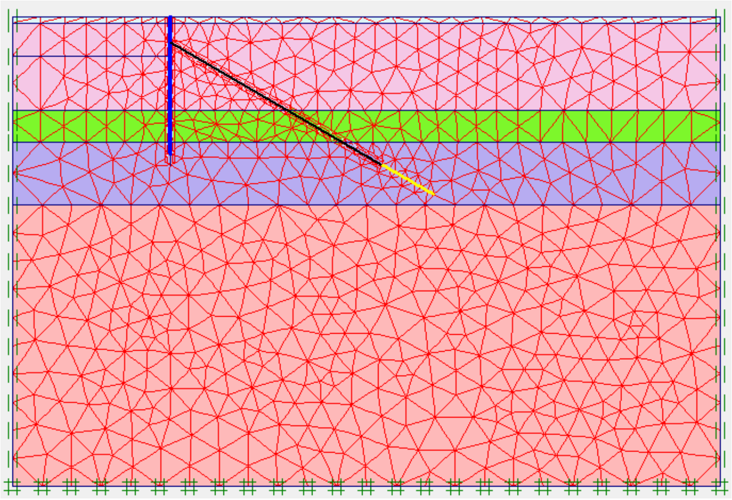

Figure 6: Plot of the mesh with significant nodes, Plaxis Output.

3.1 Phases of analyses

Four phases of analyses were performed to represent the stages of excavations procedure. These phases were performed with the same sequence of field case study and according to stages of construction which presented before. Two issues were investigated with these analyses. First, is soil deformation. Second, is displacement of diaphragm wall. Both these issues are the most imported results that influence soil support system response.

Construction Phases as presented in figure 3

Wall installation + Surcharge 65 kN/m2

1st Excavation stage -5.00 m from ground surface.

Install row of ground anchors.

Final Excavation -12.00m from ground surface.

3.2 Numerical modeling results

The deformed mesh representing the soil-retaining system deformations for the final excavation stage, is shown in figure 7, the figure shows that the maximum horizontal displacement occurred at the top of the wall. Figure 8 presents contour lines for the horizontal deformation distribution and figure 9 presents contour lines for the vertical deformation distribution.

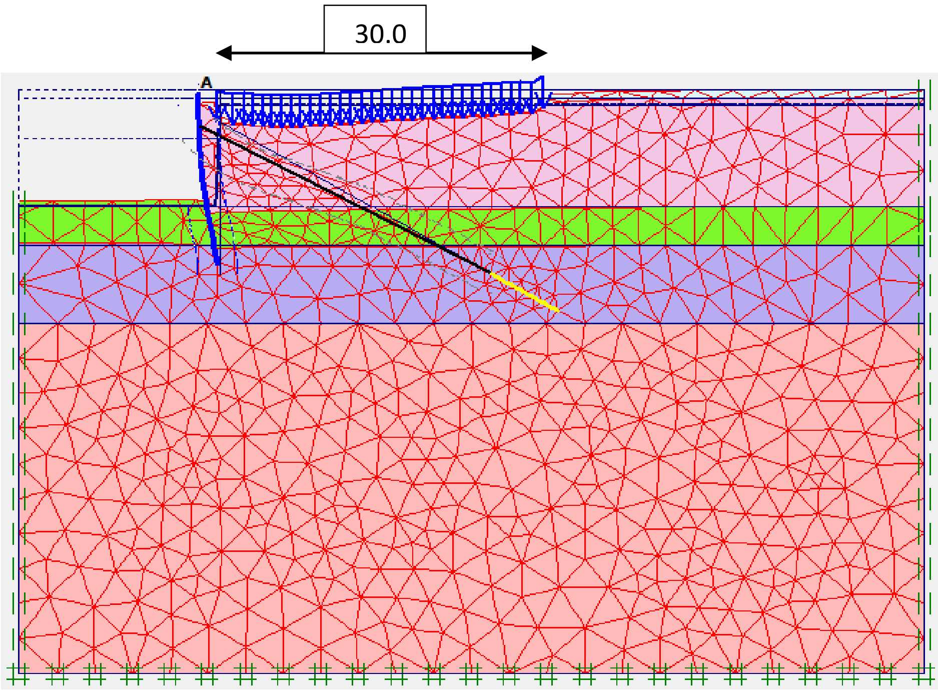

Figure 7: Deformed mesh for case study, (F.E. results, HSM).

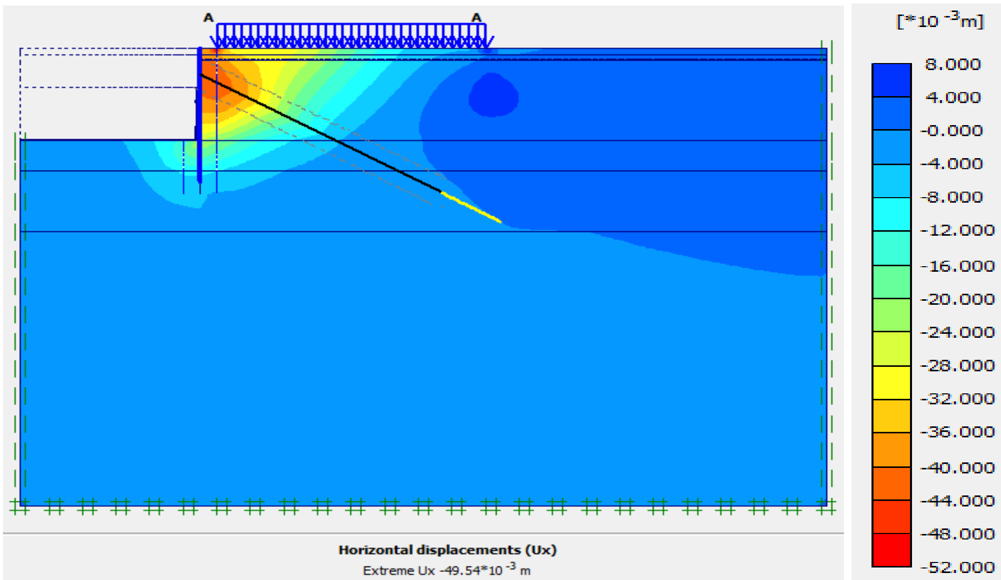

Figure 8: Contour lines for the horizontal deformation distribution, Plaxis results, HSM.

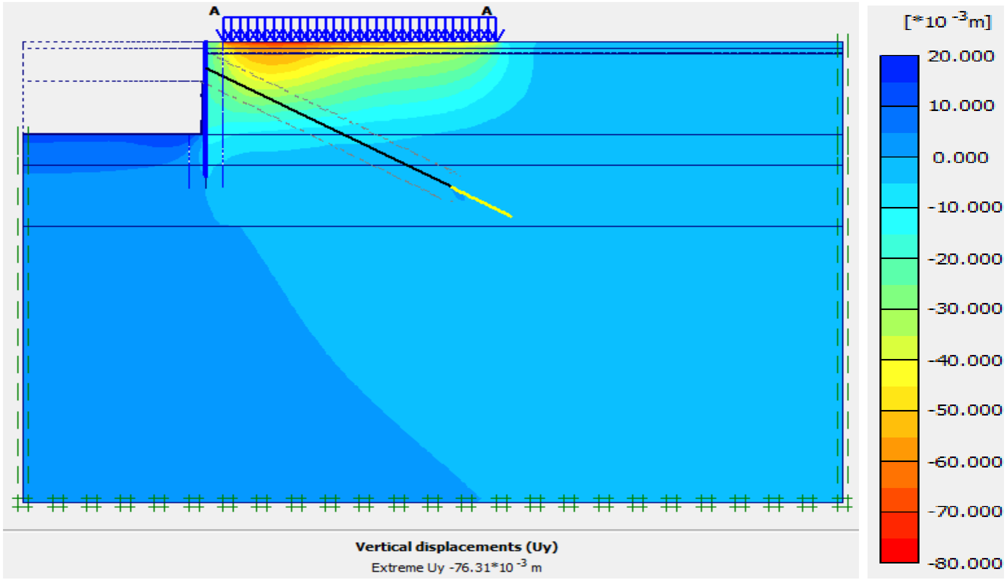

Figure 9: Contour lines for the vertical deformation distribution, Plaxis results, HSM.

3.3 Verification of Models Results

According to suggested criteria of using hardening soil model depended on soil parameters collected from field and lab tests of in-situ excavated soil. And, to verify this criterion, we had to compare its finite element model results with monitoring field data to be sure that this criterion could represents field soil support system action. Figure 10 shows horizontal displacement and vertical displacement finite element results compared with field monitoring measurements at several nodes for the final excavation stage according to case study. It is clear from the comparison that there's a good agreement between the analysis values from hardening soil model and monitored ones. Which prove that the suggested criteria, which depended on using hardening soil model based on soil stiffness collected from field and laboratory tests is a good constitutive model for modelling soil behavior.

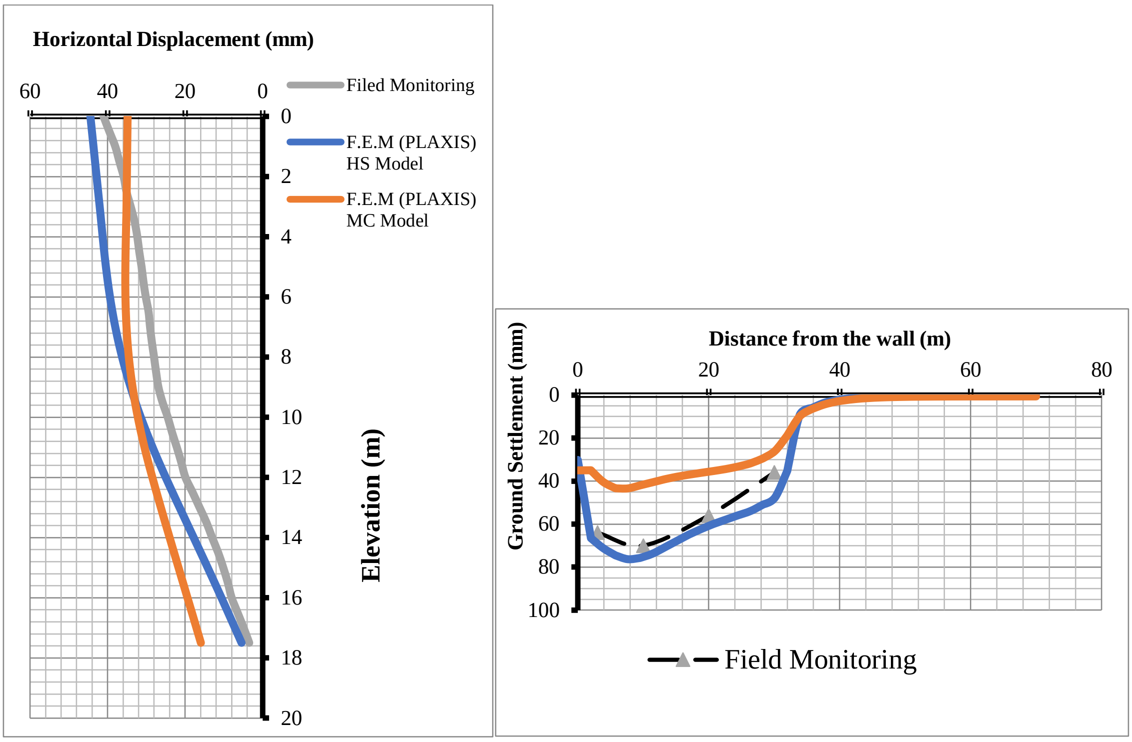

Figure 10: Horizontal Displacement and Vertical Displacement for Monitoring Readings and Finite Element Results (HS, MC).

4- Conclusions

The test result as well as the analysis comply generally with experimental investigation carried by other researchers (using other lightweight aggregate) as follow: 3

1- For the deep excavations in soil supported by reinforced concrete wall, the field measurements demonstrate that the maximum horizontal wall movement is generally within the range from (0.1%H to 0.3%H), where H is the excavation depth.

2- The maximum vertical ground movement generally within the range from (0.05%H to 0.18%H), which approximately equal half value of the horizontal wall movement, where H is the excavation depth.

3- The maximum computed vertical ground movement using MC model smaller or larger in a range of 10% to 40% with the monitored values.

4- The maximum computed vertical ground movement using HS model fits well with the observed value in field, but tending to be bigger which is reasonably accepted level with about 3% to 6%.

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