Study of big Movement of Temporary Sheet Pile in Elatf Power plant North of Egypt using Finite Element Analysis

Ahmed A. Mohamed

Geotechnical institute- TU Bergakademie Freiberg Gustav-Zeuner Str. 1 Freiberg, Germany
T: +4917684709683, E: ahmed.mohamed01@feng.bu.edu.eg

The failure of sheet pile walls used for temporary works may cause loss of project construction time and money. The failure can be due to lack of knowledge about the soil conditions or a requirement of three dimension analysis, as it may be important for some cases. In this paper a study was made for a big movement during temporary excavation works using sheet pile walls. A back analysis was made using three and two dimensional finite element analysis as well as simple manual calculation in order to find out the causes of the big movement. The results from the analysis was represented and compared with field data and observation. The results from the two dimensional analysis showed higher values than that from three dimensional analysis and both indicated lower results than that from field observation. However the wall movement values deduced from F.E. indicated possible failure. The performed simple manual calculation indicated also failure. The general conclusion was considered that the failure was due to design mistake.

Key words: finite element analysis, sheet pile, soil profile, 3D analysis, 2D analysis

Introduction

One of the techniques that used for temporary or permanent side support system is the sheet pile walling technique. The main factors that affect the design of the sheet pile walls are the soil stratification, excavation depth and water condition some other factors may affect such as the weather and available time of the project (as it affect the process of working in the project). Failure in sheet pile walls happened for several reasons such as design mistakes or construction mistakes.

Allersma et al. (2000) described a case history of collapsing temporary sheet pile wall in Japan that caused a death of two workers. They created centrifuge models to understand such a failure. They discovered that cracks are initiated from the anchoring sheet pile walls, which lead to unstable behavior of the retaining wall. Also they showed that buckling in the struts caused failure.

A database regarding deep excavations for retaining walls and ground movement was created by Long (2001). He showed the range of horizontal displacement of the support system for different soil conditions.

In this paper a case study of a big movement for temporary sheet pile wall that happened during excavation was discussed and back analysed. The case study is an intake structure which is part of hydropower planet project. The intake is located in one of the river Nile branches north of Egypt (at the Delta). The soil stratification began with natural Fill followed by soft to medium cohesive soil overlay a layer of dense to very dens sand. The water level changes according to the season as it become in its highest level during the summer.

The time of the projected was limited and the contractor had to perform the excavation in summer during the peak of the water level. This was not a preferred situation for the temporary works as the water pressure on the sheet pile wall is considered to be higher.

During excavation for the project a big movement accrued and the contractor stopped the excavation to avoid complete failure and the seepage of river water inside the project area which would cause loss of equipment and project time.

A back analysis was made for this problem to point out the reason of failure.

Case Study

The project is a hydropower plant project located beside one of the Nile River branches north of Egypt. The studied structure is an intake structure for the project, while sheet pile wall system was used for that intake structure as temporary and permanent elements. The intake structure dimension are about 30mx23 m. the final excavation level of the intake structure was designed to be at level (- 6.30) and the excavation was stopped at level (-4.30), while the finished level of the intake structure was at +5.00 m. The natural ground surface at the site is nearly +4.00m the bed level of the Nile river at this area are varied and can be taken as an average of (-1.50). The main purpose of this structure was to withdraw water from the Nile into the power Plant area.

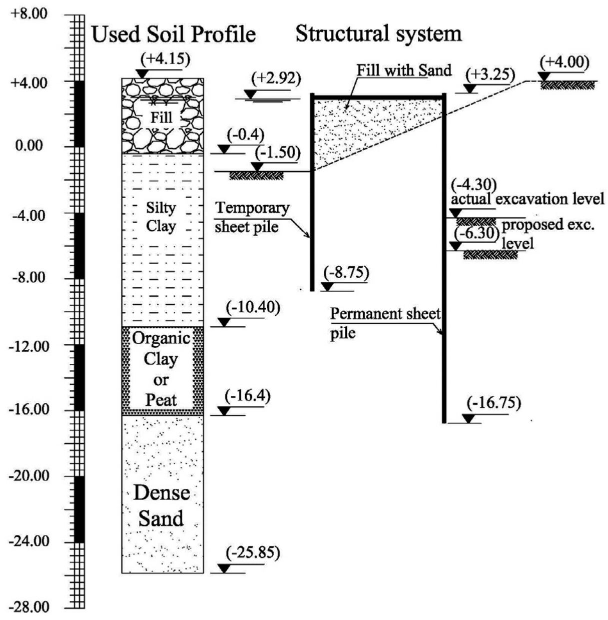


Fig. 1. Studied structure and soil profile

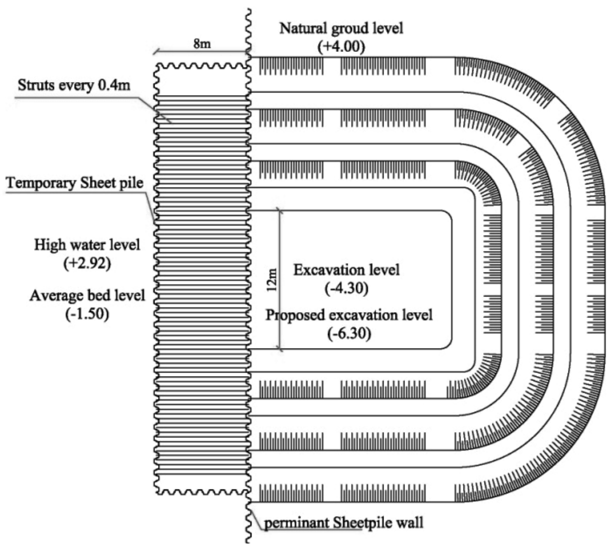


Fig. 2. Plan showing excavation inside the project area

In order to perform construction of the intake an open excavation works was required to a depth of nearly 10.3m and water should be retained to about 9.3m high.

The system was a double-row sheet pile with connecting steel ties every 0.4m. The sheet pile row at the water side was temporary while the inner served the intake structure was permanent. The upper level of both rows was about +3.25 m and the tip levels of the permanent and temporary sheet piles were -16.75 m and -8.75 m, respectively. The sheet pile was a Larsen L6 with a section modulus Z = 2250 cm3/m`.

Tab. 1. Material properties of modeled soil layer

Soil type	γ_b (kN/m^3)	Su/c' (kN/m^2)	E (kN/m^2)	ϕ degree
Fill	19	5	5000	26
Silty Caly	18	40	5000	0
Organic Clay	16	5	3500	15
Dense Sand	18	0	55000	40

The elevation of the structural system and the soil profile chosen in the analyses is shown in Figure 1. Plan of the excavation inside the project area is shown in Figure 2

The geotechnical data was deduced from two separate soil reports. The first soil report was including two boreholes and was preliminary while the second was including four boreholes for confirmation. The soil formation was quite identical in the two reports and it was Fill, silty Clay followed by organic Clay or peat and then a layer of dense Sand, but there was some differences in layers' thicknesses. Table 1 shows the soil properties used in the analyses while the soil formation shown in Figure 1.

Sheet Pile Walls Observed movement

During the high water level of the Nile River in the summer and after dewatering and excavating to a level (-4.30) inside the excavation area, a large horizontal movement happened in the temporary and permanent sheet pile walls. This large horizontal movement reached about 90 cm as a maximum movement towards the excavation side.

The movement was measured using survey points at several points in several locations along the wall length and only at the top of the wall. The shape of the movement can be easily observed as in photos (1) and (2). Photo 1, a virtual line drawn along the supposed original alignment of the temporary sheet pile (Nile side sheet pile) in the horizontal plan can clearly be seen. Photo 3 shows the simultaneous curvature of the permanent sheet pile (land side sheet pile).

After observing the wall movement backfilling was placed to level (-1.70) in order to avoid excessive movement and complete failure which may cause the penetration of water inside the site. This step was not simulated the simulation was only for the steps of construction that was from the start of dewatering until the excavation level that causes for the excessive lateral movement.

Back Analysis

In order to deeply understand how the failure accrued, a finite element analysis was used. Models were simulated the temporary structure taking into consideration the different construction stages.

Finite element analysis

Finite element analysis is a very important tool in the recent research and design in this paper the finite element analysis

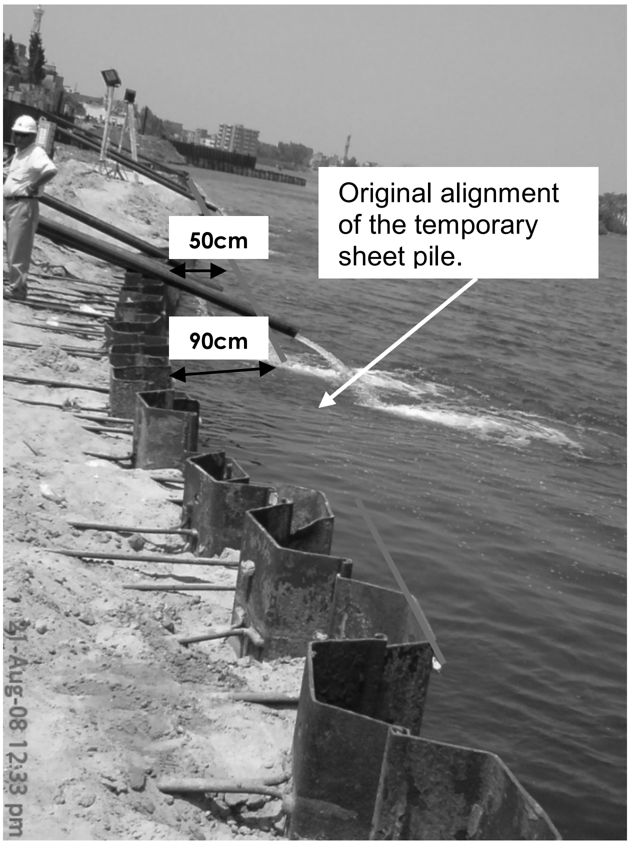


Photo. 1. Curvature of the temporary sheet pile in the horizontal plan

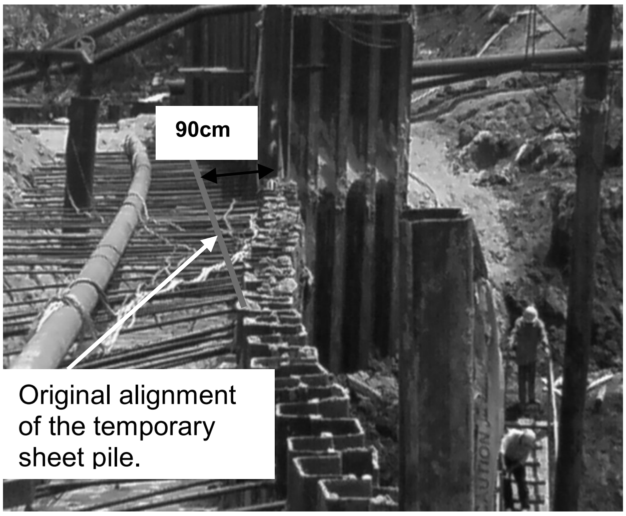
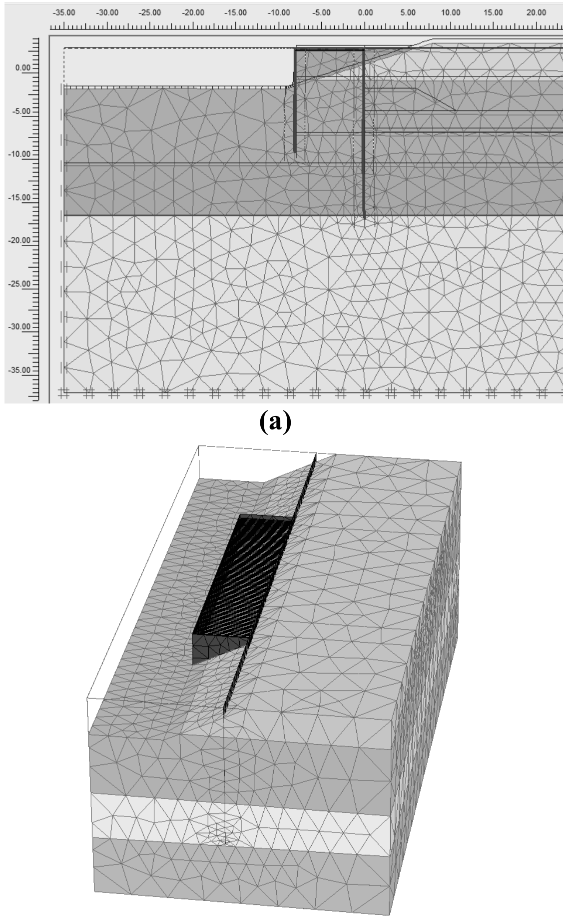


Photo. 2. Curvature of the permanent sheet pile in the horizontal plan



(b)

Fig. 3. Mesh model used in the finite element analysis (a) 2D model (b) 3D model

was conducted using PLAXIS® [4] which is a widely used finite element program for geotechnical engineering problems. Based on soil formation, the soil was modeled using the drained Mohr-Coulomb model (elastic perfectly-plastic behavior) for silty Clay, Organic Clay and fill layers while hardening soil model was used for the dense Sand layer.

The Mohr-Coulomb model was defined by five parameters; Young's modulus (E), Poisson's ratio (ν), friction angle (φ), cohesion (c) and dilatancy angle (ψ) while for the hardening soil models additional more parameters are required for the deformation modulus unloading reloading.

Figure 4 (a) and (b) illustrates the mesh model used by the 2-D and 3-D finite element analysis; the 15-node triangular element with 15 Gaussian points was used to model the soil layers.

The soil properties and water table were chosen according to the data shown in Figure 1 and Table 1.

The temporary and permanent sheet piles were modeled as a beam element with axial stiffness (EA) = 5.09×10^6 kN/m and bending stiffness (EI) = 8.11×10^4 kN/m^2/m for the 2D analysis while they was modeled as a plate element in the 3D analysis. The tie was modeled as a link element with spacing of 0.4m and axial stiffness (EA) = 1.60×10^5 kN. A fill layer was used to fill the space between the two sheet piles.

Construction phases

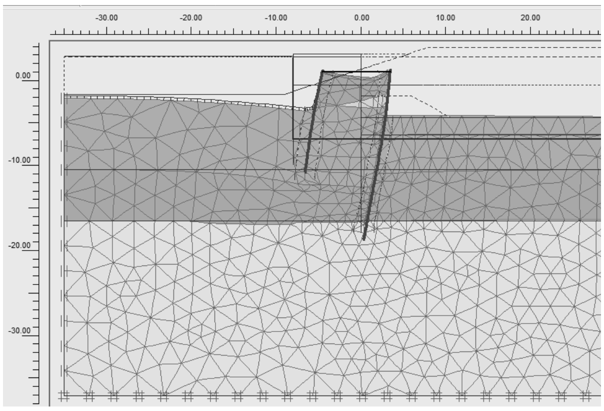
The simulation process of the sheet pile installation, dewatering and excavation should be in contrast with such processes in reality. The construction of the permanent and temporary sheet piles was the first to be simulated according to the natural process in the field. Filling between sheet piles and perform dewatering was the second stage. Finally as staged excavation was performed and was ended at level -4.3m from the ground level.

Results and output

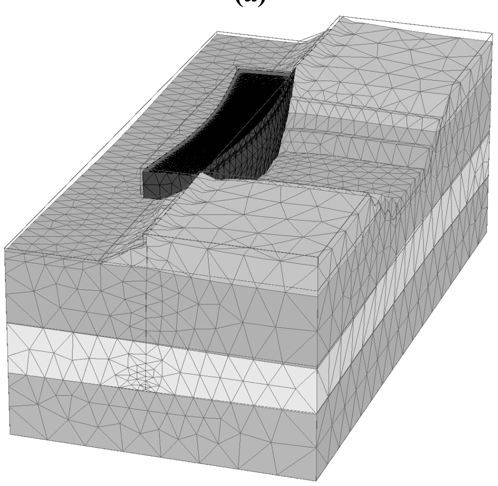
The deformed mish from both the 2-D analysis and 3-D analysis are presented in Figure 5, which shows obvious movement of the sheet pile walls towards the excavation side, the deformed mish from the 3-D analysis shows deformation at the middle of the wall more than that at the edges just like as was visually observed in the field.

The horizontal displacement for the temporary and permanent sheet piles from finite element analysis and field data are shown in Figure 6.

The values of the horizontal displacement from the field were measured at the top of the wall using survey points. The movement under the top was predicted by observation as shown in Figure 6.

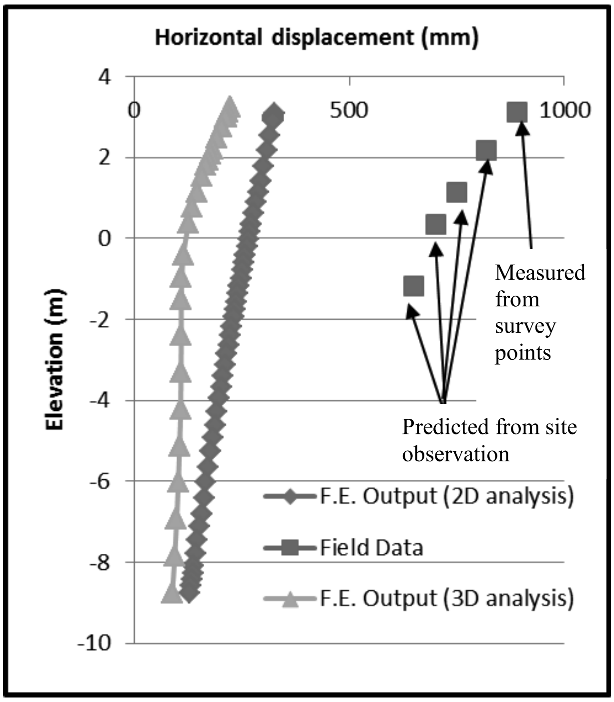


(a)

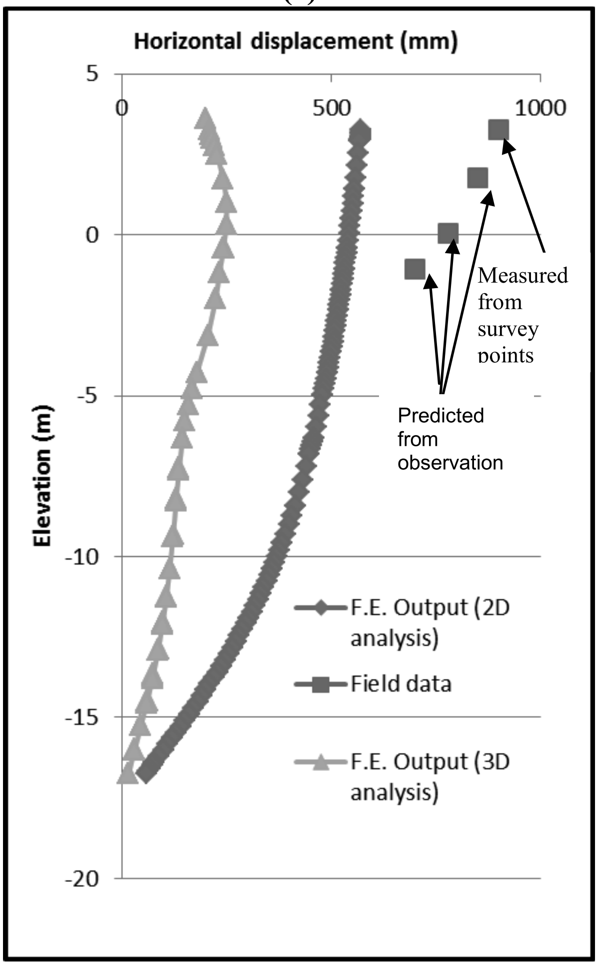


(b)

Fig. 4. Deformation of the sheet pile wall system from (a) 2-D (b) 3-D



(a)



(b)

Fig. 5. Horizontal displacement from F.E. analysis and field measurements of (a) temporary sheet pile (Nile side) (b) permanent sheet pile (land side)

Finite element output for 2D and 3D shows horizontal displacement at the top of the permanent sheet pile wall and at the final construction stage of about 350mm and 200mm respectively, while for the temporary wall it was about 325mm and 224mm respectively, the general trend of displacement shows a decrease with depth so the maximum horizontal displacement was at the top of the sheet pile walls. It was observed that the displacement toward excavation started after dewatering and increased with the advance of excavation, the horizontal displacement just after dewatering showed a value of about 20% of the final excavation stage values.

Horizontal displacements were also detected from the 3-D analysis at the long side (parallel to the Nile), it can be neglected as it was very small values and has very limited effect on the project area.

The stress distribution from the finite element analysis showed increase with depth while there was a concentration of tension cut-off points behind both permanent and temporary sheet pile walls. Failure points also appeared between the sheet pile walls at lower depths and it was highly concentrated at the tip of the walls which indicate the plastic deformation at these regions.

Discussion of the results

The deformation due to excavation in the field can be easily observed from Photos 1 and 2 while the deformation from the finite element analysis can be observed from the deformed mish shown in Figures 5 (a) and (b). The shape of the deformation from the 2-D and 3-D finite element analysis shows that both of the sheet piles moved in the same direction toward the excavation side. The displacement was noted with the dewatering and increased with the progressing in excavation stages.

It can be noticed from Figure 6 that the horizontal displacement from field observation are much bigger than that from finite element analysis and that from 2-D finite element analysis indicate higher values than that from 3-D finite element analysis.

In other hand the shape of the horizontal displacement from the 3-D analysis are much similar to the shape of the deformation in the field. The maximum horizontal displacement for the permanent sheet pile wall from the 3-D analysis was not at the top of the wall as the tie rod play a role in decreasing the movement at the top, while in the field some of these ties was yield and that was not simulated in the F.E. analysis.

The reason behind the high values of 2-D F.E. results and that from 3-D F.E. is due to the three dimensional property of the excavation that was not taken into consideration in the 2-D analysis. However the noticeable gab between the field horizontal movement and that from F.E. is considered due to the failure of the sheet pile that was happened in field. The finite element analysis from both 2-D and 3-D didn't indicate direct failure; but the big horizontal movement from the finite element analysis indicates a possible failure. According to Long (2001) wall considered to be safe if the value of horizontal displacement didn't exceeds 3.2%H and that is a special case for retaining a material of height soft thickness material (>0.6H) which is in these case study. The values of horizontal displacement from 2D analysis are about 7.57% and from 3D are about 3.3% as both values are greater than 3.2% which should mean a possible failure and in reality the failure is almost a successive failure. In case of failure the field horizontal displacement is expected to be larger than that calculated by any type of calculation.

It is now clear that the case of failure was due to a mistake in design. The designer didn't analyze the data and notice the relatively high horizontal displacement value. The designer used only 2-D analysis; however the 3-D analysis would not be the best solution to indicate the failure better than 2-D analysis.

The careful analysis of the results from F.E. analysis is considered to be highly important. It is also recommended to use the engineering judgment as well as the analysis to understand different engineering problems. The engineer should not only really on the modern analysis with F.E. or finite difference but a quick manual calculation that depend on the first principals could provide an indication for the performance and safety of studied structure. The following section shows how a quick manual calculation can be a good indication for the maintained case study.

Manual analysis

The use of F.E. analysis is a modern method to estimate the lateral displacement and check the stability of the problem. The manual methods were used from centuries to check the stability of retaining walls such as Rankine's earth pressure theory. It can be applied for cohesive and cohesive less soil but it can't be applied for the adhesion or friction between soil and retaining wall (Ou, 2006).

Manual analysis was made in order to find the value of the total active earth pressure and compared it with that of passive earth pressure. The earth pressure diagram is shown in the following Figure 7.

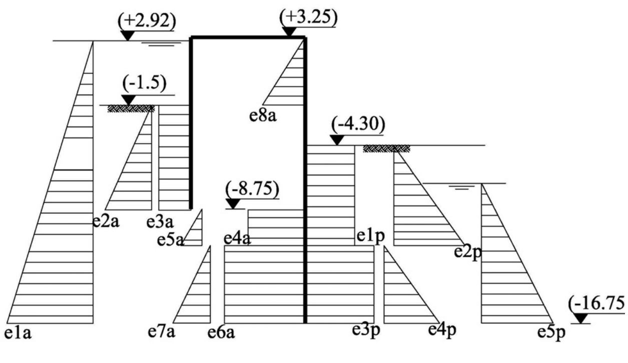


Fig. 6. Earth pressure diagram

The total active earth pressure was calculated as well as the total passive earth pressure and the results shows that the active earth pressure equal 2080 kN while the total passive earth pressure equal 1970 kN. It can be noticed that the active earth pressure is bigger than the passive earth pressure which indicate instability.

Conclusions

In this paper a case study was back analysesd with 2D and 3D analysis also a manual analysis was provided. The three types of analysis indicated failure of the system. This means that the failure was due to design mistake. The project was a power plant and the time was limited (one day delay costs 50,000 Egyptian pound ≈ 9000 Euro) and this design mistake caused a delay in the project which costs the contractor a lot more money.

It was obvious that the system was all embedded in a soft soil and it should be penetrated a sufficient distance in the dense sand layer.

The displacement was noticed at the top of the permanent (land side wall) and this indicates that the temporary (Nile side) wall was not effectively working to prevent the front wall from moving.

The results of the 2D analysis give higher values than that from 3D analysis. That can be due to the 3D characteristic of the system. The shape of the displacement deduced from the 3D analysis was much similar to that in the field.

The engineer should carefully deal with the results from the finite element analysis, also quick and approximate manual solution is important for preventing any mistakes that appears from the finite element solution.

It is also worth to maintain that the 3D analysis not always required as in this case the 2D provide a conservative displacement values more than the 3D analysis.

References

[1] Allersma, H.G.B. & Toyosawa. “Simulation failure mechanism of anchored sheet pile walls in a small centrifuge”. Geotechnical aspects of underground construction in soft ground, Tokyo, Japan, (2000): 475-480.

[2] Long M. (2001). Database for retaining wall and ground movements due to deep excavations. Journal of Geotechnical Geoenvironmental Eng 127(3), pp. 203–24.

[3] A&A Engineers and consults (2008). El-Atf Power station 750 mw Combined cycle project: intake cofferdam sheet piles, Design of permanent and temporary sheet piles.

[4] Hamza Associates (2006). El-Atf power station 750 mw combined cycle project, Elatf, Egypt, Geotechnical Report.

[5] PLAXIS B.V., PLAXIS Version 8 Finite Element Code for Soil and Rock Analyses Tutorial Manul, 2002.

[6] Ou, Chang-Yu (2006). Deep excavation. BALKEMA – Proceedings and Monographs in engineering, water and Earth Sciences.