Deep supported excavation for the underground parking of the Hellenic Parliament: measured vs. predicted behavior

Excavation profonde soutenue pour le stationnement souterrain du Parlement Hellénique:comparaison des prédictions théoriques avec les mesures *in-situ*

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ABSTRACT: Results are presented of borehole inclinometer and electronic tiltmeter measurements concerning the behavior of the wearthered schist surrounding the deep soil excavation for the construction of the underground parking structure of the Hellenic Parliament as well as the behavior of the structural components of the Parliament building. The results indicate that the ground displacements were very small (of the order of a few millimeters) whereas the tilt of the floors and walls of the building did not exceed the value of 1/500. The excavation was modeled by the Finite Element Method and the agreement between the observed and predicted displacements was remarkable.

RÉSUMÉ: On présente les résultats de mesures d'inclinomètre et de clinomètre concernant le comportement du schiste altéré entourant l'excavation profonde efectué pour la construction du stationnement souterrain du Parlement Hellénique, ainsi que le comportment des éléments structureaux du Parlement. Les résultats indiquent que les déplacements sont restés très petits (de l'ordre de quelques millimètres) tandis que la pente des planchers et des murs du batiment n'a pas excédé la valeur de 1/500. Le processus de l'excavation a été simulé par la méthode des éléments finis et l'accord entre les déplacements observés et prévus était remarquable.

1 INTRODUCTION

Construction associated with important infrastructure projects, such as subways and underground garages, is confronted with the problem of conducting deep soil excavation in urban environment (Gould et al., 1992). The main concern in such construction activities is the stability of soil masses surrounding the excavation and the displacement of the foundations of nearby structures (Hashash and Whittle, 1996). When these displacements exceed the allowable values, structural damages may occur which in most cases, are followed by litigations resulting in undesirable budget overruns and construction schedule delays (Boone, 1996).

The problems associated with deep supported excavations (i.e. stability of soil masses and displacement of nearby structures) are at present studied and analyzed either by the finite element (Chang-Yu at al., 1996) or the finite difference (Loukakis and Gazetas, 1997) methods. Important role in the development of rational methods of design of deep supported excavations plays the utilization of results of measurements conducted by appropriate instrumentation (Koutsoftas, 2000) during the various stages of construction of deep supported excavations (Whitman et al., 1991). Results of such measurements are available in the technical literature for different types of soil support systems (Whittle et al., 1993).

In this study results are presented of measurements obtained during the construction of a deep supported excavation under the courtyard of the Hellenic Parliament. The results include borehole inclinometer and building floor/wall tiltmeter measurements. The results of a finite element analysis of the excavation are also included in the paper as well as a comparison between observed and predicted behavior.

2 PROJECT DATA

The need for a drastic increase of the available parking spaces in the Hellenic Parliament building has recently led to the decision of constructing an underground parking structure underneath the courtyard surrounding the building.

The three-story building of the Hellenic Parliament (approximately square in plan) is located at the center of Athens and has been built with stone masonry about 150 years ago, with several subsequent additions and modifications. It is surrounded by a continuous court having a width of 15m which was, until recently, being used to a large extend as a parking space (Fig. 1).

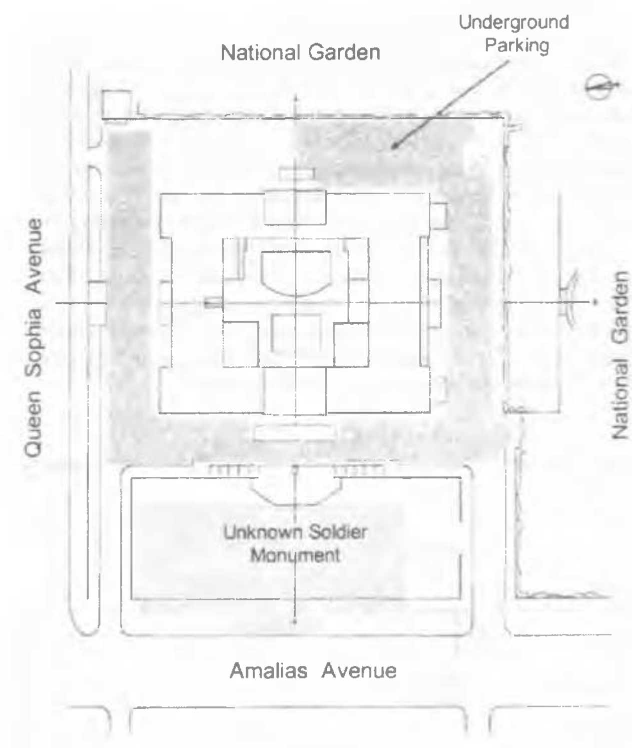

Figure 1. Plan view of the Hellenic Parliament building

2.1 *Construction details*

The new parking structure was planned as an underground five-story reinforced concrete structure founded at a depth of 17.5m from ground surface and providing 700 parking spaces (Papagiannis, 1997). The structure was constructed by utilizing the "top-down" method in order to avoid any disturbance of the court area and any major interruption of the building operations (Papalopoulou, 1998). The construction started in January 1997 and the project was completed by the end of December 1999.

The deep soil excavations associated with the construction of the underground structure were supported by bored reinforced concrete piles with diameter varying from 0.80m to 1.00m and length equal to 20m. The piles were installed at axial distances varying from 1.50m to 1.80m and were anchored by 7 to 9 rows of prestressed tiebacks. Excavation of soil started after the construction of the reinforced concrete slab that formed the roof of the first underground story and progressed down to the foundation level of the structure (Fig. 2).

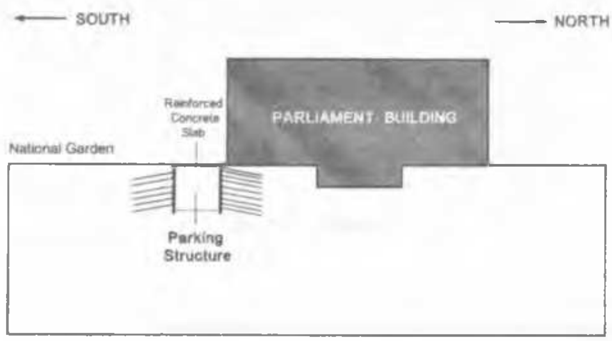

Figure 2. Typical cross section of supported excavation (south side of Parliament building)

2.2 *Soil conditions*

The geotechnical investigation conducted at the construction site included the drilling of eight (8) boreholes with sampling to a depth of about 30m. According to this investigation the soil stratigraphy at the site consists of a surficial layer (approximately 5m thick) of a cohesive fill material underlain by shale formations (Athens shale) of varying stiffness up to a significant depth from ground surface. (Fig. 3). The geotechnical data also indicated that the ground water level at the site ranges, normally, from 4.5m to 22.0m from the ground surface. The ground water table was not found, however (within the depth of influence of the proposed construction) during the works of the present project because of the continuous pumping due to the construction of Athens METRO.

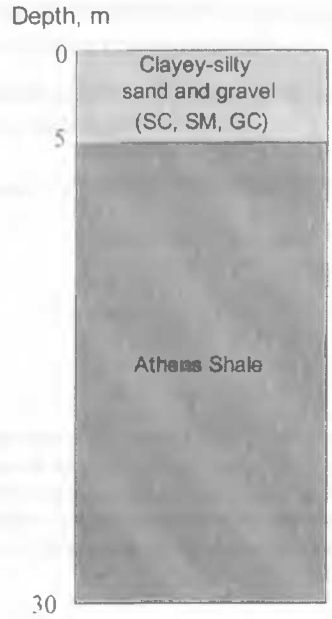

Figure 3. Soil profile at the site of excavation

3 FIELD MONITORING PROGRAM

The field monitoring program encompassed periodic measurements of 1) four inclinometer casings (I-1, I-2, I-3 and I-4) installed in vertical boreholes drilled to a depth of 21m, 28m, 26m and 29m, respectively, from the ground surface at small distances behind the pilewall supporting the excavation and 2) of thirteen electronic tiltmeters attached to ground floors (T-2, T-4, T-6, T-8, T-10) and walls of the Parliament building (T-1, T-3, T-5, T-7, T-9) as well to the Unknown Soldier Monument (T-11, T-12, T-13). Figure 4 shows the locations of the four (4) inclinometer boreholes and the thirteen (13) horizontal and vertical tilt plates. Inclinometer and tiltmeter readings were taken after the completion of each stage of soil excavation and after the prestressing of pile anchors.

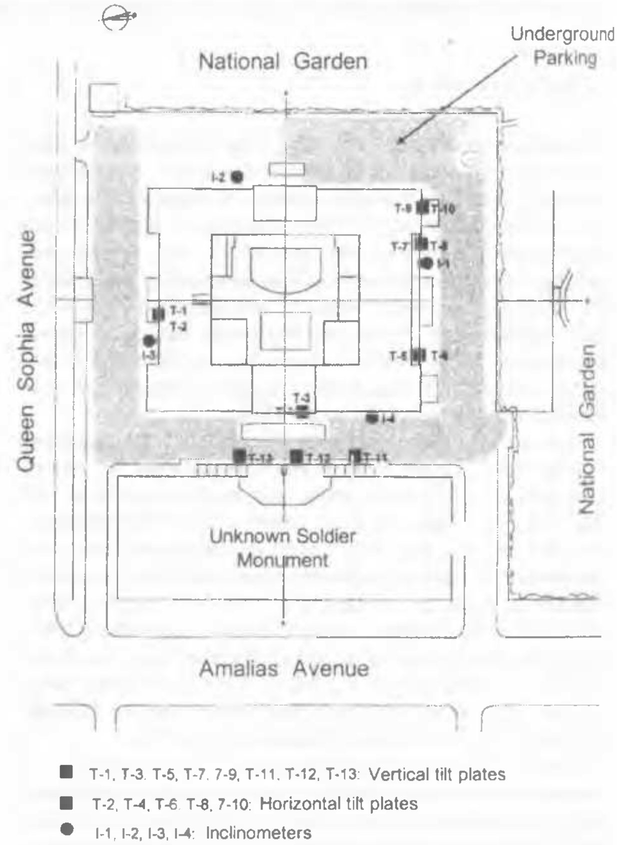

Figure 4. Plan view of the Hellenic Parliament building with the location of the inclinometers and the electronic tiltmeters

4 RESULTS OF MEASUREMENTS

4.1 *Inclinometers*

Out of the four inclinometer casings installed before the start of excavations only two, I-4 and I-2, remained operational through the completion of the excavation. Inclinometer casings I-1 and I-3 were damaged during installation of the tie-

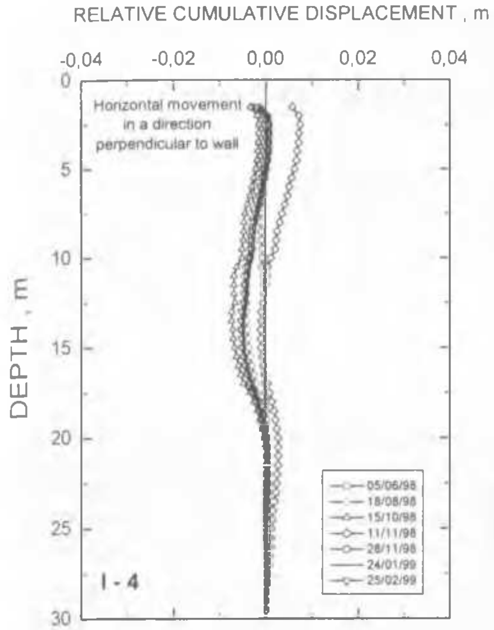

Figure 5. Results of inclinometer measurements at point I-4

backs and only limited sets of data are available at their locations.

The results of measurements indicated that the ground masses moved, in general, toward the excavation. Horizontal and vertical displacement values remained, however, very small. The diagram of Figure 5 presents the results of inclinometer I-4 measurements indicating a maximum horizontal displacement at the top of soil support system equal to 5mm.

4.2 *Tiltmeters*

The results of tiltmeter measurements indicated that, in general, the floors and walls of the building tilted toward the excavation. The tilt angle of floors and of the walls running parallel to the pilewall was approximately the same. The amount of rotation remained very small and the maximum value of angular distortion, β, was lower than 1/500. The diagrams of Figure 6 depict the variation of tilt angle (and of the corresponding angular distortion value) as a function of time for the tilt plates T-1 and T-2. Periodic visual inspections of the floors and walls of the Parliament building showed no signs of cracking or other disturbance as a result of the excavation activities.

5 FINITE ELEMENT ANALYSES

The present study, in addition to field measurements, included a plane strain finite element analysis of the behavior of the supported excavations by using a commercially available Finite Element code (Z_SOIL). The installation of the soil retaining system and the successive stages of excavation and anchor prestressing were modelled in this code by assuming non-linear soil behavior and the Mohr-Coulomb failure criterion. Figure 7 shows the typical soil profile used in the analyses. Values for the mechanical parameters of strength and deformation of the soils were selected based on the results of the geotechnical investigation and empirical correlations. The major part of the analyses were conducted by using the following set of parameters: φ=27°, c=20 kPa and E=200 MPa. Figure 8 presents the finite element mesh (initial and deformed shape) used for the analyses of soil excavation of North side of the Hellenic Parliament building.

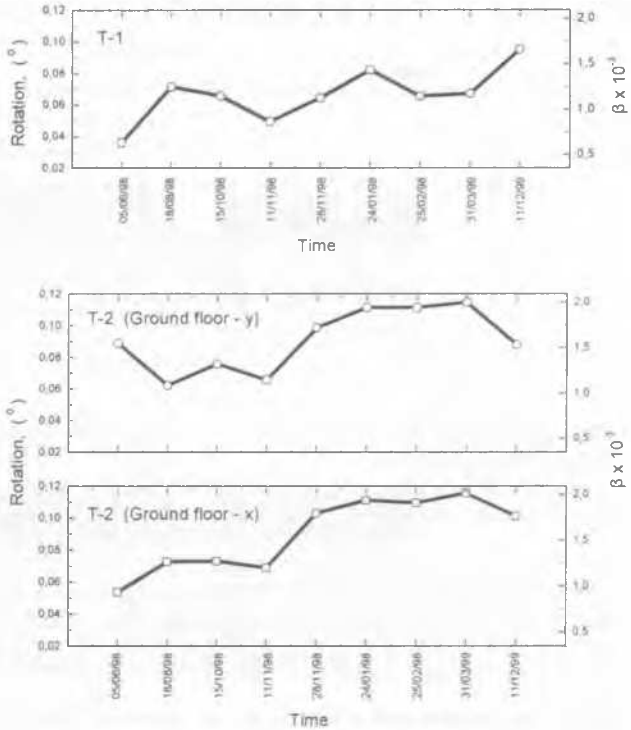

Figure 6. Results of tiltmeters measurements at tilt plates T-1 and T-2

Generally, the values of the predicted horizontal displacement of soil masses around the excavation site and the vertical displacement of the foundation of the Parliament building are low (up to 5mm and 2mm, respectively).

Finally, the results of analyses allowed the evaluation of horizontal soil movements as a function of depth at the location of inclinometer as well as the rotation of the horizontal and vertical elements of the building during and after completion of soil excavation. Figure 9 shows the remarkable agreement between the observed and predicted horizontal displacements at site I-4.

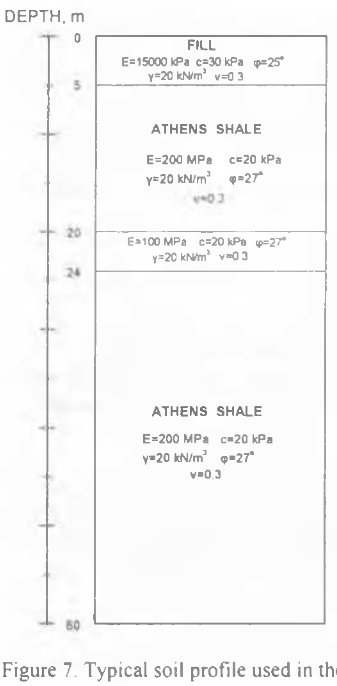

Figure 7. Typical soil profile used in the analyses

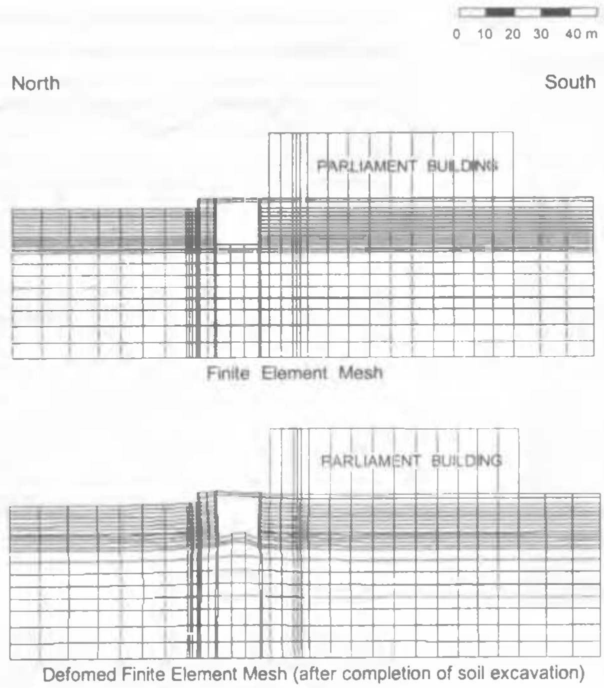

Figure 8. Finite element mesh used for the stability analysis of excavation at the North side of the Hellenic Parliament

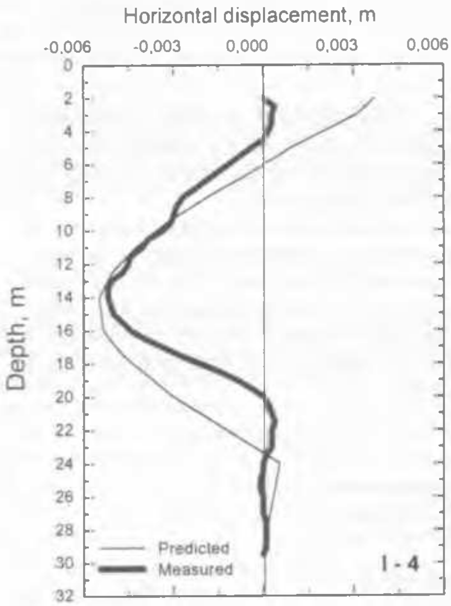

Figure 9. Comparison between measured and predicted horizontal displacements at I-4

6 CONCLUSIONS

1. The results of borehole inclinometer and tiltmeter measurements obtained during the deep supported excavation for the construction of underground garage of Hellenic Parliament indicate very small ground movement and verify the effectiveness of the soil support system.
2. The behavior of the deep supported excavation was predicted with satisfactory accuracy by utilizing a commercially available finite element code with rationally selected values of mechanical parameters of soil materials.

ACKNOWLEDGEMENT

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