Case Studies of Complicate Urban Excavation from Design to Construction

Études de cas d’excavations complexes en site urbain: de la conception à la construction

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ABSTRACT: Various types of retaining walls, e.g. H-Pile with Timber, C.I.P (cast in place pile) and subsurface continuous walls, are domestically used for excavation sites in Korea depending on the site conditions, architectural structure and geotechncial conditions. Ground Anchor, strut and permanent slab are used as support methods. The wall displacements and axial forces of the struts are variable depending on the excavation depth, groundwater level and construction methods, etc. In this study, case studies are performed for the excavation sites, where the modified slab methods, e.g S.P.S, and S.T.D are used and the ground anchors as temporary supports. The wall displacements and the axial forces predicted at the design stage and monitored in the actual excavation stage are analyzed. The advantage of construction time using the permanent slab method is discussed.

RÉSUMÉ : Différents types de murs de soutènement, par exemple pieu en H avec du bois, CIP (Pieu en béton coulé en place) et des parois continues ancrées dans le sol, sont à usage domestique pour les sites d’excavation en Corée suivant les conditions du site, la structure architecturale et les conditions géotechniques. Ancrage au sol, entretoise et dalle fixe sont utilisés comme méthodes d’étaiement. Les déplacements du mur et les forces axiales des entretoises sont variables en fonction de la profondeur de l'excavation, du niveau des eaux souterraines et des méthodes de construction, etc. Dans cet article, des études de cas sont réalisées pour les sites d’excavation, où les méthodes de dalle modifiées (SPS, MST) sont utilisées et aussi les ancrages au sol comme des appuis temporaires. Les déplacements du mur et les forces axiales prévus au stade de la conception sont examinés et analysés dans la phase réelle d'excavation. L'avantage de la durée de construction en utilisant la méthode de dalle permanente est discuté dans cet article.

KEYWORDS: S.P.S, S.T.D, C.I.P, Ground Anchor, Strut, Slab, Displacement, Axial force, Construction time

MOTS-CLÉS : S.P.S, S.T.D, C.I.P, Ancrage au sol, entretoise, dalle, déplacement, force axiale, durée de construction

1 INTRODUCTION

Recent urban building construction has trends of deep excavation and the methods of excavation are diversified. In addition, various types of structures, e.g. the subway tunnels and utility lines and pre-existing buildings are located around the excavation sites. Therefore, when the excavation is done in the metropolitan area, the excavation plans must be made considering the safety, constructability and cost effectiveness synthetically.

In this paper, the retaining wall displacements and the axial forces of the excavation sites which are constructed using the various supports, e.g. C.I.P. with ground anchor, and the permanent slab methods, i.e. S.P.S and S.T.D., are monitored and analyzed using the related case histories.

2 EXCAVATION METHODS

In the case studies, two new excavation methods, i.e. S.P.S and S.T.D, are used and the concepts of each methods are introduced. In the S.P.S(Strut as Permanent system) method, the subsurface steel frame and beams are designed strong enough to endure the temporary and permanent external pressures. They are used as temporary retaining walls while the excavation is going on. They can also be used as the walls of main structures without dismantling of strut after the excavation is finished. Fig. 1 shows the conceptual diagram and the field example.

S.T.D (Strut Top Down) method can use the struts which increase the resistance to horizontal pressures. It can also use various types of basement slabs such as beam & girder as well as one or two way wide beams (Sho et al. 2004). Fig. 2 shows the conceptual view of S.T.D construction and the field example.

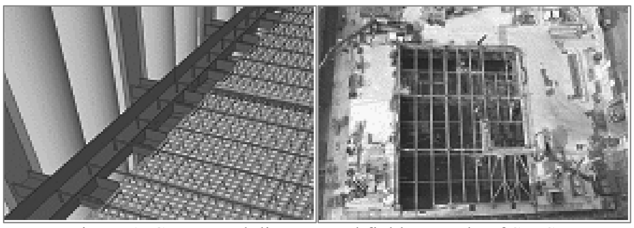


Figure 1. Conceptual diagram and field example of S.P.S

Figure 2. Conceptual diagram and field example of S.T.D

3 SITE CONDITIONS

3.1 Site 1: S.P.S and ground anchor on C.I.P wall

Site 1 is the office facility of 7th floor on the ground and 3rd floor in the basement. The building is located at Chung Ju in the central region of Korea (Saegil E&C, 2011a). The excavation depth is in the range of of GL.-14.0m~GL.-20.0m. High apartments with deep parking lot are in the southern part of the site. A building with basement is located 20m apart from the site in the west. Roads of 35m and 23m are located at the north and the east part of the site.

Two types of retaining walls are used, i.e. rigid C.I.P wall and H-Pile & Timber. Ground anchor is used as the support of both walls. Considering the tall buildings with basements, S.P.S method is used at the southern part (Fig. 3).

The soil profile of the excavated site is composed of buried soil layer, alluvial layer, weathered soil and rock layers from the surface. Most of the excavated parts are composed of soils (Fig.4). Two sections, i.e. S.P.S and ground anchor, are selected as the analysis section in this paper (Fig. 5).

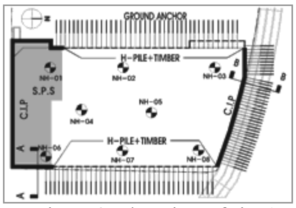


Figure 3. Plan view of site 1

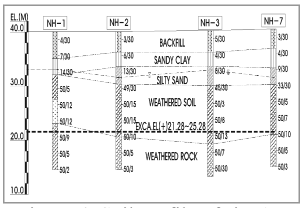
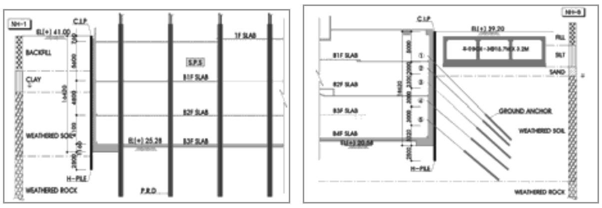


Figure 4. Soil profile of site 1



a) Sec. A-A' (C.I.P & S.P.S) b) Sec. B-B' (C.I.P & Anchor)
Figure 5. Section view of Site 1

3.2 Site 2: S.T.D and C.I.P

Site 2 is the office facility of 23rd floor on the ground and 7th floor in the basement. The building is located at Sang Am dong, Seoul, Korea (Saegil E&C, 2011b). The excavation depth is in the range of GL.-25.0m~GL.-31.0m. A building of 20th floor on the ground and 5th floor in the basements is located to the north of the site. In the east, the road of 30m wide and the building with 21st floor on the ground and 7th floor in the basements is located. The roads of 30m wide are located to the south and the west directions.

The retaining wall is composed of C.I.P in the soil layer and H-Pile & shotcrete in the rock layer. S.T.D method is used as the support of the excavation site (Fig. 6).

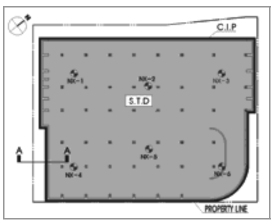


Figure 6. Plan view of site 2

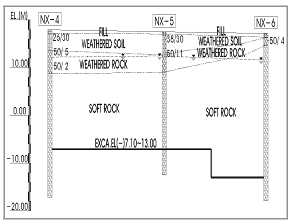


Figure 7. Soil profile of site 2

The soil profile of the excavated site is composed of buried soil layer, weathered soil and rock layers, and soft rock layer from the surface. The geotechnical investigation shows that the soft rock appears at the shallow depth of GL.-2.4m and GL.-9.2m (Fig. 7).

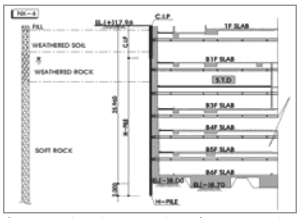


Figure 8. S.T.D Section A-A'

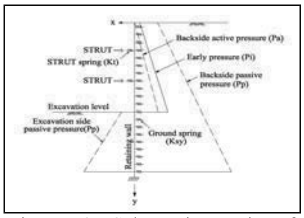


Figure 9. Schematic section for Analysis Program

The sections of retaining walls, i.e. C.I.P in the soil layer and H-Pile & shotcrete in the rock layer are selected for analysis. S.T.D method is used as the supports of the excavated site (Fig. 8).

4 ANALYSIS PROGRAM FOR DESIGN

The program used in the design stage is SUNEX(Step UNder ground EXcavation), which is a stress-strain analysis program commonly used for the design of the deep excavation site in Korea (Geogroup Eng., 2010). This program calculates earth pressure on the braced earth retaining system, horizontal displacement, shear force and bending moment of vertical wall and axial force of supports and tieback anchors for step by step excavation.

The program adopts elasto-plastic behavior of soil to calculate earth pressure on the retaining wall. Calculation model includes elastic beam for vertical wall (elastic-plastic beam optional), elastic spring for strut and tieback anchor, elasto-plastic spring for active and passive soil (Fig. 9).

5 COMPARISON OF DESIGN AND MONITORED VALUES

Both the wall displacement and the axial stress of the struts obtained either from the design stage using the SUNEX or from the field monitoring using the field installed instruments. In this section, The two values are compared by separating to the mid and the final stage of the excavation.

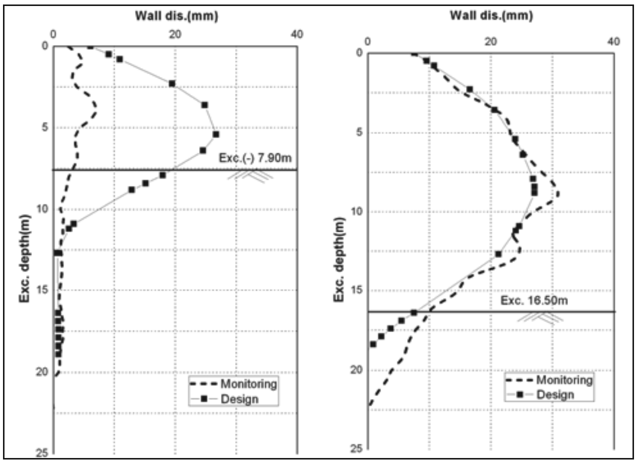
5.1 Wall displacements

5.1.1 Site 1 : S.P.S and ground anchor on C.I.P wall

The displacements of wall in which S.P.S method is applied are shown in Fig. 10 for the mid and final stages of excavation, i.e. GL.-7.9m and GL.-16.5 m.

In the mid stage of excavation, the predicted design displacement was 26.7mm and was greater about 20mm than the monitored displacement of 7.0 mm. This discrepancy seemed to come from the fact that the influence factors, e.g. the loads behind the wall, the excavation height for installation of supports, and weak soil profiles near the ground surface, were selected conservatively compared with the real field conditions.

However, in the final stage the two values were come out quite close. The reasons for this consistency are: (1) The construction conditions was very similar to the one adopted in the design stage, according to the construction process identified at the site; (2) In S.P.S method, it is able to install the steel supports immediately after the excavation. This gives an advantage of reducing the time delayed displacement of the wall, which developed the quite consistent displacements between the design stage and the actual excavation.



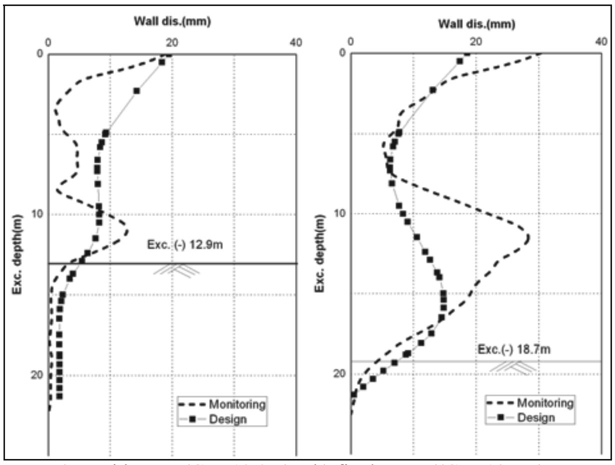
a) Mid stage (GL.-7.9m) b) final stage ((GL.-16.5m)

Figure 10. Wall displacements for S.P.S applied section

The displacements of the wall where the ground anchors are applied are shown in Fig. 11. As can be recognized in the figure, the predicted displacement in the mid stage was larger than the monitored value. In the final stage, the two displacements are consistent partly but larger displacements of 10mm are monitored at the upper and central positions of the wall.

This large displacement seems to come from the initial over-excavation length of more than 5m due to the sewage culvert box near the ground surface in Fig. 5b. As the excavation went on the final stage, the spacing of the ground anchors was about 3m and the over-excavation which was greater than the designed strut spacing was made in the field.

Therefore, it is judged that a particular sites like this one which has large sewage culvert box near the ground surface and the over excavation is made near the final stage needs the detailed design and construction considering all the factors related to spacing of the ground anchor and strut, initial displacement of the wall near the ground surface and the geotechnical conditions included.



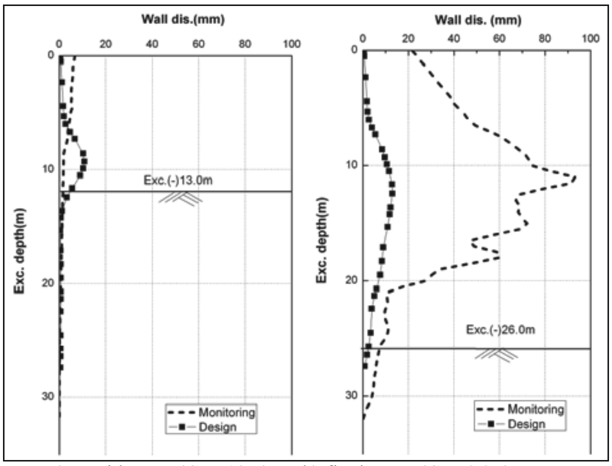
a) Mid stage (GL.-12.9m) b) final stage ((GL.-18.7m)

Figure 11. Wall displacements for ground anchor applied section

5.1.2 Site 2: S.T.D and C.I.P

Fig. 12 shows the wall displacements for mid and final stages of excavation in the site 2 where S.T.D method is applied. The excavation depths of mid and final excavation stages were GL.-13.0m and GL.-26.0m, respectively. In the mid stage, the predicted and monitored displacements came out very similar. In the final stage, large discrepancy was recognized for the predicted and the monitored displacements, i.e. 13mm and 93.1mm, respectively.

Proper construction process and the favorable soil conditions near ground surface seemed to create the consistent wall displacements in the mid stage. Large monitored wall displacements may come from the fact that (1) The design condition would not include the time effect of concrete curing in the slab; (2) over excavation was made since the weathered and soft rocks appeared in the initial stages of excavation. The large discrepancy of the wall displacement about 80mm was the accumulated displacement of the 26m deep excavation.



a) Mid stage (GL.-13m) b) final stage (GL.-26m)

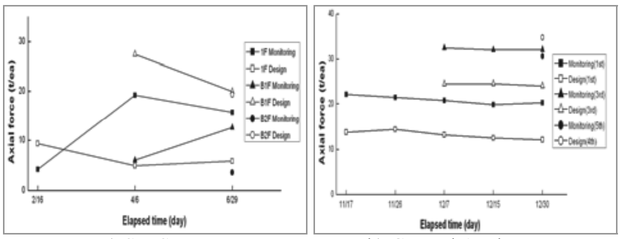
Figure 12. Wall displacements in S.T.D method applied

6 AXIAL FORCES OF RESISTANT BODIES

6.1 Site 1 : S.P.S and ground anchor on C.I.P wall

Fig. 13a shows the predicted and monitored axial forces acting the struts of S.P.S. The two axial forces in the initial stage showed large difference, because the construction conditions, e.g. ambient temperature and impacts, etc, create large changes in the strain gages measuring the axial forces. However, this discrepancy was reduced as the predicted and monitored displacements became similar (see Fig. 10b).

It is necessary to indentify the wall displacements together when the axial forces in the supports of S.P.S are analyzed.



a) S.P.S b) Ground Anchor

Figure 13 Axial forces for site 1

Fig 13b shows the axial forces of ground anchors in the locations where the ground anchors were applied. In general, the pre-stress considered in the design stage is sufficiently reflected on the ground anchors constructed in the field. However, the monitored axial forces tend to be larger than the predicted values in the design stage in site 1, although the pre-stresses designed are fully reflected at the excavation.

According to Fig. 11b, the axial forces were large at the locations in which the large wall displacements are detected. At the location of 5th floor in which the design and monitored displacements are closer to each other, the two axial forces were also close to the values of 35tons.

High correlation is recognized between the wall displacements and the axial forces in the struts. In addition, the changes of axial forces were negligible as the time elapses at the locations where the large wall displacements are detected. This means that the ground anchors are working quite well at such locations (Jang et al., 2012).

6.2 Site 2: S.T.D and C.I.P

Fig. 14 shows the axial forces which act on the slab of S.T.D method by comparing design and monitored values. The monitored axial forces are mostly larger than the predicted values set in the design stage. This result came from the increased wall displacement due to over-excavation and the characteristics of S.T.D. method.

Contrary to the direction of the soil pressures, tensile forces are developed on the 1st anchor from the top. This may come from the large displacement in the central part of the wall, i.e. B2F and B3F, which gave reverse stresses on the upper part of the wall.

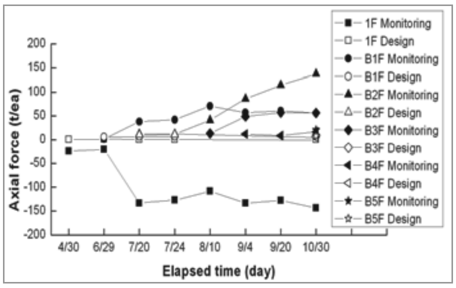


Figure 14. Section A-A' Slab axial forces

7 COMPARISON OF CONSTRUCTION TIME

The current retaining wall design, which uses slab as the support of the wall, applies S.P.S and S.T.D methods. These methods can save the construction time because they can support the retaining walls as well as can use the slabs as the permanent basement structure of the building. The two sites have different excavation area and depth. Hence a direct comparison of the construction period was difficult. In this study, construction period was calculated and relative comparison was made based on the Site 1, which was quantified by area (15,000 m2) and the excavation depth (GL.-19m).

Table 1shows the comparison of the construction time of the basement for different support methods. In Site 1 where the ground anchors are partly used, the construction time was 9 months. However, in Site 2 where the slab support S.T.D is used, the slabs are installed simultaneously with the excavation and the time taken to finish the basement structure was 7 months.

Table 1. Comparison of construction time for two sites

Construction Method		Site 1: Chung Ju	Site 2 : Sang Am
		S.P.S & Anchor	S.T.D
Excavation Depth		GL.-19m	GL.-26m
Excavation And Sub- structure	Start	2010.10	2012.04
	End	2011.06	2012.11
	Period	9 month	7 month

8 CONCLUSIONS

In this study the displacement on the C.I.P. walls and the axial forces on the slabs are monitored in the two excavation sites. In the sites, two new top down methods, S.P.S & S.T.D, are applied with the traditional support method, i.e. ground anchor. The monitored values are analyzed and compared with those predicted at the design stage. The conclusions obtained are the following:

1) The monitored displacements of C.I.P rigid walls with S.P.S support were similar to the predicted values. The displacement of the S.P.S support wall came from the characteristics of the support which does not applies the pre-stresses to the wall. The displacement of the wall is allowed by the slab without restriction.

2) Even though the rock layer is appeared in the shallow depth, large displacements and axial forces are monitored compared to the values predicted at the design stage in the site where S.T.D. method is applied. This is because the excavation depth is deep and the over-excavation was made at the final stage of construction to reduce the construction time.

3) It is necessary to reflect the characteristics of the excavation method and the soil conditions when the retaining walls are planned for excavation site. At the site of excavation, the monitored value in each stage should be reviewed and compared with the designed values. Feedback analysis is sometimes needed when some field problems are anticipated.

4) Quantitative inspection of the construction time of the selected sites indentifies the significant reduction of the construction time when the slab support methods are applied compared with the traditional ground anchor supports.

9 ACKNOWLEDGEMENTS

This research was supported by the Basic Science Research Program through the National Research Foundation of Korea (NRF), funded by the Ministry of Education, Science and Technology (No.2012-0002408). This paper is also a part of the result from the "Maintenance of Foundation Design Criteria under the Construction Facilities for Standardization", the "Construction & Transportation R&D Policy and Infrastructure Project".

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