Back analysis for a deep excavation in Taipei MRT Underground Station

Calcul a posteriori pour une excavation profonde à la station du métro de Taipei MRT

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ABSTRACT
A deep excavation for the underground structure of St. Ignatius High School Station of the Taipei Mass Rapid Transit System has been chosen for case study. This project used the bottom-up construction techniques with an excavation depth of 31.65 m in 11 stages. At the final stage of excavation, an accident of water and soils burst-in occurred in one section and induced a very large diaphragm deflection, some ground settlement and some minor damages of adjacent buildings. The complete record of diaphragm deflection was retrieved herein and back analysis was performed to simulate the field situations. Results obtained showed the significant changes of soil properties due to the influence of various constructional works.

RÉSUMÉ
Une excavation profonde pour le sous-structure de St. Ignatius High School Station du Taipei Mass Rapid Transit System a été choisi pour l'étude de cas. Ce projet a utilisé le "bottom-up" techniques de construction avec une profondeur de l'excavation 31.65 m en 11 étapes. Au stade final de l'excavation, un accident de l'eau et des sols en rafale a eu lieu dans une section et induit une très forte déflexion du paroi moulée, un peu de tassement et quelques dommages mineurs de bâtiments adjacents. Le enregistrements complet de déflexion du paroi moulée a été récupéré dans cet article et calcul a posteriori a été réalisée pour simuler les situations sur place. Les résultats obtenus ont montré l'importance des changements des propriétés du sol due à l'influence de divers travaux de construction.

Keywords : deep excavation, underground construction, deformation analysis, field measuing data

1 INTRODUCTION

For the past two decades, the construction of the Mass Rapid Transit (MRT) network has been the major civil project in the metropolitan Taipei area. To date, five lines have been completed and in operation, another five lines are still under construction. Since the construction of the Taipei MRT, several constructional accidents have occurred due to the difficult conditions of soft ground and high water level in this area (Moh, 1991). The Luzhou line, which passes through the Sanchong and Luzhou area, is one of the difficult lines under constructing. It has a length of 6.4 km with five underground stations and a maintenance depot. The ground conditions along the route are mainly alternating layers of soft clay and loose silty sand, which have been characterized as a very soft and sensitive ground. The water level is very high, close to the ground surface (CECI, 2001).

The St. Ignatius High School Station of Luzhou Line is a three-floor island-platform station with 150.6 meters in length and 42.3 meters in width as shown in Figure 1. It was constructed by the method of cut and cover with an average excavation depth of 31.65 m and 10 levels of internal struts as shown in Figure 2 (K/R/P, 2004). During the construction, when the excavation had just reached the bottom, an accident occurred on September 8 in 2005 (K/R/P, 2005a). At first, a small amount of water leakage occurred at GL. -30 m near the mid-section of the north retaining wall. The leakage was soon blocked by using a plate welded on to the wall temporarily. However, the high water pressure squeezed out another hole a few hours later. A large amount of water and soils flowed into the excavation area. At the same time, not only the internal supporting struts and piles displaced upward gradually, but also the ground surface and adjacent buildings have started to subside. Some cracks even occurred on the road surface. For emergency response, the contractors decided to retreat and refill water into the excavated space immediately. When the water level inside the pit was raised up to the level as the ground water level outside the wall, the internal bracing and the ground were stabilized. The damage was controlled with a limited ground subsidence of 30 cm plus some small tilting and cracks in adjacent buildings. Finally, ground improvement on surrounding soils and subsequent retrofitting work on internal bracing system were carried out in order to resume the excavation and followed constructional work. Now, this station has been fully completed.

2 DEFORMATION OF DIAPHRAGM WALL

For the construction of The St. Ignatius High School Station, the reinforced concrete diaphragm wall of thickness 1.50 m and depth of 55.0 m was used as the retaining structure. The excavation was divided into 11 Stages with 10 Levels of steel strut as shown in Figure 2. During the constructions, an intense monitoring system had been installed to monitor the deformations of constructional elements, surrounding soils and structures (K/R/P, 2005b). The recorded data included the inclinometers for lateral deformation of diaphragm wall and strain gauges for the axial force of struts, as shown in Figure 3. In addition, there were a large amount of monitoring gauges for the uplift of interim pile, the subsidence of ground and surrounding buildings, which are not shown in the figure.

Since the accident of water and soil burst-in occurred near the mid-section of the north side, the deformation of the diaphragm was well recorded by the inclinometer SID 2001. During the stages of excavation before the leakage of water, the deformation profiles during the 11 Stages of excavation are shown in Figure 4. Based on the results obtained, it can be further deduced to get the maximum lateral deformation of the

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diaphragm in relation to the depth of excavation as shown in Figure 5, and the location of the maximum lateral deformation occurred with respect to the depth of excavation as shown in Figure 6 (Wen, 2008). From Figure 6, it can be seen that the location of maximum lateral deformation occurred at a depth of a little above the surface of excavation before Stage 7 (i.e., before H_e=-19.7m). Afterwards, it moved to the depth of a little lower than the surface of excavation. While the maximum lateral deformation of the diaphragm wall was about 0.002 H_e before Stage 7, and increases with respect to H_e afterwards. It was also noted that it became abnormally large in Stage 11, which was believed to be the preceding clue of failure.

During the period of water leakage accident, the deformation profiles of SID2001 are shown in Figure 7, and the associated axial loads on strut VG23 are shown in Figure 8. In these figures, the D0(Date 9/6) indicates the state before the leakage of water, the maximum lateral deformation v_{max} in SID2001 is about 114 mm. The D1(Date 9/8) indicates the state of water leaking, the v_{max} in SID2001 increases to 179 mm and the axial loads of VG23 in Levels 9 and 10 increase correspondingly. The D2(Date 9/10) indicates the state when the refilling water is raised up to 16 m, the v_{max} in SID2001 is about 196 mm and the axial loads of VG23 in Levels 6 to 10 reduce correspondingly. The D3(Date 9/12) indicates the state after the pressure grouting conducted behind the wall mainly at the elevation from GL. -20 m to -43 m, the v_{max} in SID2001 is increased to 253 mm and the axial loads of VG23 in Levels 6 to 10 increase significantly due to the pressure grouting. From these recordings, it is really beneficial for controlling the damages as well as planning the subsequent construction work.

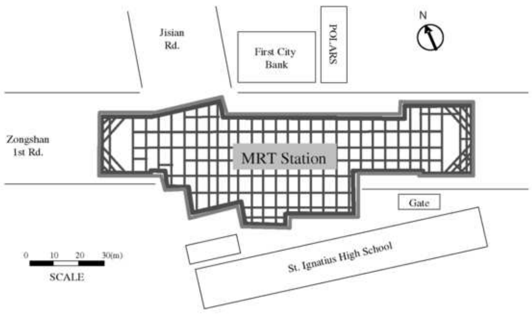

Figure 1. Plane view of the St. Ignatius High School Station

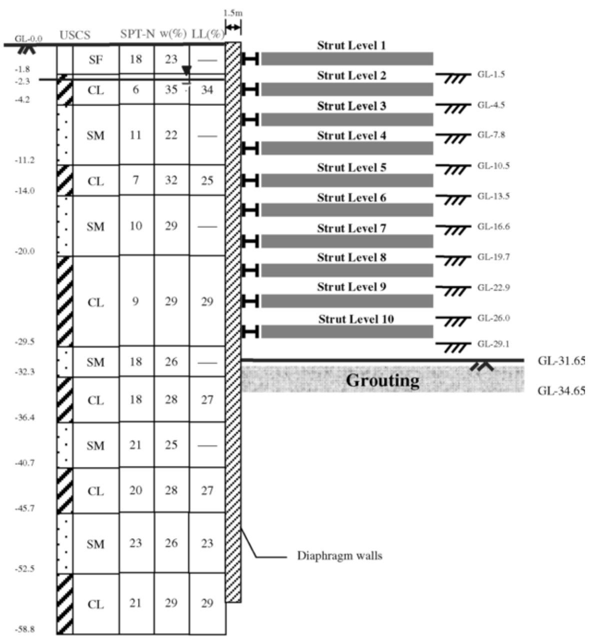

Figure 2. Typical section of the excavation

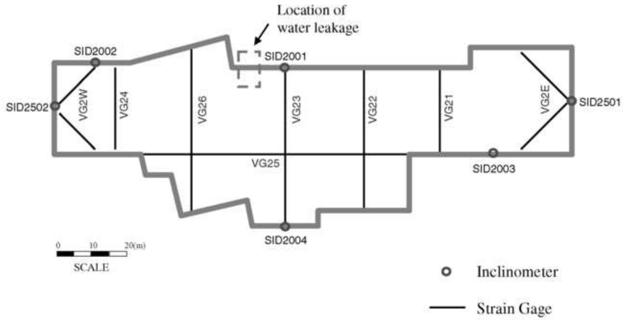

Figure 3. Layout of monitoring system and location of water leakage

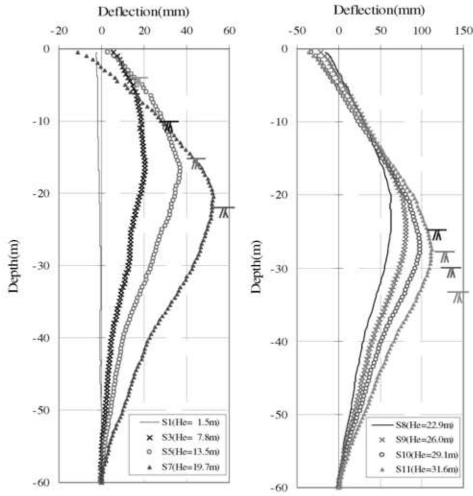

Figure 4. Deformation profiles during the 11 stage of excavation

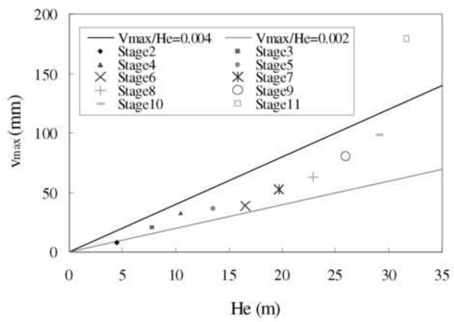

Figure 5. Maximum lateral displacement versus to depth of excavation

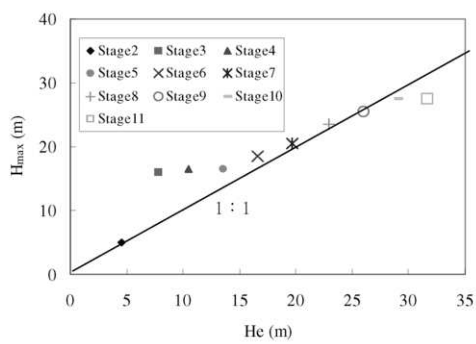

Figure 6. Location of maximum lateral displacement with respect to depth of excavation

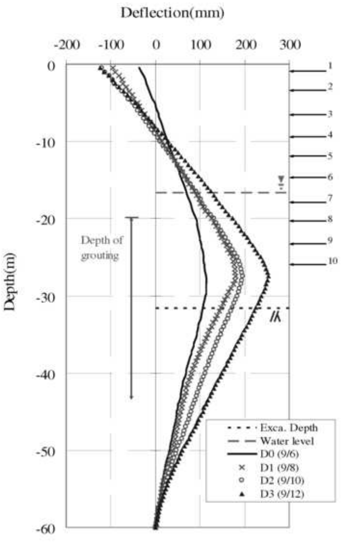

Figure 7. Deformation profiles during the period of water leakage and counter measures

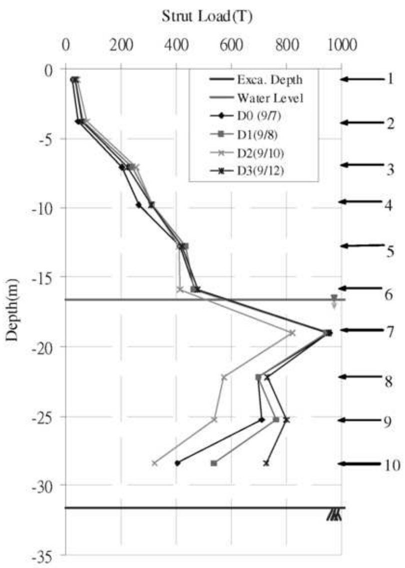

Figure 8. Axial load of struts during the period of water leakage and counter measures

3 BACK ANALYSIS

In recent years, the design of deep excavation is usually based on the results of numerical simulations. Although the elasto-plastic model is often adopted to simulate the sequential constructional work, the result obtained still involved many uncertainties, particularly the in-situ soil conditions due to the disturbance of various constructional processes. The predictions have to be verified by field measured data to ensure the safety of constructions. Therefore, back analysis based on the field measured data is usually performed to adjust the design in engineering practice.

Since the inclinometer SID2001 shown in Figure 3 is very close to the location of accident that suffered the maximum lateral deformation, it is therefore selected for back analysis in this paper. The casing of inclinometer SID2001 was installed in the diaphragm wall and down to the underneath soil at the depth of 60.5 m. The method of analysis is to use the computer program RIDO (R.F.L., 1998), which has been commonly adopted for the design of the Taipei MRT project.

3.1 *Ground conditions*

Sanchong and Luzhou are situated beside the Tanshui river which has been characterized as a soft ground. The typical soil strata at this site are the Sungshan Formation, which are alternating layers of silt sand and silt clay as shown in Figure 2. The ground water is about 2.3 m below the ground surface. The site investigation data indicates that the deposits are very loose or very soft. The water content of clayey layers is almost the same as or slightly over its liquid limit, and is generally regarded as normally consolidated clay in local practice. Therefore, in order to minimize the wall deflections during the excavations, the -33 m to -36 m soil inside the diaphragm walls was improved by cement grouting in the original design, as shown in Figure 2.

3.2 *Model A0 and A1*

The first case selected for back analysis is the site condition with the station that was excavated to the depth of foundation base (-31.65 m) but before the occurrence of water leakage, i.e., the D0 state in Figure 7. According to the original design report, the soil parameters adopted for the design analysis are shown in Model A0 of Table 1, in which the K_h value represents the stiffness of elasto-plastic soil spring used in RIDO analysis. By using this set of soil parameters, the maximum deflection of the wall obtained was only 59 mm as shown in Figure 9, which is much smaller than the field measuring data of 114mm. In order to fit the field data in this stage, a series of analyses were conducted by modifying the K_h value of each layer until a better agreement in deformations was achieved. The model deduced is indicated as the Model A1 as shown in Table 1. By using this set of soil parameters, the wall deflection calculated reaching 111 mm, which is in good agreement with the measuring data as shown in Figure 9.

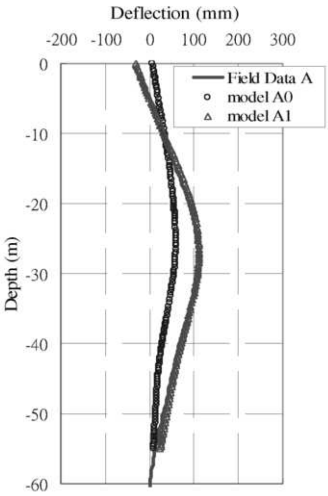

Figure 9. Simulation analysis – Model A0 and A1

3.3 *Model B*

The second back analysis was performed to simulate the D3 state in Figure 7. It was the situation when the damage occurred, the excavation pit was refilled with water of depth 16 m and the pressure grouting behind the diaphragm wall was completed. Based on the result of Model A1, a series of analyses were conducted by further modifying the K_h value of each layer until the deformation pattern obtained agreeing with the D3 curve of Figure 7. At this stage, the maximum deflection of the wall reached 253 mm. From back analysis, the soil parameters deduced were designated as Model B and shown in Table 1. The comparison of diaphragm deformation with the field measured data is shown in Figure 10. The strut loads obtained from simulation analyses are compared with field measured data as shown in Table 2.

Table 1. Site stratification and adopted material properties

				MODEL A0			MODEL A1			MODEL B		
Soil type	Depth	r_t (t/m^3)	N	c (t/m^2)	φ' (deg.)	K_h (t/m^3)	c (t/m^2)	φ' (deg.)	K_h (t/m^3)	c (t/m^2)	φ' (deg.)	K_h (t/m^3)
SF	1.8	1.98	—	0.0	30	35+53σ'	0.0	30	10	0.0	30	5
CL	4.2	1.85	6	0.0	31	23+35σ'	2.0	0	30	1.0	0	15
SM	11.2	1.97	11	0.0	31	25+38σ'	0.0	31	450	0.0	31	150
CL	14.0	1.88	7	0.0	31	28+40σ'	5.0	0	80	5.0	0	160
ML/SM	20.0	1.88	10	0.0	31	23+35σ'	0.0	31	420	0.0	31	840
CL	29.5	1.90	9	0.0	32	45+63σ'	7.0	0	90	5.5	0	45
SM	32.3	1.94	18	0.0	32	55+75σ'	0.0	32	300	0.0	32	105
CL	36.4	1.93	18	0.0	32	90+125σ'	11.5	0	150	11.5	0	30
SM	40.7	1.94	21	0.0	33	83+105σ'	0.0	33	450	0.0	33	300
CL-ML	45.7	1.92	20	0.0	33	130+170σ'	13.0	0	500	13.0	0	450
SM	52.5	1.95	23	0.0	33	90+115σ'	0.0	33	800	0.0	33	600
CL	58.8	1.92	21	0.0	33	138+175σ'	13.5	0	1700	13.5	0	1350

Table 2. The strut load obtained from simulations (Unit : tons)

NO.	1	2	3	4	5	6	7	8	9	10
TYPE	H350	H400	2H414	2H414	2H428	2H428	2H458	2H428	2H428	2H428
Model A0	33	64	196	136	171	243	401	363	309	239
Model A1	0	29	231	287	274	115	267	320	340	216
Field data A	24	43	99	129	204	231	374	344	350	196
Model B	0	0	44	632	398	137	269	280	246	213
Field data B	36	59	114	153	212	239	379	368	396	363

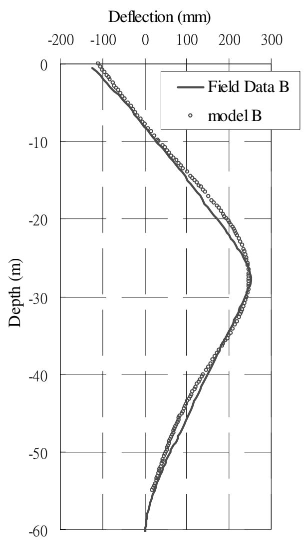

Figure 10. Result of back analysis –Model B

4 CONCLUSIONS

A series of back analysis to simulate the deformation behavior of the diaphragm wall during the construction of The St. Ignatius High School Station of the Taipei MRT system was conducted in this paper. The analyses included the conditions when the excavation reached the depth of 31.65 m, followed by the accident of water leakage, the process of refilling water and pressure grouting for emergency response. Results of back analyses obtained were in good agreement with the field measuring data. The changing of soil stiffness during the whole process can thus be deduced. They were very helpful for planning the subsequent repairing works.

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REFERENCES

Moh, Z.C. 1991. Geotechnical consideration for underground Mass Rapid Transit System, *Proceedings of Ninth Asia Regional Conference on Soil Mechanics and Foundation Engineering.*

CECI. 2001. *Luzhou Line CL700B Design Report*.

K/R/P Luzhou Office. 2002. *Luzhou Line CL700B Supplementary Geological Investigation Report*. Kajima/RSEA/PAC JV.

K/R/P Luzhou Office. 2004. *Plan of Construction, Luzhou Line CL700B*. Kajima/RSEA/PAC JV.

K/R/P Luzhou Office. 2005a. *Accident & Emergency Response Report, Luzhou Line CL700B*. Kajima/RSEA/PAC JV.

K/R/P Luzhou Office. 2005b. *Monitoring Report, Luzhou Line CL700B*. Kajima/RSEA/PAC JV.

Wen, T.R. 2008. *Deformation Behavior of Diaphragm Wall of a Deep Excavation Case in Luzhou Area*. Master Thesis, Department of Civil Engineering, National Taiwan University.

Robert Fages Logiciels. 1998. *RIDO User's Manual, Version 4.0*.