Protection of the Existing Railway Tunnels from an Adjacent Deep Excavation

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ABSTRACT: With the booming of urban development, construction of new infrastructures faces challenges on rapidly disappearing space. More and more underground constructions are inevitably conducted adjacent to existing buildings, and the associated safety concerns become an important issue. This paper presents a particular case where a deep excavation is conducted in the proximity of operating public transportation facilities. The underground construction is a joint-development for major substation of the Taipei MRT Circular Line, intercity bus terminal, and commercial purposes. The close-by operating facilities include tunnels for Taipei MRT Blue Line, Taiwan Railway (TRA), and Taiwan High Speed Rail (THSR) and none of them can be suspended during the excavation. The paper first briefs the environment constraints. It then discusses the design considerations of protection measures against excavation-induced risks to the operation and safety of the public transportation, including demolition of existing underground structure, trench protection of diaphragm wall (i.e., D-wall), strutting and groundwater control, and monitoring. Conclusions are provided at the end of the paper
Keywords: Deep excavation, shield tunnels, underground structure, pumping, protection measures.

1. INTRODUCTION

The project is located at the north side of Banqiao Train Station in New Taipei City. The site was an intercity bus terminal and is planned to merge with the adjacent lands to construct a joint-development building for the original bus terminal, main substation of the Taipei MRT Circular Line and commercial purposes. The scope of the project includes the construction of the building from the basement to the fifth floor, above which will be constructed by the future developer. Since there are quite a few important infrastructures around the site, least construction effect on these facilities will be the first priority. Furthermore, the bus terminal shall be relocated to not only remain its functions but also allow the project to proceed.

The deep excavation of the building is a critical and key issue to the success of the project. The surrounding facilities include the tunnels of the MRT Blue Line, joint-tunnels of Taiwan Railway (TRA) and Taiwan High Speed Rail (THSR), and three underpasses connecting the bus terminal and Banqiao Train Station. The excavation therefore is required not only to keep the facilities in operation but also to remain the bolts on the top slab of the joint-tunnels that were pre-installed for the piers of the elevated Circular Line in a tolerant position. Further, since part of the piers of the elevated station that situates right next to the joint-development building is overlapped with the existing underpasses it is of particular concern to the construction interaction between the excavation and the foundation. In response to such complicated construction constraints, the retaining structure adopted for the project include diaphragm wall (i.e., D-wall), cross-wall, and buttress. In addition, deep guide wall and ground improvement were conducted at some regions to reduce ground disturbance by D-wall excavation.

Since the joint-development building is constructed on the existing bus terminal, conflicts of the new and existing structure would be inevitable. The D-wall of the building is especially designed for both retaining and permanent use and thus its quality shall be strictly controlled during the removal process of conflicted structure and backfill.

In addition, the building is seated on the Songshan Formation, a sand-clay interbedded alluvium that is underlain by the highly permeable Jingmei Gravels with abundant groundwater. In view that the project only covers the building up to the fifth floor, the control of hydraulic pressure on the bottom of the excavation becomes a particular concern for both excavation stage and the complete stage of the project before the developer finishes the upper stories of the building. Based on the deep excavation experience accumulated on the Taipei Basin (e.g., Young et al., 1996; Huang et al., 1997; Chen et al., 1999; Moh, 2004), it was suggested except for base grouting to introduce cross-wall to panel the excavation site and dewatering could thus be restricted within a relatively small region that would make the distribution and change of groundwater easy to control. This paper first introduces the background the project, including the adjacent existing railway and MRT tunnels, and geological and groundwater condition. It then illustrates the design consideration of the protection measures for excavation. Preliminary monitoring results are presented followed by the concluding remarks.

2. BACKGROUND OF THE PROJECT

2.1 Site Layout

To meet the requirement of the structure layout for the joint development and the substation, the depth of the excavation is designed to be approximately 33.3 m and 29.8 m, respectively. Figure 1 shows that the site is a rectangular shape with about 157 m in the east-west direction, 27 m in the north-south, and the total area of about 3,750 m^2. The basement of the building is a single wall system constructed using the bottom-up method. The D-wall is adopted for both retaining and permanent structure purposes with 1.5 m thick and 52 m deep into the Gravels. Besides cross-wall and buttress, the inner strutting is adopted to reduce wall deformation during excavation. A ten- and nine-level strutting system is planned for the joint-development building and substation, respectively.

2.2 Overview of Adjacent Railway and MRT Tunnels

As depicted by Figure 1, on the west side of the site is the operating Blue Line of Taipei MRT; the south side is Banqiao Train Station which is connected to the site through three underpasses; the east side is the operating tunnels for TRA and THSR; the north side is a temporary bus terminal substituted for the one situated on the site. Among the surrounding facilities, the tunnels for MRT, TRA, and THSR are of most importance. There is literally no substitution of transportation for the tunnels and protecting them from excavation-induced effects is the only feasible way.

The up- and down-track of the Blue Line are constructed by two single shield tunnels that operate daily for as long as 18 hours and serve the trains as short as in every 3 minutes during the rush hours. The outer diameter of the tunnels is 6.1 m with clearance of about 7 m and overburden of about 18 m within the region of the site. The tunnels are aligned roughly in the south-north direction passing by the site with the closest distance of about 6.4m on the southwest corner.

On the other hand, the joint-tunnels for TRA and THSR are box structure with one and two story below ground surface, respectively. Both tunnels adopted D-wall as retaining structure with 0.8-m-thick, 30-m-deep for TRA and 1-m-thick, 40-m-deep for THSR. The tunnels pass by the site with the closest distance of about 6 m on the southeast corner. There are 9 places on the top slab of the tunnels

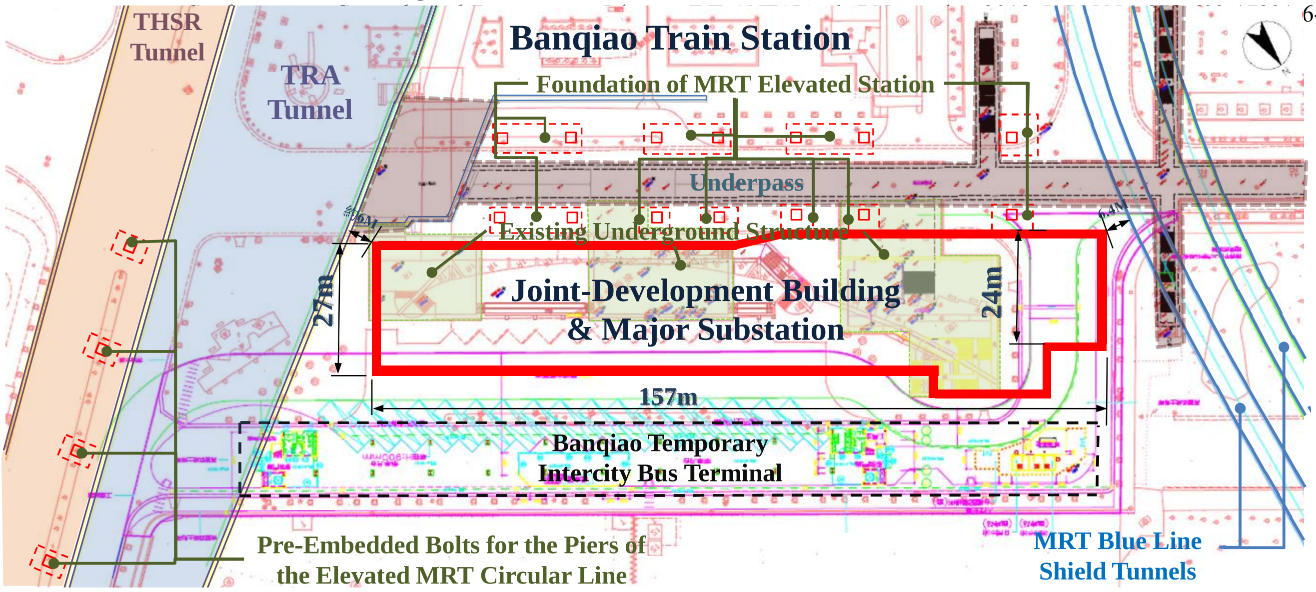


Figure 1 Schematic of project site and adjacent facilities

and concourse level for the Banqiao Train Station that were embedded bolts for the future piers of the elevated Circular Line.

3. GROUND AND GROUNDWATER CONDITION

According to the results of geological investigations, the depth of the Gravels on the site is about 50 m below ground surface. Except for the fills, the Gravels are overlain by 5 alternating sand and clay layers. It is identified as the sublayer I to V in the Songshan Formation but the sublayer VI is not clearly shown on the site (Hu et al., 1996). The soil profile for the site is generally divided into 7 layers that from top to the bottom are:

(1) Fills – distributed from ground surface to 4.0 m below with an average thickness of about 4.3 m.
(2) Silty Sand – distributed from 4.0 m to 11.0 m below ground surface with about 7.3 m in average.
(3) Silty Clay – distributed from 11.0 m to 20.0 m with a significantly varying thickness and about 6.7 m in average.
(4) Silty Sand – distributed from 20.0 m to 28.0 m in depths with an average thickness of about 6.7 m.
(5) Silty Clay – distributed from 28.0 to 36.0 m with about 6.8 m thick in average.
(6) Silty Sand – distributed from 36.0 to 50.0 m with about 11.3 m thick in average.
(7) Gravels – distributed from 50.0 m deep and below at least till the bottom of the borehole at the greatest depth of 59.1 m with the largest grain size of about 10 cm.

A simplified soil profile and its engineering properties adopted for excavation analyses are presented in Table 1.

Table 1 Simplified Soil Profile and its Engineering Properties

Layer	Depth	Soil Classification USCS	SPT-N	γ_t	s_u	ϕ'
1	4.0	SF	8	19.7	-	28
2	11.0	SM	9	20.0	-	30
3	20.0	CL	9	19.4	62	32
4	28.0	SM	15	19.7	-	31.5
5	36.0	CL	13	19.5	115	33
6	50.0	SM	32	20.0	-	32.5
7	> 50.0	GM	50	22.0	-	38

Note: Unit for depth, unit weight, undrained shear strength, and effective friction angle is m, kN/m^3, kN/m^2, and degree, respectively.

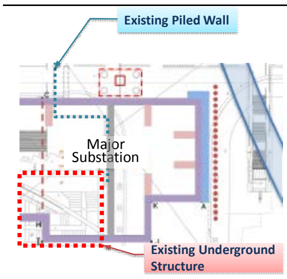
In addition, based on the recordings obtained from the observation wells and piezometers during the investigation period between May and August of year 2009, the groundwater level is located at about 5 m below ground surface with a hydro-static distribution with depths. It is especially noted that there is no sign of hydraulic pressure in the Gravels that is below the hydro-static state (e.g., Chao et al., 2015; Hu et al., 1996). The hydraulic pressure has been recovered in the Gravels after deep well pumping was banned for domestic and industrial water use in late 1960s.

4. PROTECTION MEASURES FOR CONSTRUCTION

In the deep excavation where D-wall is adopted as the retaining structure, the induced ground deformation generally originates from trench excavation of D-wall, base excavation and strutting, and dewatering. The project is particularly challenging in view of the existing underground structure and foundation for bus terminal and underpasses on the site that shall be demolished during excavation. In response to such environmental constraints, any possible construction risks were evaluated and the corresponding protection measures were planned to meet the regulated requirements. They are illustrated in the following sections and summarized in Table 2.

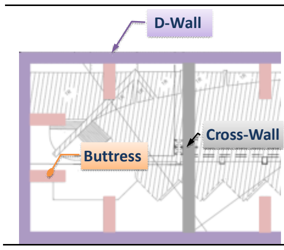
Table 2 Critical Issues and Strategies for Excavation

(a) Removal of existing underground structure



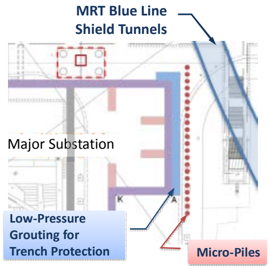
- **Removal of existing piled wall and backfill with grouting materials.**
- **Partly destruction of existing underground structure to build deep guide wall for D-wall excavation**
- **Site excavation and demolish the remaining underground structure**

(b) Retaining system



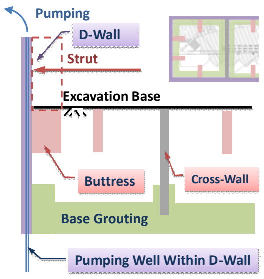
- **D-wall**
- **Cross-wall**
- **Buttress**
- **Steel strutting**

(c) Trench protection and construction monitoring during D-wall excavation



- **Depth of micro-piles: 30m**
- **Low-pressure grouting: depth 4 m ~ 20 m**
- **Automatic monitoring: total station, reflector prism, beam sensor, and convergence point for the shield tunnels of MRT Blue Line**

(d) Groundwater control



- **Base grouting (existing basement floors must be penetrated in partial area)**
- **Pumping within D-wall**
- **Section dewatering in excavation site**

4.1 Removal of Existing Underground Structure

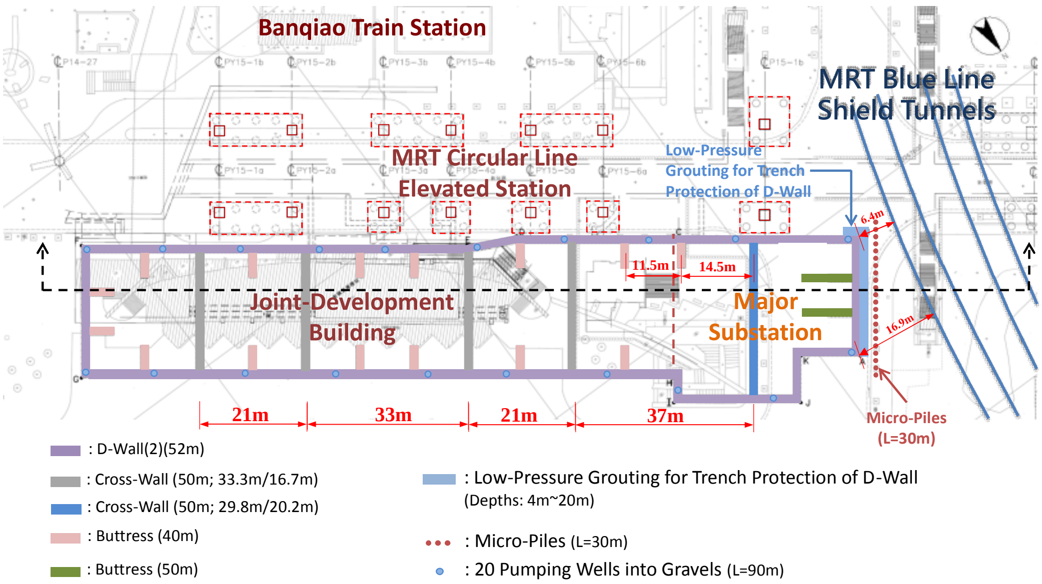
If the removal of existing underground structure is not fully complete, the remaining part would result in potential risks in excavation. It would create a passage for groundwater leakage piled wall within the site and cavity was backfilled with grouting materials. For those in conflict with the new D-wall, the separation panels and retaining structure were constructed, respectively, within and outside the existing basement as the guide wall for the D-wall. They were demolished after the D-wall was complete.

4.2 Trench Protection During D-Wall Excavation

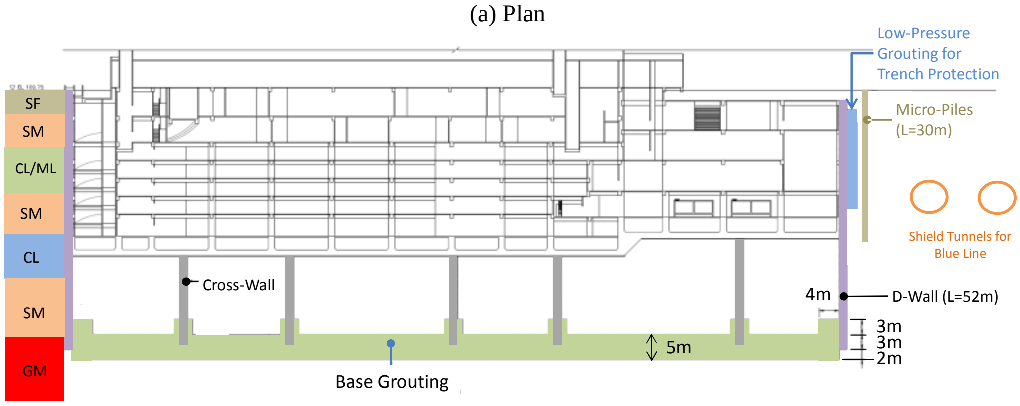
The project is in close proximity of the tunnels for MRT, TRA, and THSR with minimum clearance of about 6 m. Since D-wall was used for the excavation of the TRA/THSR box tunnels, it is estimated that the effect of ground deformation induced by trench excavation on the site would be relatively slight on the box tunnels. For the MRT's shield tunnels that exhibit smaller volume and have no retaining structure as a protection, the effect would be significant. Figure 2 shows that a series of low-pressure grouting with depths varying from 4.0 m to 20.0 m was therefore conducted accompanied by 30-m-deep, steel-tube micro-piles to strengthen the soils outside the trench. The ground deformation could be reduced as well as the effect on the surrounding soils.

4.3 Strutting and Groundwater Control During Excavation

Strutting and groundwater control are the two major issues for the stability of excavation. As depicted by Figure 2, except for steel struts used in the retaining system the inner buttress and cross-wall are additionally introduced to the site to reduce the excavation-induced wall deflection. The inner buttress is a pure concrete mass with depths of 50 m on the side close to the MRT shield tunnels and



(a) Plan



(b) Section

Figure 2 Schematic layout of protection measures for excavation

resulting in additional ground deformation around the site. Therefore, the casing method was adopted to remove the existing 40 m for the rest of the site. The cross-wall is 50 m deep with pure and reinforced concrete for depths above and below excavation levels, respectively. The cross-wall is used not only as part of retaining system but also as panels for dewatering in the project.

Since the groundwater level is about 5 m deep and the site is excavated up to 33.3 m below ground surface, it was estimated that piping and uplift would be the issues against the stability of excavation. Furthermore, the pumping output would increase as the excavation depth closes to the underlain aquifer (i.e., the Gravels). It is thus particularly crucial to maintain the stability on the excavation base. The base grouting was adopted to block the recharge of groundwater from the Gravels to the bottom of the excavation. The permeability of the improved soils is required to be below 1×10^{-5} cm/sec. Pumping wells were installed on the site to lower the groundwater table below the excavation level. Besides, additional pumping wells were installed within the D-wall and penetrated down to 90 m deep with inlets opened at depths greater than 60 m to control the hydraulic pressure on the bottom of the improved soil mass in the Gravels. To effectively control the dewatering efficiency, the site was panelled by six pumping area through cross-walls.

4.4 Construction Monitoring

To keep the site and adjacent structure in a safe condition over the excavation period, a construction monitoring plan was implemented and focused on the significant factors. During the excavation, the monitoring targets, instruments, and the associated frequency and management levels involved are summarized in Table 3.

Figure 3 shows the monitoring results from the inclinometer installed in the D-wall close by the shield tunnels and in between the buttresses. Due to the support of ground improvement, micro-piles, and barrettes, the resulting wall deflection was significantly reduced with a maximum of about 16.6 mm in comparison of the corresponding calculated free-field value of about 35 mm. The

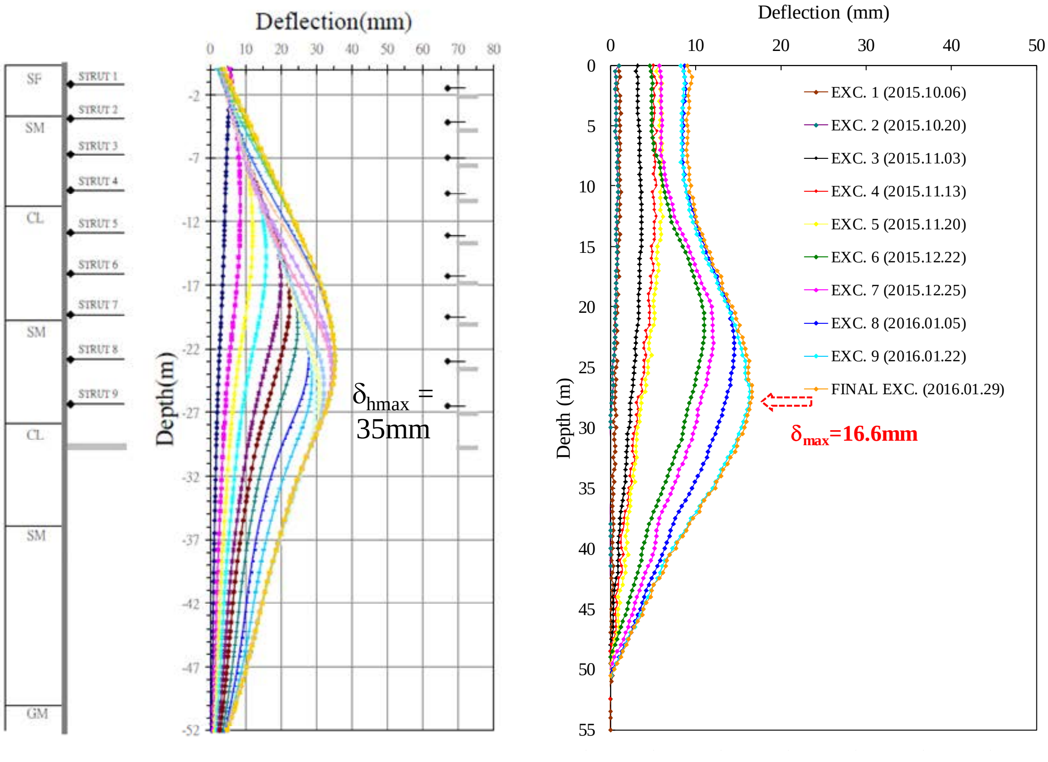
Table 3 Summary of monitoring system

Target	Instrument	Label	Frequency	Management Level		Recording Type
				Alert	Action	
Surface & ground movement	settlement point	SM	Once a week & twice during excavation	32 mm	40 mm	Manual
	inclinometer	SIS		34 mm	42 mm	Manual
Structure movement & deformation	stand point	SB	Once a week & twice during excavation	80% Action level	Note 3	Manual
	tiltmeter	TI				Manual
	crack meter	CG		visible	1 mm (concrete)	Manual
	crack gauge	CM			3 mm (brick/masonry)	Manual
Groundwater level & pore pressure	observation well	OW	Twice a week & once a day during pumping	Initial value ±1.0 m	Initial value ±2.0 m	Manual
	stand-pipe piezometer	PS		Notes 1 & 2 (within excavation)	Alert level +1.0m (within excavation)	Manual
	electronic piezometer	ELP		Initial value ±1.0 m (outside excavation)	Initial value ±1.0 m (outside excavation)	Automatic
Strut load	strain gauge	VG	Twice a week & once a day during excavation	90% design load	125% design load	Manual
D-wall stress	rebar stress transducer	RS		250 MPa (60 Grade) 170 MPa (40 Grade)	300 MPa (60 Grade) 200 MPa (40 Grade)	Manual
	inclinometer	SID	Once a week & once a day during excavation	34 mm	42 mm	Manual
Excavation base	heave indicator	HI	once a day during excavation	100 mm	150 mm	Manual
Tunnel deformation	total station & reflector prism	RP	10-30 min.	0.96/1,000 (9.6mm/10m)	1.2/1,000 (12mm/10m)	Automatic
	convergence point	CB	10-30 min.	16 mm	20 mm	Automatic
	horizontal electronic beam sensor	EBS	10-30 min.	0.96/1,000 (9.6mm/10m)	1.2/1,000 (12mm/10m)	Automatic

Note: 1. Factor of Safety (FS) against piping and uplift shall not be smaller than 1.5 & 1.2, respectively; 2. FS against buoyancy shall be 1.03 & 1.07 for temporary and permanent condition, respectively. 3. See table below.

Table 3a Settlement control criteria for buildings & structures

Building Type	Settlement δ (mm)	Tilt θ	Current tilt falling b/w 1/500 & 1/300 (65%)	Current tilt greater than 1/300 (40%)
Temporary (timer or iron)	40	1/500	13/10,000 (~1/769)	1/1,250
Brick	25	1/1,000	13/20,000 (~1/1,538)	1/2,500
RC (footing)	40	1/500	13/10,000 (~1/769)	1/1,250
RC (mat foundation)	45	1/500	13/10,000 (~1/769)	1/1,250



(a) Calculation (b) Measurement

Figure 3 Comparison of measured and calculated wall deflection closest to MRT tunnels

effect on the shield tunnels was therefore greatly reduced as well. According to the readings of instruments mounted on the tunnels, the deformation and differential deflection were remained within the management levels over the excavation period.

5. CONCLUSION

In the early stage of design for the project, the deep excavation experience on the Taipei Basin was collected and studied. The protection measures, such as cross-wall, inner barrette, and base grouting, were proposed based on the past experience, site characteristics, and environmental constraints. Up to the first half of year 2018, the construction of basement is almost complete and the effects of D-wall and base excavation were fairly controlled with no interference to the tunnel operation. The relevant monitoring results are still under summary and study. It is hoped to be shared in the near future.

6. ACKNOWLEDGEMENTS

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