The Effectiveness of Jet-Grout Slabs and Cross-walls in Restricting Wall Movements in Deep Excavations

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ABSTRACT: This paper presents observations made at some well-instrumented deep excavations during the construction of the Taipei Rapid Transit Systems. Jet-grout slabs and in-situ cross-walls were used inside these excavations to reduce the lateral displacements of the retaining walls. Based upon these case histories, the effectiveness of these two types of support systems in restricting lateral displacements of retaining walls for deep excavations in soft clay is assessed.

1 INTRODUCTION

The construction of a deep excavation in soft ground generally results in ground movements, which if uncontrolled, could result in damage to adjacent buildings and services. Precautions may be adopted to reduce ground movements during wall installation and dewatering, but if the soft soils extend below the final excavation depth, the main phase of excavation is almost always accompanied by ground movements that are difficult to prevent. The key to minimising such movements is to install a stiff internal support system below the final excavation level before the start of the main excavation. In the past perimeter walls have occasionally been supported at depth by cross-walls (or partition panels) installed with diaphragm walling equipment (Eide et al. 1972), or by pre-stressed struts installed in hand-excavated tunnels (Stevens et al. 1977). More recently the use of jet-grouting to replace soil below the final excavation level has become wide-spread.

Several deep excavations for the Nankang Line of the Taipei Rapid Transit Systems (TRTS) have recently been carried out in an area where the ground conditions are relatively uniform (see Figure 1). Here soft to firm clay and silt extends to about 40 metres depth, and is underlain by dense gravel deposits. The undrained shear strength of the lightly over-consolidated clay varies from 40 to 100kPa.

At one site no special support was provided at depth whilst at others jet-grouted slabs or cast-in situ cross-walls were used to reduce the lateral displacements of the retaining walls. The sites were heavily instrumented providing an opportunity to compare the effectiveness of the different support systems. The methods of construction, the soil improvement works and observations made are described in this paper, and some conclusions drawn about the relative efficacy of the measures used.

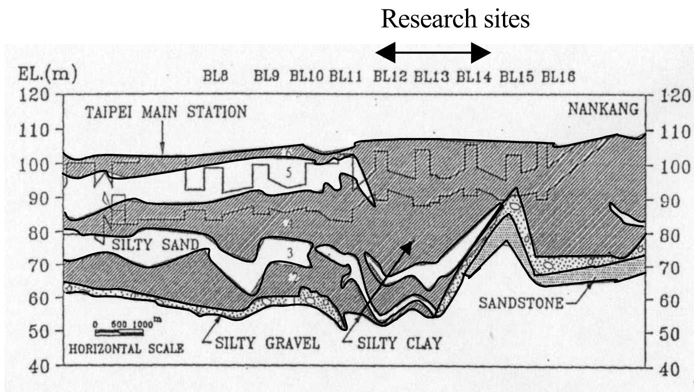

Figure 1 Soil profile along the Nankang Line of TRTS

2 THE CASES STUDIED

The excavations studied are briefly described as follows:

2.1 *Sun Yat Sen Memoral Hall Station (BL12)*

This is a 2-level underground station where excavation to a depth of 16.2m (see Figure 2) was carried out using the semi-top-down method of construction. Although soil improvement was carried out in excavations for some of the station entrances to protect adjacent structures, there was no ground improvement used for the main body of the station. The diaphragm walls were braced by the roof slab and 5 levels of steel struts which were preloaded to 50% of their design loads (Moh and Associates Inc., 1995a). Further details of this case record are given by Hsiung, et. al. (1999).

2.2 *City Hall Station (BL13)*

This is another 2-level underground station, where excavation was carried out to a depth of 18.8m (see Figure 3) using the bottom-up method of construction. A grouted slab of 4m in thickness was installed before excavation started immediately below the final excavation level using the high pressure jet grouting (JSG) method. Grouted columns of 1.2m in diameter were formed at 1.04m centres in a triangular pattern. Laboratory tests on cored samples gave unconfined compressive strengths of the treated ground varying from 2 to 5.5 MPa. The diaphragm walls were braced by 5 levels of steel struts, which were preloaded to 50% of their design loads (Moh and Associates Inc., 1995b).

2.3 *Yung- Tsung Station (BL14)*

Yung- Tsung is another 2-level underground station, where a semi-top-down excavation was made to a depth of 16.7m (see Figure 4). Here a 3m thick jet-grouted slab was installed before excavation started immediately below the final excavation level using the Swing method. Grouted columns of 1.6m in diameter were installed at 1.2m centres on a triangular pattern. Laboratory tests on cored samples gave unconfined compressive strengths of the treated ground varying from 2 to 4 MPa. The diaphragm walls were braced by the roof slab, B1 slab and 3 levels of steel struts, which were preloaded to 50% of their design loads (Moh and Associates Inc., 1998).

2.4 *Joint-Development Building (JDB)*

The JDB was constructed alongside BL14 Station after the station excavation was completed. With a 5-level basement, it is connected to Entrance A of the station by a short passageway at the B2 level. Excavation was carried out bottom-up to a depth of 21.1m (see Figure 5). Full-height cross walls 1m wide made from un-reinforced lean concrete were installed to 4m below the final excavation level using diaphragm walling equipment. The design strengths of the concrete were 14 N/mm^2 for the walls above the bottom of excavation and 20 N/mm^2 for those below. Cross-walls were spaced at 10m intervals and were demolished in stages as the excavation proceeded. The diaphragm walls were braced by 7 levels of struts which were preloaded to 50% of their design loads (Moh and Associates Inc., 2000).

3 OBSERVATIONS

The lateral wall displacements observed with inclinometers at each site are given in Figures 2 to 5. Although the excavation at BL12 was the shallowest, the wall displacements at BL12 were generally larger than those observed at the other sites, probably because no special support system was used. This suggests that the support systems used at the other sites were indeed effective in reducing wall displacement. It should be noted however that at the BL13 site, installation of the jet-grout slab resulted in outward movement of the wall before the start of main excavation by up to 60mm (Hsiung et al. 2001). These movements are not included in Figure 3.

Cast-in situ cross-walls had been used previously in Taipei to reduce the lateral wall deflections (Moh

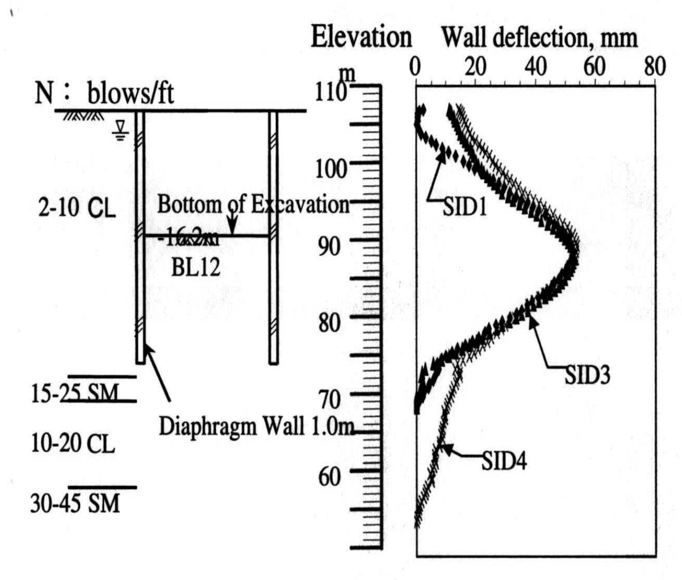

Figure 2. Sun Yat Sen Memorial Hall Station (BL12)

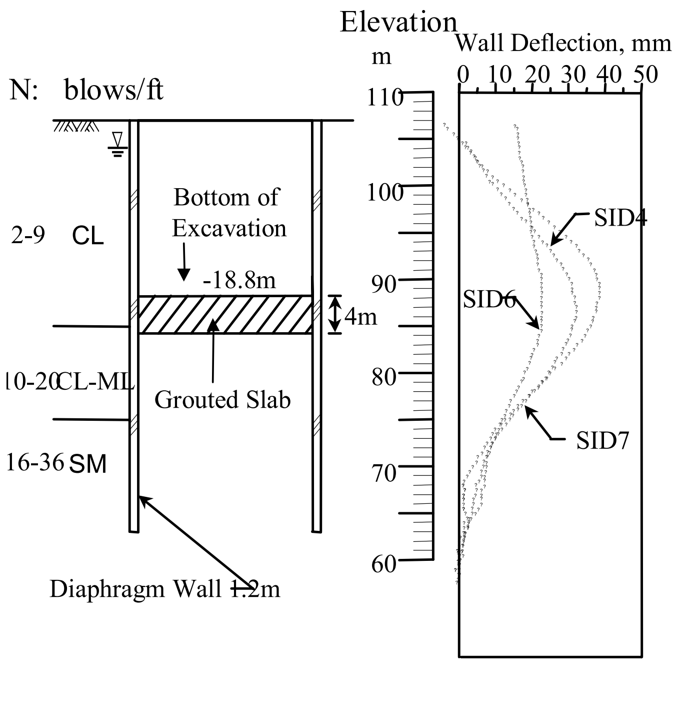

Figure 3 Taipei City Hall Station (BL13)

and Hwang, 1999). In an excavation for another 20m deep TRTS station, cross-walls of a similar design to those at the JDB site reduced the displacement of 800mm thick diaphragm walls to 7mm from 40mm observed at a nearby unsupported section (Woo and Lee, 1996). The lateral displacements measured by two inclinometers at JDB differ by a factor more than 2. While the readings obtained by Inclinometer SID12 accord with this previous experience, the larger movement observed with Inclinometer SID13 may result from:

(1) The joints between the panels in the cross-walls and the connections with the longitudinal walls, might have been inadequately cleaned resulting in poor contact. Similar observations were reported at excavations carried out in Oslo (Karlsrud, 1983).

(2) The installation of struts was delayed due to slow progress in demolishing the concrete cross-walls (Moh and Associates Inc., 2000).

(3) The installation of the cross-walls may have disturbed the soils inside the excavation and thereby reduced the passive resistance of the soil. This situation is similar to that observed in an excavation carried out in Oslo (Eide et al. 1972).

(4) The BL14 station excavation carried out prior to the excavation for the JDB might have caused stress relaxation of the ground and thus reduced the passive resistance of the soils.

Although (2) to (3) above are possible reasons for the large displacement observed at SID13, they would also have increased the displacement at SID12. It appears most likely that the difference is due to (1) or (4). Problems due to compressible joints could perhaps have been avoided if pressure grouting were carried out within the joints.

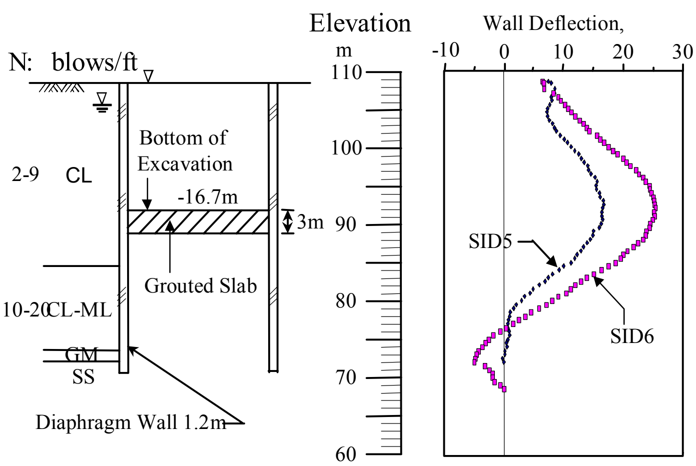

Figure 4 Yung- Tsung Station (BL14)

4 DISCUSSION

In the cases discussed above, the depths of excavation vary from 16.2m to 21.1m. In comparing the behaviour of excavations with different support systems, it is useful to normalise displacements to take account of varying excavation depth, rather than comparing movements directly. It is convenient to relate the maximum lateral movement to the excavation depth by:

$$\delta_{\max} \propto H^{n} \qquad (1)$$

For most deep excavations with depths exceeding 10m carried out in Taipei, Moh and Hwang (1999) have reported that the exponent *n* varies from 1 to 2. In the simplest normalisation with n=1:

$$\frac{\delta_{\max}}{H} = \beta \qquad (2)$$

whilst better agreement with field data has been found using n=2 where:

$$\frac{\delta_{\max}}{H} = \alpha H \qquad (3)$$

The performance of various retaining systems may then be evaluated by comparing their α and β values; α and β for the cases outlined above are shown in Table 1. A more sophisticated comparison would take the flexibility of the wall into account as well (for example see O'Rourke, 1993). Table 1 shows that the α and β values in all other cases are smaller that those for BL12, so it is clear that the ground improvement/cross walls were effective in providing additional support. The data given in Table 1, suggests that jet-grouted slabs of sufficient thickness installed below the bottom of excavation effectively reduced displacements by factor of 2 while cross walls extending to below the base of the excavation, reduced displacements by factor of 3.

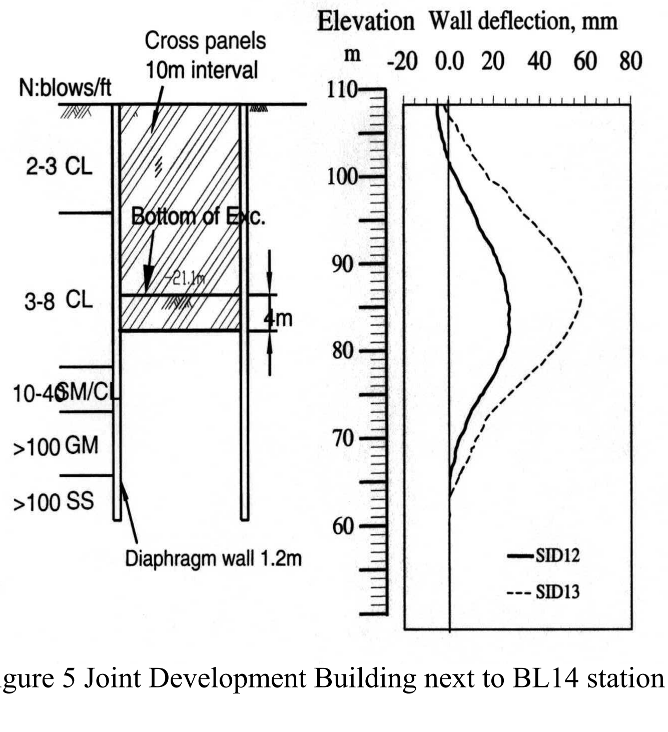

Figure 5 Joint Development Building next to BL14 station

5 CONCLUSIONS

From field observations at several deep excavations in similar soft clay ground conditions, it may be concluded that jet-grouted slabs with 100% replacement are indeed effective in reducing the lateral deflections caused by the main excavation. A reduction factor of 2 was achieved for the cases discussed here. Cross-walls are also effective in reducing wall displacements and a reduction factor of 3 is suggested. However, the quality of joints between adjoining panels and between the cross-walls and the longitudinal walls appears to influence the effectiveness of such a support system. Further reductions in lateral movement could probably only be achieved by a prestressed support system installed before the start of construction.

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Table 1 Evaluation of performance of support systems

	Depth of excavation	Method of construction	Special support system	Maximum displacement	α	β
	m			mm	10^{-6} m^{-1}	
BL12	16.2	semi-top down	none	53	202	0.0033
BL13	18.8	bottom up	4m slab	38	108	0.0020
BL14	16.7	semi-top down	3m slab	26	93	0.0016
JDB (SID12)	21.1	bottom up	Cross-walls	28	63	0.0013
JDB (SID13)	21.1	bottom up	Cross-walls	59	132	0.0028

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