BUILDING PROTECTION FOR CONSTRUCTION OF TAIPEI MRT

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SYNOPSIS The paper discusses a few building protection measures adopted in the construction of the mass rapid transit systems in the Taipei City. Reducing ground movements at the source was found to be the most effective measures for reducing damage potential. For deep excavations, wall deflections were reduced to a half by preloading struts. Further reduction was achieved by improving the soils inside the excavation. In a few cases, ground treatment was continuous forming buried struts bracing against two walls. For tunneling, settlements over tunnels were reduced by simultaneous tail void grouting. Limited success was achieved by compaction grouting. In clays, dissipation of porewater pressure led to settlement canceling the benefits of compaction grouting. In sands, a large volume of grout was required for the heave to be measurable.

1 INTRODUCTION

In order to meet the ever-increasing demands for public transportation, the municipal government of the Taipei City launched an ambitious construction program of the mass rapid transit systems (TRTS) in 1987. The first phase of the program consists of seven lines, namely, the Mucha, Tamshui, Hsintein, Nankang, Panchiao, Chungho and Neihu Lines, with a total length of 88 km and a total budget of US$16 billions. A system map is shown in Fig. 1.

As shown in Fig. 2, which depicts a simplified subsoil profile running along the east-west routes, the Taipei Basin is underlain by a thick layer of alluvial deposits containing alternations of soft-to-medium-stiff clays and loose sands, i.e., the so called Sungshan Formation. Underlying the Sungshan Formation is the Quaternary Chingmei Gravels which contains sandstone cobbles with sizes varying typically from 100 to 300 mm. However, boulders up to 1m in size have been occasionally encountered in the Chingmei Gravels.

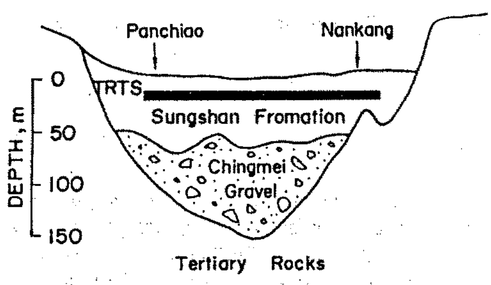

Figure 2 Simplified Subsoil Profile Along East-West Routes

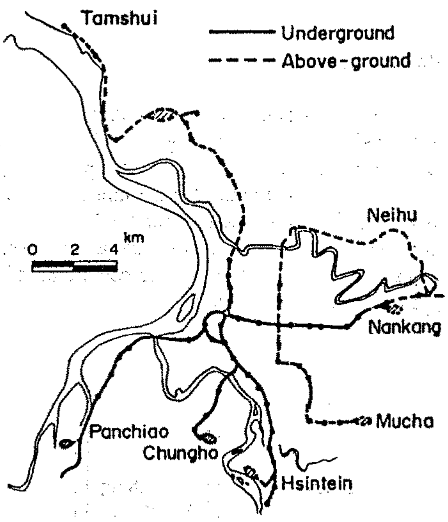

Figure 1 Taipei MRT Systems

About a half of the total length of TRTS routes is underground. Deep excavations were carried out in very close proximities from adjacent structures in rather poor ground conditions and, at places, bored tunneling was carried out underneath existing structures. Therefore, building protection was one of the major issues in both the design and the construction stages.

2 BUILDING CONDITIONS AND SETTLEMENT CRITERIA

Influence zones along the routes were estimated by designers and the contractors were required by specifications to inspect buildings within these zones. The lines of influence, as shown in Fig. 3, extend from the outer edges of permanent structures with slopes of, mostly, 1 : 1.5 but, occasionally, flattened to 1 : 2. The information obtained serve as the basis for the contractors to work out the building protection programs to be implemented and also serve as background information in the cases of claims.

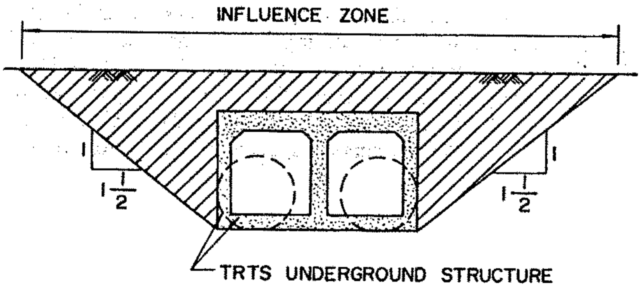

Figure 3 Zone of Influence

2.1 Settlement Criteria

Most of the designers adopted the guidelines proposed by Burland and Wroth (1974) for determining the allowable settlements of buildings. The total settlements quoted generally vary from 25 mm for normal structures on footings to 50 mm for frame buildings on mat or piles. Inclinations were generally limited to 1/500 for the former and 1/300 for the latter. Considerations were also given to the age, quality of construction and/or conditions of structures but the judgments were often subjective.

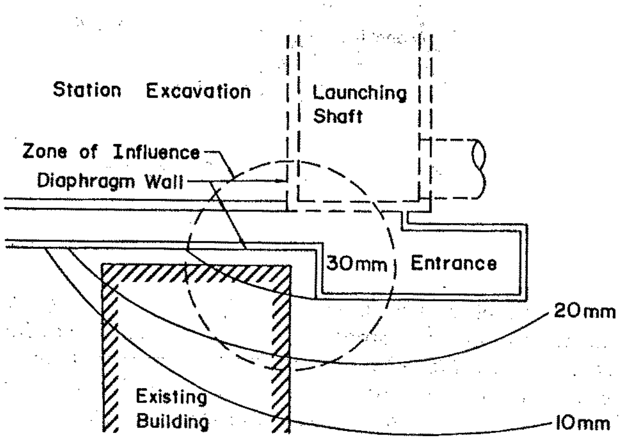

Figure 4 Settlement Due to Diaphragm Walling

3 PROTECTION MEASURES FOR DEEP EXCAVATIONS

Ground settlements of 10 to 20 mm maximum were often induced by diaphragm walling with their influence extending to a distance of 10m from the wall with diminishing magnitudes. Figure 4 shows an interesting case in which the settlement at the corner of a building reached 30 mm at the end of diaphragm wall installation. It was reasoned that the unusually large settlement was a result of accumulation of the settlements induced by all the panels within the zone of influence. In a few cases, even trenching for guide walls caused local collapse of surface material, especially the loose backfill near footings, resulting in 10 to 20 mm settlements of structures.

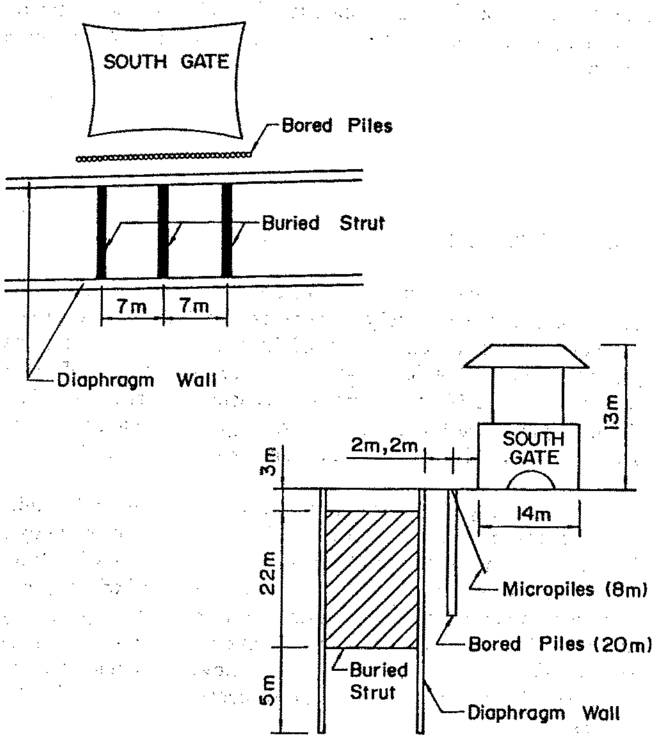

Figure 5 Protection of South Gate

For these reasons, as illustrated in Fig. 5, bored piles of 450 mm in diameter were installed before trenching for protecting a historical monument, the South Gate. Furthermore, a row of micropiles serving as tiebacks were installed to provide fixity at the top of the bored piles. And yet, settlements of the Gate were of the order of 5mm after trenching for guide walls and a maximum settlement of 17 mm was recorded at the completion of diaphragm wall panels. The heavy weight of the Gate must be responsible for this unusually large settlement.

3.1 Ground Treatment

Where calculated wall deflections were excessive, cross-beams were installed prior to excavation to serve as buried struts bracing against two walls. The case shown in Fig. 5 is a typical example. The ways these buried struts were installed differed from one contract to another. It was recognized that diaphragm walling would give better integrity of the beams, but underground utilities often made it difficult for panels to be installed across streets. On the other hand, jet grouting columns can be set out at locations away from utilities and installed at angles. Furthermore, the smaller space required by jet grouting operation caused less traffic problems. Therefore, more contractors opted for jet grouting or soil-mix-wall technique instead.

There were cases in which ground treatment was carried out sparsely in part of the site for the purpose of improving soil strength so the passive resistance could be increased. Where there were buildings on the opposite side as well, the treated zone was often extended across the site to form a continuous slab bracing against the two walls. In addition to reducing wall deflection, the slab had the advantage that the bottom of excavation was hard and became an neat work platform.

3.2 Preloading Struts

To minimize wall deflections all the struts were preloaded to 50%, or even greater, of their design loads upon installation. No direct comparison could be made for evaluating the effects of preloading on wall deflections because all the struts for TRTS excavations were preloaded. However, for typical excavations to depths of 16 to 18m in the central city area (T2 zone), the maximum wall deflections were generally limited to 30 to 60 mm, while past experience on constructions for building basements showed values of, typically, 90 to 110 mm. In theory, TRTS excavations were much larger in size

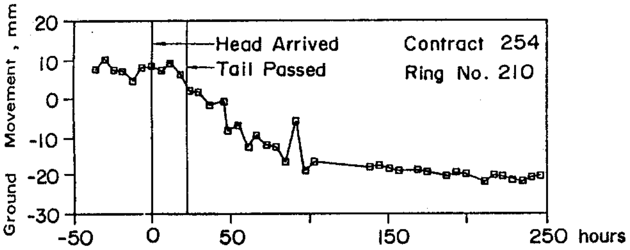

Figure 6 Settlement Due to Tunneling

and should have resulted in larger wall deflections, but yet the deflections were only a third to a half of those recorded for basement excavations. The achievement is attributed mainly to the preloading of struts. Other factors, such as greater rigidity of diaphragm wall and strict ban on over- excavation, also have partial contributions.

4 PROTECTION MEASURES FOR BORED TUNNELING

For TRTS, only a couple of contractors chose slurry/muddy types of shield machines. All others chose earth pressure balancing shields. Even so, provision was made for injecting water or slurry in case difficulty is encountered. Pressures at the face were deliberately kept high to heave up the ground in front slightly, as shown in Fig. 6, so the final settlement could be kept low. The modern computerized navigating system enabled the operator to know the position of the shield any time and adjustment could be made continuously for the shield to follow the specified alignment with minimal deviations. This reduced wiggling of the shield and overcutting, and resulted in less ground loss.

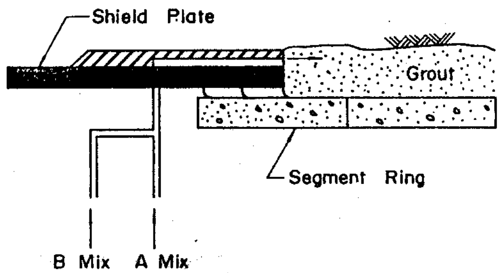

Figure 7 Automatic Grouting of Tail Void

4.1 Tail Void Grouting

To further minimize ground settlements due to the closure of tail voids, it was stipulated in the specifications that tail void grouting be carried out immediately as each ring of segment leaves the shield. This specification was strictly followed. The performance of the simultaneous grouting facility used in a few contracts, see Fig. 7 for illustration, was excellent and ground losses were generally limited to 1 to 2 % with typical surface settlements of the order of 20 mm as shown in Fig. 8.

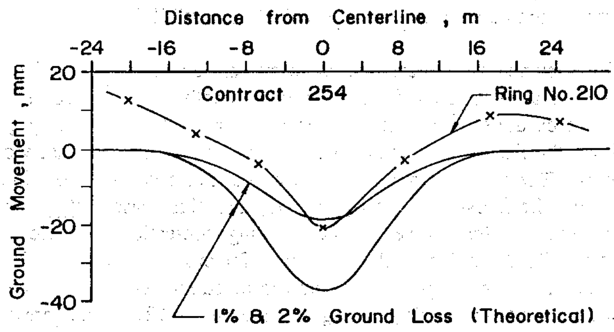

Figure 8 Settlement Trough Due to Tunneling

5 COMPACTION GROUTING

Compaction grouting was adopted in a few contracts as a corrective measures for buildings suffering excessive settlements as illustrated in Fig. 9. In clays although grouting was able to heave up the ground initially, however, as the excess porewater pressure dissipated, the ground settled back to its original levels defeating its purpose. It is therefore concluded that the clays in the Taipei Basin with a soft to medium stiff consistency are too soft for the technique to be effective. For sands, the volume of heave was only a small fraction of the volume of the injected grout and a very large volume of grout is required. It should also be noted that the lateral displacements of the ground are large and may be damaging to diaphragm walls.

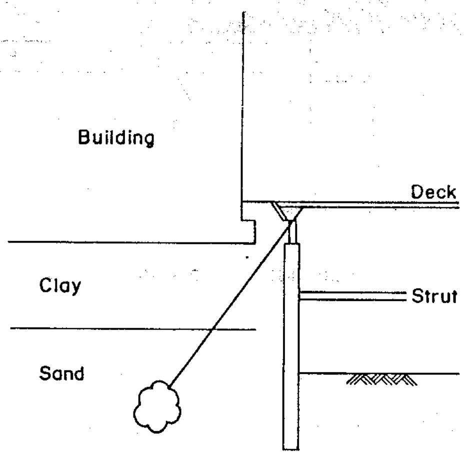

Figure 9 Compaction Grouting

6 DISCUSSIONS

The above-mentioned measures mainly aimed at reducing ground movements at sources. They are believed to be the most effective measures for the purpose. Other measures are of course available. However, the site constraints removed most of the options and ground conditions further eliminated other possibilities.

The designer often faces the dilemma that all the measures he can think of are unsuitable for one reason or another, and yet something has to be done to protect the adjacent properties. He usually goes down the list and eliminates the ones he knows for sure that won't work. The one he chooses at the end does not necessary work but is the one he knows the least about it. For this reason, it is worth mentioning that some of the building protection measures are potentially damaging. Underpinning, for example, has been found to induce as much ground settlements of structures as if it had not been carried out (Todo, Hwang and Hulme, 1992). High pressure grouting was reported to produce larger ground movements causing damages to basement walls and utilities (Hulme, Potter and Shirlaw, 1989). Therefore, one should be extremely careful in adopting such measures.

7 CONCLUSIONS

For cut-and-cover constructions, preloading of struts and ground treatment inside the excavations are effective in reducing wall deflections and are thus the most effective building protection measures. For bored tunneling, simultaneous grouting of void at shield tail reduced ground losses and it is possible to limit ground losses to 1 to 2 percents.

The soft clays in the Taipei Basin are too soft for compaction grouting to be effective. For sands, a very large volume of grout is required for obtaining meaningful magnitudes of ground heaves.

ACKNOWLEDGMENT

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