GROUND IMPROVEMENT AS A MEASURE FOR PROTECTING ADJACENT BUILDINGS – TRTS EXPERIENCE

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Abstract: Protection of buildings adjacent to underground works has always been a serious concern, especially for rapid transit systems which normally call for deep excavations and tunneling in the immediate vicinity of existing buildings. Much efforts have been made in the construction of the Initial Network of Taipei Rapid Transit Systems in an attempt to minimize problems with adjacent buildings and, as a result, very few buildings were damaged. The poor ground conditions, however, necessitated special measures to be taken in critical cases. This paper discusses the effectiveness of various ground improvement techniques adopted with case histories presented. The data given herein will be valuable reference for the future constructions.

Keywords: protection, excavation, ground improvement.

1. INTRODUCTION

Underground constructions inevitably involve the release of geo-stresses and, as a result, ground movements will definitely occur. Figure 1 is a schematic diagram showing the commonly adopted building protection measures, which can be grossly classified into 3 categories as follows:

(1) those reducing ground movements at source,
(2) those limiting the propagation of ground movement to structure,
(3) those strengthening the endangered structures themselves or their foundations, and
(4) those rectifying the endangered structures if they already settle or tilt.

It has been found that the most effective measures are those limiting ground movements at source, i.e., at the pit. Once ground movements occur, it will be very difficult to limit their propagation. It is even more difficult to rectify a building once it settles or tilts. It is thus always the first priority to limit ground movements at source.

There are several ways to reduce ground movements at source, including

(1) reducing active pressures acting on retaining walls,
(2) increasing passive resistance on the walls,
(3) maintaining groundwater table, and
(4) increasing the rigidity of the bracing system.

Ground improvement can be used to serve all these purposes with different degrees of success.

Various ground improvement methods have been adopted in the construction of the Initial Network of the Taipei Rapid Transit Systems (TRTS). High-pressure jet grouting technique appears to be the most popular one among all and has been used for nearly all the above-mentioned purposes. Compaction grouting has been adopted to jack up structures and/or to rectify a tilted building with some success. Fracturing grouting was used to jack up a 12-story building successfully. The effectiveness of these ground improvement measures is discussed herein with case histories presented.

2. JET GROUTING

Because it is easy to operate and the treated ground has high rigidity and high strength, jet grouting is frequently proposed as a protection measure to limit ground movements, either at source or near endangered structures. For cut-and-cover constructions, damage to buildings can mostly be attributed to ground movements which in turn are a result of lateral displacement of retaining walls and consolidation settlement due to the lowering of ground water table. Jet grouting is commonly adopted to form slabs, panels or beams to brace the diaphragm walls for the purpose of limiting lateral

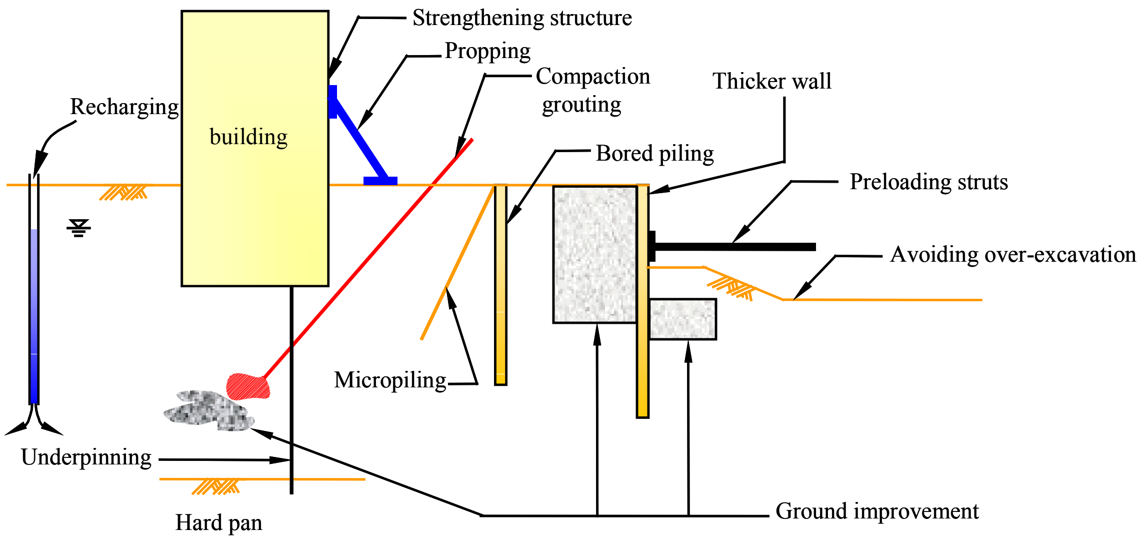


Figure 1. Concept of building protection

wall displacements in deep excavations. It is also adopted sometimes to treat the soil below diaphragm wall toe to cut off seepage flow.

Figure 2 shows a comparison of the lateral displacements of diaphragm walls obtained in TRTS constructions in the K1 Zone in which soft clay dominates. The effectiveness of ground improvement is obvious as indicated by the lower deflection-to-depth ratios (Moh and Hwang, 1999). Based on this figure and observations made in other geological zones, it is concluded that ground improvement reduced wall deflections, in general, by a half. Among all the improvement schemes, it is postulated that grouted panels (partition walls) will be the most effective, while grouted beam will be the least effective. However, the differences in effectiveness are not evident as depicted in Fig. 3. It shall be noted that, as depicted in Fig. 2, with improved quality of both design and workmanship, wall deflections observed in TRTS constructions were only one third of what was observed previously (Woo and Moh, 1990) and the potential of damage to structures has been greatly reduced. This was achieved by using thicker walls, heavier struts and by exercising better workmanship and better quality control. With this new finding, it is now unsure whether ground improvement is indeed necessary or cost effective as previously thought.

Jet grouting was sometimes proposed to be used directly underneath structures to underpin these structures. It was also proposed sometimes to be used in the space between structures and diaphragm walls to solidify the ground for the purpose of reducing active pressures acting on the walls, refer to Fig. 1, or to limit the propagation of ground movements. This is a dangerous action and its effectiveness is doubtful

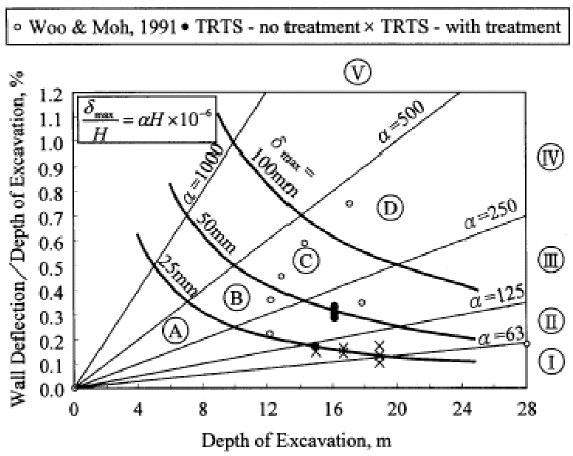
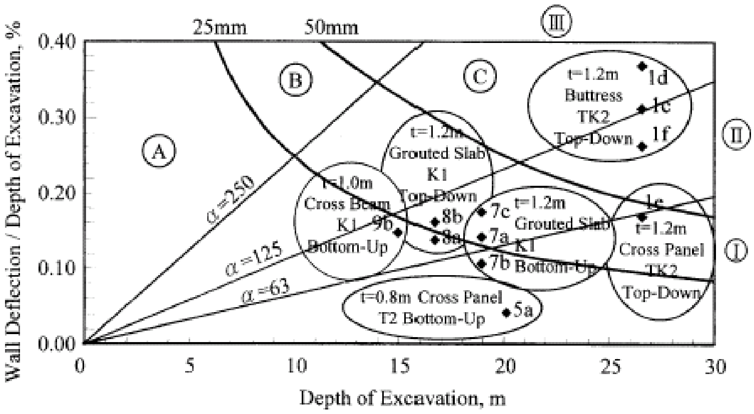


Figure 2. Wall deflections in the K1 Zone of the Taipei Basin

because adverse ground movements might occur rather rapidly during grouting and the damage made to the structure might be far greater than what would happen otherwise. Sufficient experience indicates that high pressure jet grouting will lead to rapid heave in clays because of the undrained behavior of clays. The subsequent settlements as the pore water pressure dissipates might be greater than the heave, resulting in net settlement and defeating the purpose. Considerable damages occurred to pavements, sidewalks, basements and utilities due to jet grouting in the construction of Singapore Mass Rapid Transit System (Buttling and Shirlaw, 1988). There have been many attempts in the past to reduce ground heave due to grouting but little has been achieved (Wang, Ju and Wu, 1997). Drilling operation, on the other hand, might lead to more ground settlements in



Note : The circled descriptions are in the sequence of appearing as follows :
a) wall thickness, b) method of treatment,
c) geological zone and d) method of construction

Figure 3. Wall deflections for different schemes of treatment

sands than what would have been otherwise. It is thus advised that jet grouting shall be left as the last measure to be considered in the vicinity of structures.

3. COMPACTION GROUTING

Compaction grouting has been used above tunnel alignment for the purpose of densifying the ground and reducing the settlement as the excavation approaches (Backer, et. al., 1981). This has been attempted in vain in one of the tunneling sections in the construction of the Taipei Rapid Transit Systems (Hwang, et. al., 1995). Presumably, Taipei Silts are too compressible for the method to be effective.

Several contractors proposed compaction grouting as a building protection measure and performed field trials in advance. In most of trials, quite large quantities of grout were injected into ground without inducing meaningful ground heave (Moh, et. al, 1997). In Chungho where dense sands dominant, however, a maximum heave of 120mm was achieved. It was observed that

(1) In clay, because of the undrained behavior of the clay, ground heaved up easily. However, the ground settled subsequently and the amount of settlement were even greater than the heaves. Therefore, if a sufficient amount of grout is to be injected, the operation has to be carried out extremely patiently.
(2) In sand, sufficient amount of grout and sufficient pressure would be required to produce cone failure, refer to Fig. 4, for ground heave to be meaningful.

Compaction grouting was indeed used in a few cases in an attempt to rectify tilted buildings with little success. In one case, however, compaction grouting in dense sand produced heaves up to 25mm to columns supporting a 4-story shop house in Panchiao (Wang, Shau and Chen, 1996). It is important to note that sufficient resultant forces, not pressure, shall be acting on the base of structure for it to be lifted up. The key to the success is thus the grouting pressure and the area in which the pressures are acting. It is therefore necessary to have multiple machines to work at the same time for grouting to be effective.

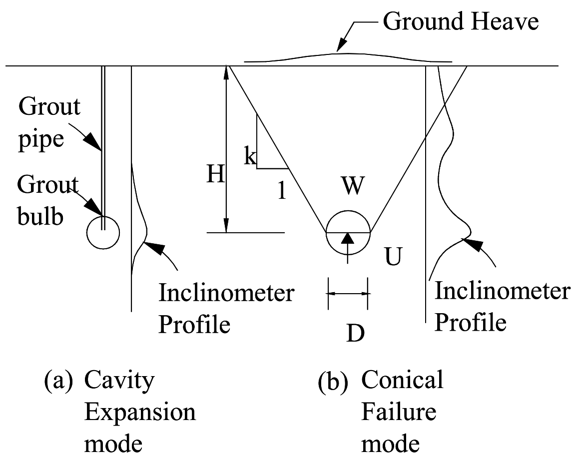


Figure 4. Heave mechanism

4. FRACTURING GROUTING

As depicted in Fig. 5, a 12-story apartment was successfully rectified by using fracturing grouting and a maximum heave of 127mm was achieved by injecting LW grout using, up to, 6 machines operating at the same time (Wang and Chen, 1997). Unlike the compaction grouting in which consistent grout does not travel, grout does go very far in fracturing grouting. Therefore, each machine is able to cover a much larger area. On the other hand, it is necessary to install curtain walls to confine the grout to within the footprint of the structure.

CONCLUSIONS

With the foregoing discussions, it is concluded that

1. cross-beams, cross-panels and slabs are effective in reducing displacements of diaphragm walls.
2. compaction grouting is ineffective in clays and can only be used at shallow depths in sands to jack up structures.
3. fracturing grouting can be used to jack up structures, however, several machines have to be used at the same time to give sufficient resultants at the base.

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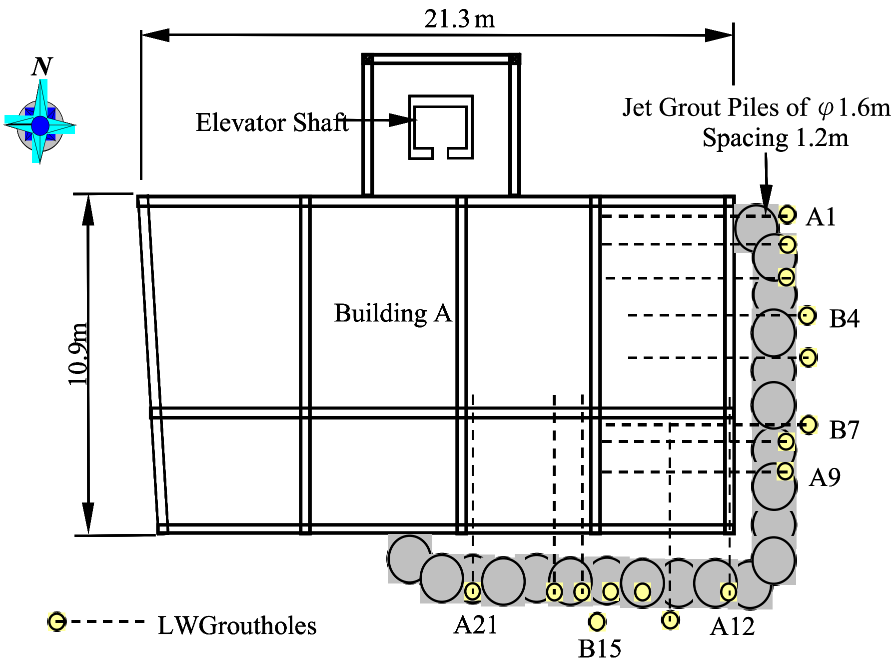

Figure 5. Fracturing grouting for rectifying a tilted building