BUILDING PROTECTION FOR DEEP EXCAVATIONS

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Reprinted from Proceedings of
Symposium of Taipei Metropolitan Rapid Transit Systems,
Vol.C, pp.295-304, Taipei, 1993

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Abstract

The paper discusses the concept of building protection and the general procedures adopted in the design and construction of TRTS. A few precautionary protection measures carried out by the contractors are briefly mentioned for the purpose of illustration.

深開挖之建物保護

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摘　　要

本文介紹台北捷運系統建物保護之設計理念及步驟,並藉數例以說明在施工時可採行之保護措施。

I. Introduction

For any deep excavation, as illustrated in Fig. 1, ground movements are inevitable due to relaxation of stresses as the retaining wall moves and/or lowering of ground water as a result of seepage flow below the toe of retaining wall and/or leakage through the wall membranes leading to consolidation of, mainly, clayey soils. In constructions of mass rapid transit systems in city areas, ground movements often become one of the major concerns because of the presence of numerous structures in close proximities of the excavations.

Building protection, in a broad sense, includes all the measures taken in both the design and the construction stages. The following are the major steps in the process of building protection:

- Risk Assessment
- Precautionary Measures
- Instrumentation and Monitoring
- Remedial Measures

This paper summarizes the concept of building protection and the general procedures adopted in the design and the construction of the Taipei Rapid Transit Systems (TRTS). For the purpose of illustration, a few precautionary protection measures adopted by the contractors are presented.

II. Risk Assessment

As shown in Fig. 1, as the retaining wall moves laterally during excavation, the ground behind the wall will move together. Besides, there will be accompanying settlements to accommodate the ground loss which is the volume of soils between the original and the new positions of the retaining wall. Within a certain distance from the wall, these movements may damage structures as a result of tilting, settling and tearing.

A. Zone of Influence

Since ground movements diminish as the distance to the retaining wall increases, as the first task in the design stage, the designer, i.e., the Detailed Design Consultant (DDC), studies the ground conditions and determines how far the influence of ground movements may reach, i.e. the so called zone of influence. For stiff sites, the ground movements are smaller in magnitudes in comparison and the zones of influence are expected to be narrower and for soft sites the zones of in influence will be wider. Zones of influences certainly depend on the depths of excavations as well. As illustrated in Fig. 2, for TRTS, the boundaries of zones of influence typically extend from the outer edges of permanent structures with slopes of, typically, 1 (vertical) in 1.5 (horizontal), and in some cases, are as flat as 1 in 2.

For each contract, the DDC estimates the magnitudes of ground movements which are most likely to occur and evaluates their damage potentials on all the structures within the zones of influence. Those structures requiring precautionary protection measures are specified in the contract and it will be compulsory for the contractor to take necessary actions for ensuring their safety. Other than those specified, all the buildings in the zones of influence have to be assessed by the contractor to see if protection measures are required.

Specifications require that the lowering of groundwater outside the excavation be limited to, normally, 1m and therefore, in determining the zones of influence, consolidation settlements are not considered. It is thus possible that, buildings outside the zones of influence are damaged if groundwater is not maintained. This is beyond the designer's control. For this reason and others, the contract states that the contractor is fully responsible for all the damages caused by his construction activities no matter where they occur. The zones of influence merely identify buildings for which assessments are specifically required and do not limit the contractor's liability.

B. Building Condition Survey

In the design stage, the DDC is required to obtain information on the adjacent properties for the purpose of assessing the necessity of protection. For newer buildings, relevant information is available in the Department of Building Control but for the older ones, information can only be obtained by inspection.

In the construction stage, all the structures within the zones of influence are subject to building condition survey. The survey is carried out by a credible third party engaged by the contractor. The information obtained serves as the basis for the contractor to work out his protection programs and also as a basis of judgment in claims should any of the structures be damaged.

The building condition surveyor, usually an architect, only records evidences such as number of stories, number of basement levels, type of structure, type of finishes, existing cracks, tilting, leakage, etc. and does not assess the structural conditions for which even structural specialists will find it difficult. Besides, structural members, i.e., beams and columns, are often covered by finishes and/or furniture, and it is thus not possible to see defects visually. It is the contractor's responsibility, if deemed necessary, to engage a qualified specialist to evaluate the structural conditions. This was done only occasionally for structures of significant importance.

C. Prediction of Movements of Foundations

Both the DDC and the contractor are required to predict the movements of the foundations of buildings within the zones of influence. It is a common practice to assume that the foundations move together with the ground, i.e., the effects of soil- structural interaction are ignored. This is somewhat conservative, particularly, for mat foundations of which the rigidity helps resisting relative movements. Furthermore, because of the numerous uncertainties associated with the construction, sophisticated analyses are not justifiable and the predictions rely heavily on the past experiences and empirical formulas. As more data become available, it appears in hindsight, ground movements have been grossly over-estimated because of the poor workmanship of the works carried out in the past. A better way of saying the same is that the TRTS construction has updated the database and background information for building protection and will drastically reduce the building protection measures in the future because of the better quality achieved.

D. Settlement Criteria

It is the DDC's duty to specify the allowable movements of the foundations and it is the duty of the contractor to reduce ground movements below these limits. Criteria which are too tight not only waste much money on unnecessary protection, but will also cause false alarms and become a source of nuisance during construction. On the other hand, loose criteria will result in poor workmanship and damages which could have been prevented. The dividing line is really difficult to draw. Even with a good knowledge on the conditions of structure, a situation which is never a reality, it is still difficult to assess the damage potentials of the movements of foundations. The correlation between building damages and foundation movements is not well defined.

Yet, notwithstanding all the difficulties, the job has to be done. Most of the DDC adopt the guidelines proposed by the Institution of Structural Engineers [1]. The total settlements quoted generally vary from 25mm for normal structures on footings to 50mm for frame structures on mat or piles. Inclinations were generally limited to 1/500 for the former and 1/300 for the latter. Consideration were sometimes given to the age, quality of construction, current structural conditions, however, the judgments were often subjective and the conclusions were inevitably inconsistent.

Although lateral movements are important but are usually not included in consideration because of the lack of guidelines. It is hoped that the settlement criteria which were developed based on observations have included the effects of lateral movements implicitly.

E. Warning Levels

Two levels of warning are stipulated in the specifications, i.e. the alert level and action level. During the construction, whenever the alert level is exceeded, warning is issued to the contractor to call his attention and to request for proposal for remedial measures. As the action level is exceeded, the contractor shall take actions immediately. This ensures that actions are taken promptly.

III. Precautionary Measures

In accordance with the contract, the contractor is required to carried out precautionary measures to reduce foundation movements to satisfy the criteria and the design of these measures is his sole responsibility. The DDC in some cases may specify the minimum measures to be taken but the contractor is required to enhance the program if deemed necessary.

Fig. 3 shows the basic concept of building protection. For TRTS, the DDC is responsible only for the design of permanent structures while the contractor is responsible for all the temporary works. Even the design of retaining walls as supports to excavations is the contractor's responsibility. The building protection is thus fully in the contractor's hand. The precautionary measures commonly adopted include:

a) Those reduce ground movements at sources
b) Those limit the influence of ground movements
c) Those strengthen foundations
d) Those strengthen structures
e) Those correct ground movements

The above list is by no means exhaustive. The measures mentioned have been applied with various degrees of success and the choice will depend on factors which are just too many to generalize. Without any doubts, soil characteristics play the dominating role. Because of the limited space available, only a few measures adopted in the construction of the Nankang Line are briefly mentioned below for the purpose of illustration.

A. Protective Curtain

It has been experienced quite frequently that the installation of diaphragm wall alone caused cave in or even collapse making it difficult to lower the rebar cage. Therefore, for protecting the South Gate, a row of bored piles were installed, as shown in Fig. 4, before diaphragm walling to prevent accidents and to reduce the ground movements during the installation of panels.

B. Soil Nailing

Furthermore, a row of micropiles were added as nails to hold the top of the curtain wall in position as illustrated in Fig. 4. The use of micropiles as soil nails was reported by Ou et. al. [2] to have reduced the deflections of diaphragm walls during excavation by a half. The combination of curtain wall and soil nails is typical for protecting properties adjacent to G12 and BL6 Stations.

C. Transverse Wall

Fig. 4 also shows that, to further reduce the lateral movements of diaphragm walls, three unreinforced transverse panels are installed inside the excavation. These panels brace against the diaphragm walls at the two ends and practically limited the wall movements to a minimum. In this particular example, diaphragm walling technique was used for installing these panels, but it is not always easy to install diaphragm wall panels across the excavation because of the interference from utilities. More commonly, jet grouting at angles is adopted for the purpose.

D. Preloading Struts

All the struts for the TRTS excavations were preloaded to 50 percents, or even greater, of their design loads. This value is reported to be the optimum in many literatures. Higher preloads gain little benefits and may cause concentration of loads on some struts.

IV. Instrumentation & Monitoring

As illustrated in Fig. 1, buildings may be damaged as a result of excessive settlements and tilting causing stress concentration in structural members and difficulties in the operation of mechanical facilities. Therefore, as a part of building protection, it is important to closely monitor the settlements and tilting of the structures during the construction so the situations can be judged all the times. It is also important to monitor the ground movements near the sources where they start, i.e. near the pit, so the causes of damages can be identified and effective remedial measures can be taken. There are other types of instrument installed mainly for the purpose of confirming the design assumptions and refining the future design, such as load cells (for struts), earthpressure cells, etc. Although they do not contribute directly to building protection per se, the readings are useful in judging the safety of the excavation and contribute to building protection indirectly. It should also be realized that based on experience, hardly more than a quarter of the instruments will survive at the end of construction, therefore, ample allowance shall be provided in determining the quantities of instruments.

It is important to take prompt actions before problems become serious. Therefore, readings are taken, normally, at weekly intervals. The frequency is adjusted to suit the construction activities. In critical stages, readings are even taken hourly.

V. Remedial Measures

Remedial measures are those carried out after the problem is observed. From a geotechnical point of view, remedial measures include

- Recharging for compensating groundwater
- Grouting for stopping leakage and
- Compaction grouting for compensating ground loss

As often said: "An ounce of prevention is worth a pound of cure (預防勝於治療)". Remedial measures should be taken before the problem becomes serious and incurable. The adoption of remedial measures for building protection may sound passive, but in some cases it is the only way to go because of the lack of effective ways to reduce foundation movements without side effects. It does have the advantages of "right-to-the-point", that means, un-necessary actions which are not only wasteful but may also be harmful can be avoid.

VI. Summary

Regarding building protection, the designers often faces the dilemma that

a) He can not come up with an accurate assessment of the building conditions in the design stage because of the lack of information, nor can he estimate with confidence ground movements which, in addition to numerous assumptions made in the design, highly depend on the method of construction and the workmanship,

b) He can not come up with an accurate estimate of budget for building protection because he does not do the design, or protection is extremely expensive and yet he does not know for sure that the measures to be taken will be effective,

c) The worst of all, he knows for sure that nothing will work and yet something has to be done, otherwise, he will be responsible for the damages.

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 may do more harm than good. Underpinning, which is favored by structural engineers, for example, has been found to induce as much ground settlements as if had not been carried out. High pressure grouting was reported to produce much damages to underground structures and utilities due to excessive ground heaves. The old Chinese saying - "Too much is as bad as doing too little (過猶不及)" should always be remembered.

VII. Summary

Building protection is an important subject for deep excavations and deserves careful considerations. The most effective building protection measures are those reduce ground movements at sources. Improper measures and/or measures improperly executed will do more harm than good.

Acknowledgements

The authors are grateful to the Department of Rapid Transit Systems of the Taipei Municipal Government for granting the permission of publishing the data presented in this paper.

References

[1] The Institution of Structural Engineers, "Structure- Soil Interaction - A State of the Art Report," 1978

[2] Ou, C. D., Lee, K. H., Tsai, K. W. and Hwang, P. T., "Diaphragm Wall Construction in Sandy Soils with Salt Water Intrusion," Proc. 9th Asian Regional Conf. on Geot. Engrg, Bangkok, Vol 1 , pp217-274, 1991

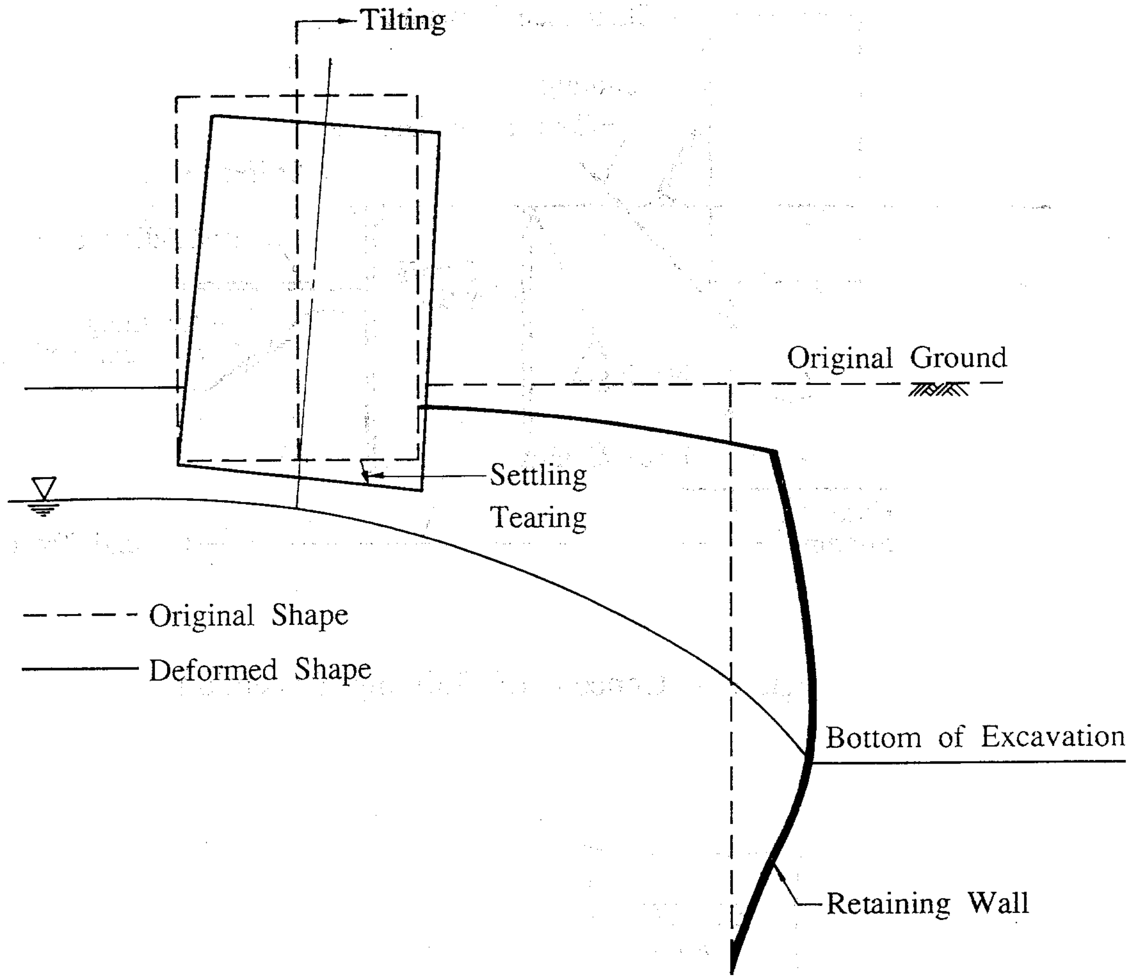

Figure 1 Effects of Excavation on Adjacent Structures

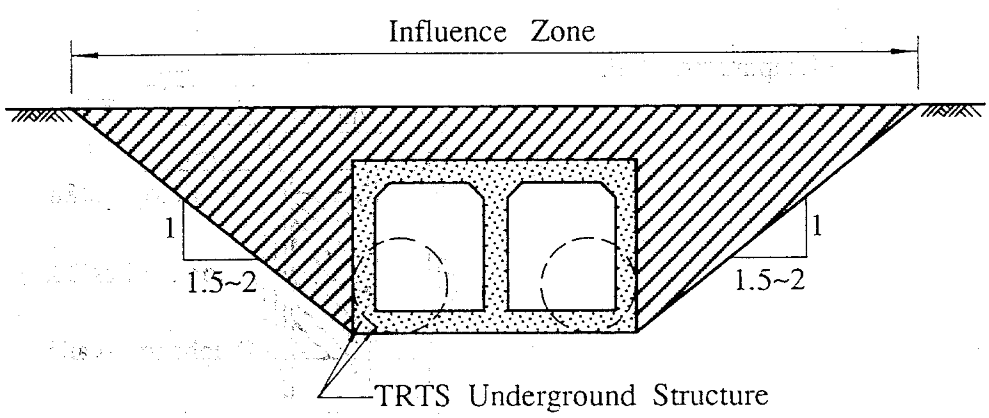

Figure 2 Zone of Influence

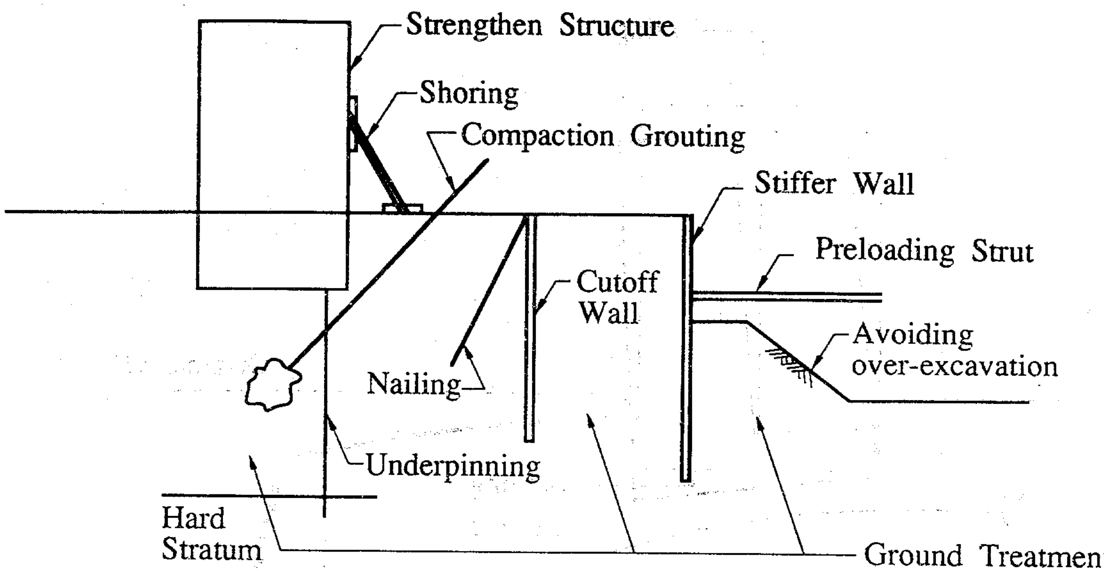

Figure 3 Concept of Building Protection

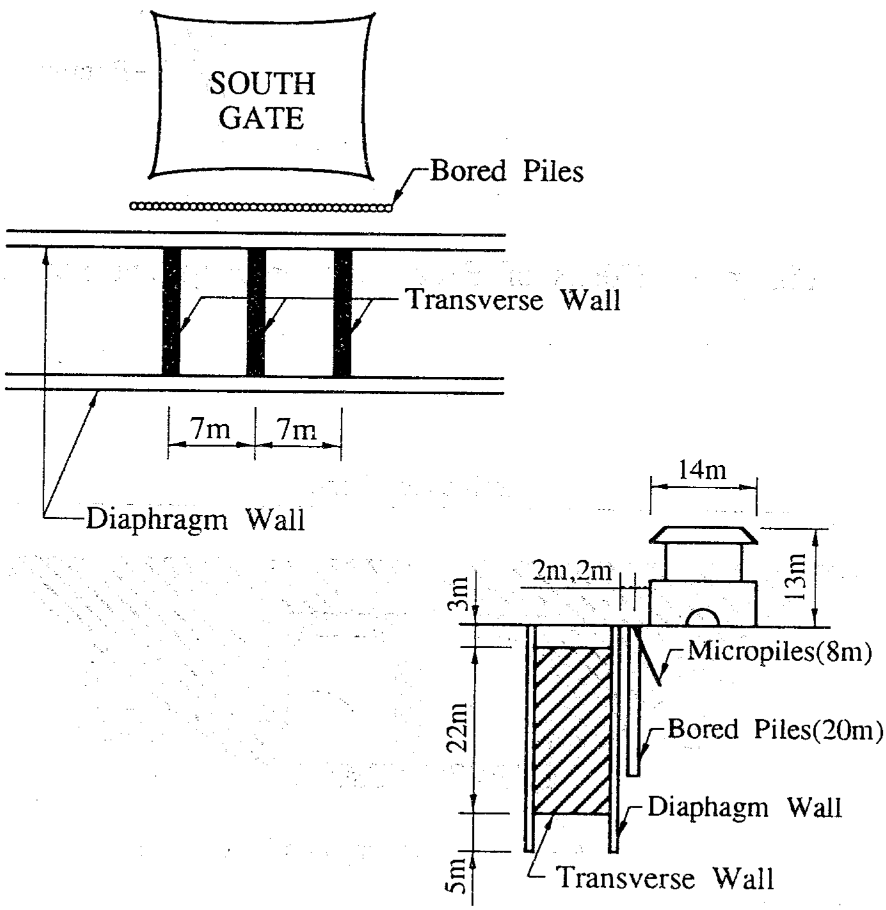

Figure 4 Protection of South Gate