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Mitigating measures for underground construction in soft ground

General Report for the 3rd session: Mitigating measures

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ABSTRACT: This general report reviews and summarises 15 papers submitted to the session on Mitigating measures. An asset management system for underground structures is introduced to help infrastructure owners or clients make decisions about construction and repair. The significance of reducing tunnelling- or excavation-induced displacement and instability within soft ground is described.

1 INTRODUCTION

In my previous General Report on TBM and Shield Tunnelling session during IS-Tokyo 99, the submitted papers were reviewed from the standpoint of risk management system (Akagi, 1999). The risk management cycle consists of the following four stages, as shown in Fig.1:

(1) Listing of risk factors
(2) Risk analyses
(3) Countermeasures against risk factors
(4) Assessment of the countermeasures.

Mitigation is the process of making something milder or less intense or severe. Therefore, mitigating measures are equivalent to "countermeasures" in the articulated risk management system.

The assessment of the countermeasures adopted shall be performed from both technical and economical points of view, the latter assessing the costs needed to conduct the mitigating measures, including those prior to, during and after the underground construction. Underground structures become aged during their service and require repairs; therefore, the cost of mitigating risks during the life cycle of the underground structure shall be taken into account in the engineering construction project. The economic assessment may be done by the cost versus benefit basis. Unless the countermeasures are appropriate, other alternative mitigating measures are examined and assessed. That is the risk management cycle.

However, the risk management system provides insufficient information for the engineering project client or its owner to make the decision to go ahead with construction, particularly in the case of repairing an existing underground structure. The project clients need a reason to conduct the repairing construction.

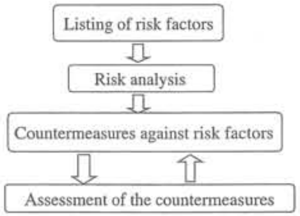

Figure 1. Risk management cycle.

This reason must be provided by an asset management system.

2 ASSET MANAGEMENT SYSTEM FOR UNDERGROUND STRUCTURE

Asset management is a term originally used in the management of property and stock. The purpose of an asset management system is to evaluate existing property and stock on a monetary basis, and it is employed by property owners to make decisions regarding their investments.

An asset management system can be used to manage infrastructure, such as transportation systems, water and energy supply systems and communication network systems, including underground structures. The value of the existing aged underground structure is evaluated by the price of its initial construction or its reconstruction cost reduced by the lost value during its usage, as indicated in Eq. (1).

$$V = V_0\left(1-\frac{t}{T}\right) \quad (1)$$

in which V is the current value of the existing aged structure, V_0 is its initial construction or reconstruction cost, T is its life span, and t is the time elapsed since its initial construction or reconstruction.

The infrastructure owner is able to make a decision about repairs based on a comparison between the cost of repairing and the value of the existing infrastructure. In other words, if geotechnical engineers have conducted an asset management analyses, they will be able to reasonably persuade the financial management section of the client or the owner to invest in countermeasures for avoiding geotechnical risk in an underground structure.

3 PAPER REVIEW AND REPORTER'S COMMENTS

The paper review and the reporter's comments are described below in the order of the initial paper number.

Cheong and Soga (No.23) present results on their investigation, via a small-scale experiment, of the effects of underground excavation on compensation grouting during tunnelling, as shown in Fig.2. One risk issue is the compensation efficiency in view of the volume change of the clay around the tunnel excavation. Another is the tunnel face instability due to the acting compensation grouting pressure close to the tunnel face. It seems to be difficult to control the fracture direction developed within the clay due to the compensation grouting in the field.

Chapman, Chan and Ahn (No.43) propose a method of predicting ground displacement due to compensation grouting during the construction of the Heathrow Airport Express tunnels, as indicated in Fig.3, using a Gaussian curve fitting procedure. This method can be employed in the risk analysis. The central risk issues include settlement, rotation and distortion of the existing tunnel structure. How can the rotation and distortion of the tunnel be predicted using the proposed semi-empirical method?

Agral, Ashkhmen, Korolev and Pronia (No.46) show a simple case history of a trial injection of a fine-disperse binding material suspension to improve an underground area, where a highway tunnel crosses a subway tunnel in Moscow. The target of the soil improvement was not indicated in the paper, and the cost of injection should be taken into account.

Simic (No.49) conducts a systematic approach to the evaluation of the interaction between super-structures and tunnelling-induced settlement. The procedure provides a useful tool for risk analysis of the damage to super-structures from tunnelling-induced subsidence, as shown in Fig. 4.

Bilotta, Russo and Viggiani (No.57) perform plane strain finite element analyses on the effects of a

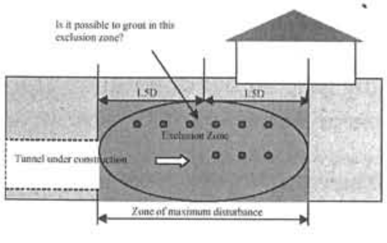

Figure 2. Grouting in exclusion zone in compensation grouting.

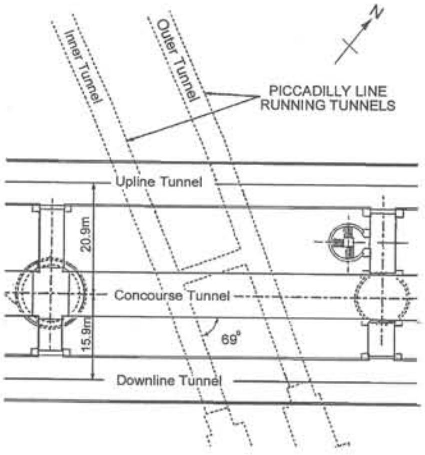

Figure 3. Layouts of the piccadilly line tunnels and the Heathrow Airport Express tunnels.

diaphragm wall embedment between a shallow tunnel and an existing structure, as shown in Fig.5. The barrier wall is shown to be deepened at least at the tunnel invert level. Useful information for risk assessment of the countermeasures is provided. Although the countermeasures to protect the existing structure are important, the control of the tunnel face stability and the reduction of the tunnelling induced settlement are considered to be much more significant.

Stadelmann (No. 60) details the selection process for the construction method of the Zurich motorway tunnel in soft ground with a high water table, as demonstrated in Fig.6. The work includes a list of the geotechnical hazards involved in the construction and the numerical simulation of the mechanical behaviour of the soft ground due to the tunnelling. Comparison among the possible construction methods with appropriate auxiliary measures was carried out from the viewpoint of risk and construction costs. This is a good

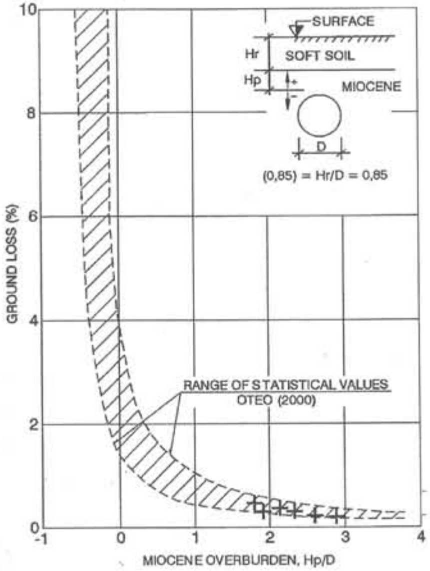

Figure 4. Ground loss measured in green filed trough.

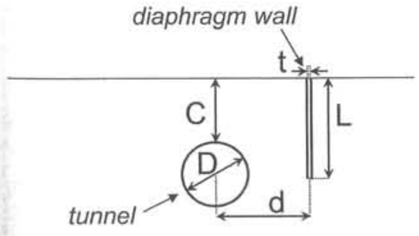

Figure 5. Sketch of the model used in the simulation.

example of risk management-based selection of tunnelling construction methods. An actual case history of this tunnel construction is expected to be reported.

Gens, Di Mariano, Gesto and Schwarz (No.66) report case histories of ground movement control in the construction of a new metro line in Barcelona using three types of methods: (i) the installation of a jet grouted column screen (Fig. 7), (ii) compensation grouting, and (iii) structural jacking. The measurement results of the vertical displacement during the tunnelling seemed to be determined by the tunnel face stability and the EPB (Earth Pressure Balanced)-type TBM (Tunnel Boring Machine) tunnelling-induced ground movement. Although the various auxiliary construction methods during under-ground excavation

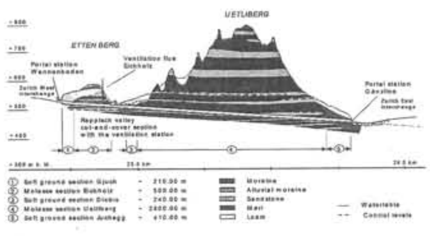

Figure 6. Longitudinal profile along the tunnel.

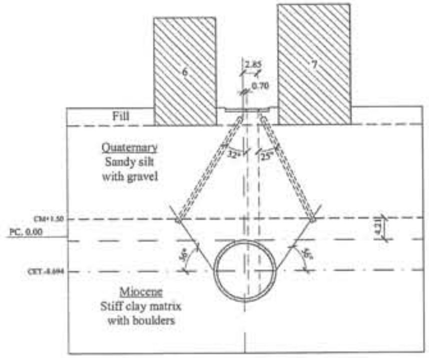

Figure 7. Cross section of jet grout columns for ground movement control.

are sure to be effective with a proper application, the appropriate tunnelling techniques using EPB-type TBM within alluvial sand and gravel or clay with boulders are crucial. The tunnelling technique controls the earth pressure acting on the cutting face of the TBM, the excavated soil volume, and the tail void grouting.

Pachen, de Groot and Meijers (No.69) indicate the geotechnical risk during slurry-type TBM tunnelling just below the existing old railway in Rotterdam, as shown in Fig. 8. The potential of the liquefaction of the saturated loose sand beneath the existing embankment was demonstrated from undrained triaxial tests. Countermeasures against the liquefaction were chosen from the viewpoints of risk reduction, interruption of rail traffic and cost. An actual case history using the adopted countermeasures shall be reported.

Haß and Schäfers (No.73) focus on the artificial ground freezing method as a countermeasure in underground construction, specifically against collapse and excessive ground movement, as demonstrated in Fig. 9. Good case histories of artificial ground freezing technology development and its successful applications in Europe, 3 German cases and 1 case in Netherlands are presented. Special attention is needed for the application of the ground freezing method to soft clay.

Christiaens, Hemerijckx and Vereerstraeten (No.88) present a successful case history of slurry-type TBM tunnelling in dense sand under the old Antwerp city centre, as shown in Fig.10. The countermeasures adopted were a pipe-jacked roofing method, a jacking method with sheeted trench and a grout injection method. Detailed information about slurry-type TBM driving processes shall be provided, i.e. the magnitude

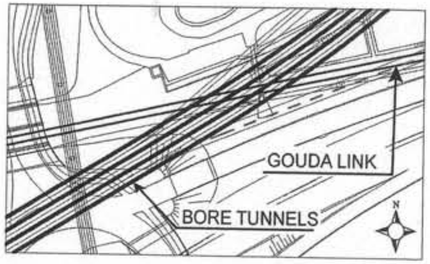

Figure 8. Overview railway crossing gouda link.

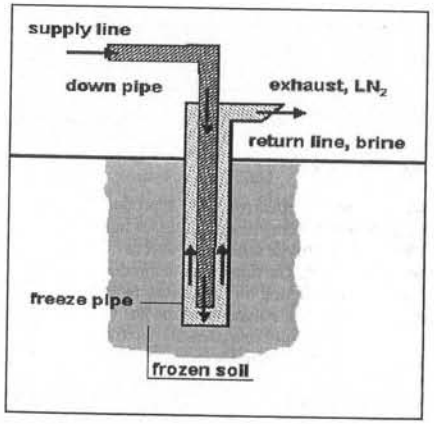

Figure 9. Ground freezing principle.

of slurry pressure, the established excavation volume and the tail void grouting.

Spasojevic, Mair and Gumbel (No.96) introduce centrifuge model test results on the interaction between an old deteriorating pipe lined with close-fitting polymeric liners and the surrounding soil, as indicated in Fig. 11. A gap in knowledge exists between the development of the trenchless renovation technique and design practice. The information gained from their series of centrifuge models of soil load transfer should bring progress to rational design approaches. The actual event is expected to be more complicated than in the centrifuge modelling, i.e. the effects of underground water and the variations of backfill soil properties will come into play. The cost aspect of the rehabilitation will also be reported.

Chiriotti, Avagnina, Grasso and Tripoli (No.106) report a successful case history of EPB-type TBM tunnelling in a weathered rock mass and granular residual soil just below historically sensitive buildings, in Porto. The countermeasures adopted included grout injection prior to the tunnelling and compensation grouting during and after the TBM driving,

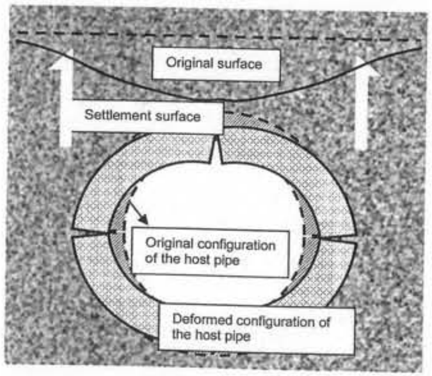

Figure 11. Stress distribution accompanying deterioration of the host pipe.

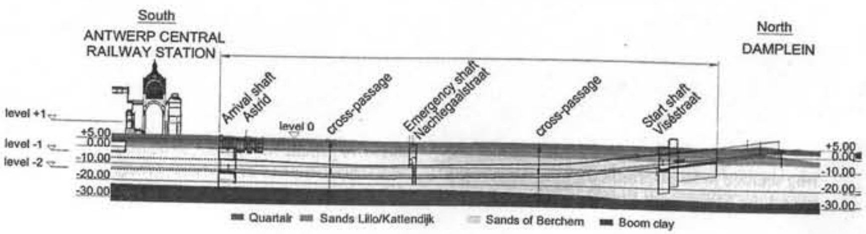

Figure 10. Longitudinal profile of the tunnel.

as demonstrated in Fig.12. Sufficient investigation of the EPB-type TBM driving technique within poor soil conditions was conducted to maintain tunnel face stability and reduce the ground settlement. Information on the costs required to conduct the countermeasures, including the monitoring and the GIS system, shall be indicated.

Petrukhin, Shuljatjev and Mozgacheva (No.121) demonstrate a vertical geotechnical barrier erected by compensation grouting, in the case of diaphragm wall excavation in soft ground, as shown in Fig.13.

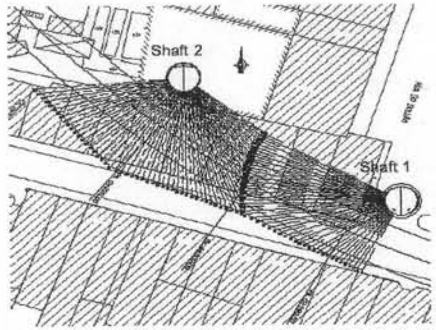

Figure 12. Plan of the sub-horizontal grout injection.

Although the authors claim the effectiveness of the vertical geotechnical barrier, the reduction of the ground displacement due to a diaphragm wall excavation seems to be much more crucial.

Shirlaw, Boone, Sugden and Peach (No.123) clearly point out the importance of managing risk through the control and the specification of EPB-type TBM tunnelling, including the shape of the disc cutter (Fig. 14). The proposed risk management system covers site

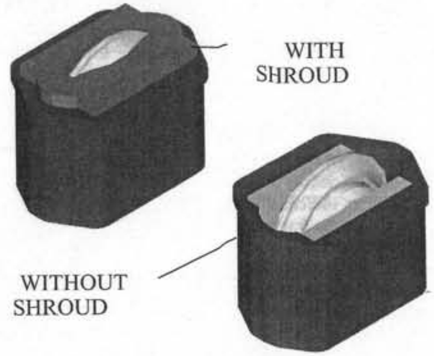

Figure 14. Shape of the disc cutter.

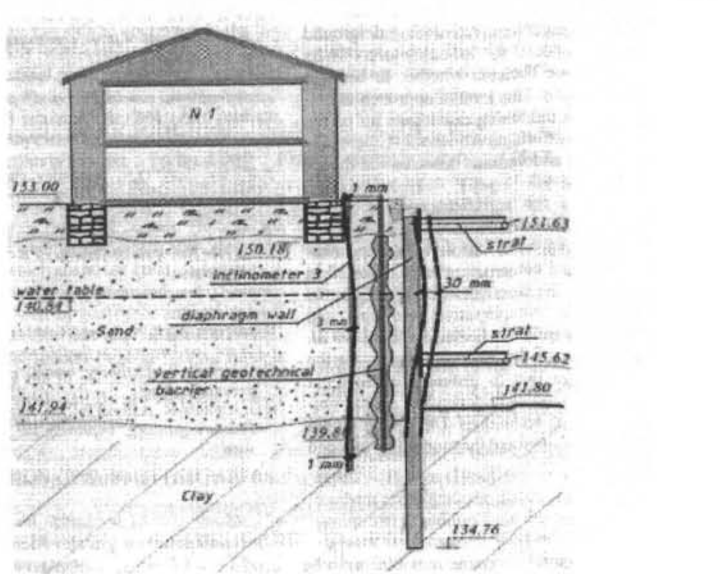

Figure 13. Excavation profile near building N1.

Figure 15. Hydraulic fracture initiation in sand.

investigation, specification of TBM, planning for tunnelling, and expert supervision. Although the countermeasures to protect the existing structure from damage using compensation grouting are important, the reduction of the risk source through successful control of the TBM driving and the excavation themselves is more crucial.

te Grotenhuis, van Tol, Haasnoot and Bezuijen (No. 128) demonstrate the modelling of fracture grouting in sand, as indicated in Fig.15. Their fracture model reproduces the fracture propagation process, the yield and friction characteristics of the grout and the bleeding of the injected grout. The validity of the modelling shall be demonstrated from experimental evidence.

4 CONCLUDING REMARKS

This general report reviews and summarises 15 papers submitted to the session on mitigation measures.

First, an asset management system for underground structures was introduced for infrastructure owners or clients making the decision whether to conduct construction and repair. This kind of approach is crucial under the recent tightening of budgets for public infrastructure. More information on the cost of the mitigating measures for underground construction should be provided.

Another issue is the significance of reducing tunnelling and excavation-induced displacement and instability within soft ground. Various mitigating measures for underground construction were reported in this session, i.e. (i) the installation of a jet-grouted column screen, (ii) compensation grouting and (iii) structural jacking, as indicated in *Gens et al.* However, the effects of the countermeasures on the reduction of damage due to ground displacement and instability are completely dependent on the tunnelling and excavation techniques. Unless the tunnel face stability is maintained and the tunnelling-induced settlement is properly controlled, as described by *Shirlaw et al.*, the countermeasures lose their objective.

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(Alphabetical order of the first author's surname)

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Chapman, D.N., A.H.C. Chan and S.K. Ahn. *Using a semi-empirical method to estimate the ground displacements caused by grouting operations.*

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