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Authors Index / *Index des auteurs*

General Report of TC204 Underground Constructions

Rapport général du TC204 Constructions souterraines

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ABSTRACT : This paper presents the general report of the TC204 session "Underground Constructions on Soft Ground" of the 18th International Conference on Soil Mechanics and Geotechnical Engineering. A total of 27 papers were assigned for this session, they were divided in six general topics and reviewed briefly in this report. Apart from the regular topics of the TC204, this session also present three papers on rock tunnelling. This report is intended to provide a general view of the papers of the TC204 session. However, for a better understanding of the presented contents, the readers are encouraged to look for the complete papers in the proceedings.

RÉSUMÉ : Ce document présente le rapport général de la session TC204 "Travaux souterrains en sol meuble" du 18e congrès International de Mécanique des Sols et de Géotechnique. Au total, cette session comporte 27 communications, qui ont été réparties en six thèmes généraux et sont brièvement analysées dans le présent rapport. Outre les thèmes du comité TC204, cette session présente également trois communications concernant les tunnels au rocher. Ce rapport est destiné à fournir une vue d'ensemble des communications de la session TC204. Pour une meilleure compréhension des contenus présentés, les lecteurs sont encouragés à consulter les articles complets dans les comptes-rendus.

KEYWORDS: Underground constructions, soft ground, rock, tunnels, maintenance, construction

1 INTRODUCTION

Underground constructions have been one of the most challenging endeavours of engineering for centuries. The effort of researchers and engineers has given the society the opportunity to explore the full potential of the underground space in any geological conditions preserving the surface structures.

The papers for the TC204 session "Underground Constructions on Soft Ground" on the 18th ISSMGE conference show the on-going development of this broad field, covering several important topics, proposing solutions for different problems and tracing the way for future research.

A total of 27 papers from 13 nations have been located in the TC204 session. Figure 1 illustrates the number of papers submitted per nation.

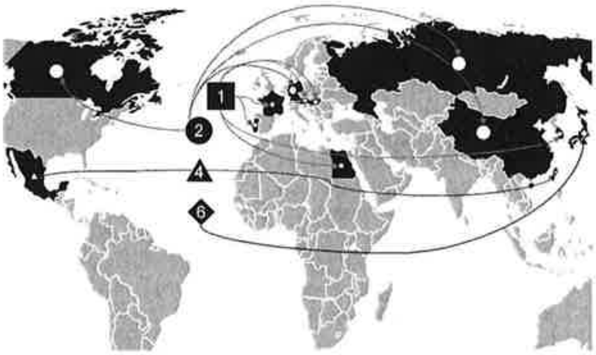

Figure 1. World Map indicating the number of papers submitted per member society.

It is also remarkable to note that some countries did not send papers for the TC204 session, although these countries have a tunnel tradition and still a number of projects running: Brazil, Iran, India, UK, and USA. Despite the TC focus on Underground Constructions in Soft Ground, the ISSMGE Conference session also presents some cases for underground constructions in rock.

The papers were divided in six general topics as follows:

1. Underground Constructions in Soil (9)
2. Mitigation Measures (7)
3. Tunnel Maintenance and Instrumentation (3)
4. Rock Tunnelling (3)
5. Seismic Analysis of Tunnels (3)
6. Construction Techniques (2)

2 UNDERGROUND CONSTRUCTIONS IN SOIL

This topic gathered nine papers that had a general view about tunnels constructed in or based on soil. Discussions about soft soil deposits, twin tunnel interaction, stress arching in trenches, analytical stability methods, assessment of surface settlements, wearing of TBM tools, cavity formation around underground structures and even immersed tunnels are presented.

Rangel-Núñez et al. in their paper "Performance of the tunnel lining subjected to decompression effects on very soft clay deposits" present a case study of tunnel excavated with a Tunnel Boring Machine (TBM) in the Mexico City soft clay. The study evaluated the particular case of the Eastern Emitter Tunnel where a channel was dredged above the tunnel alignment and the unloading reactivated pre-existent semi-vertical cracks in the clay deposit. These cracks were identified visually during the construction of a shaft near the channel and were an indication of the unloading of that zone. Piezocone tests confirmed that, as the measured coefficient of earth pressure at rest was three times smaller near the channel compared to the value at some distance from the channel.

Instrumentation of the tunnel revealed an increasing rate of lining displacement after a dredging procedure at the channel above. A multistep Finite Element Analysis (FEA) was carried out to evaluate if this anomalous behaviour could be attributed to the reactivation of the cracks. The modelling methodology achieved great results with lining displacements of the same order of magnitude to the in-situ observations. Figure 2 presents the convergence of a lining section below the channel that was dredged, however the authors of the general report believe that the division entitled "Beginning of the lining stability" was intended to state instability.

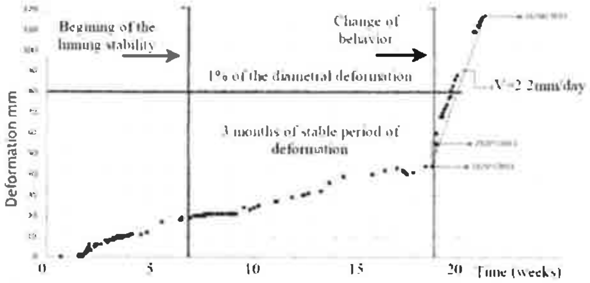

Figure 2. Ring 671 time evolution of deformation (after Rangel-Núñez *et al.*).

In their paper "Design of tunnel lining in consolidating soft soils", **Rodríguez-Rebolledo *et al.*** study the effects of consolidation on the lining by a series of FEA. The Mexico City valley is affected by an on-going regional subsidence process associated to intense pumping of water from the aquifer below the urban area. This process is locally combined with the consolidation due to the excess of pore pressure generated by the excavation of the tunnel and installation of the primary liner. A multistep FEA was performed and several tools to account for plastic flow of lining, joints and interfaces were applied. The results indicate a very unfavourable condition for the final lining, with vertical loading and horizontal confinement loss.

Shahin *et al.* combine 1:100 centrifuge model tests with 2D FEA to analyse the excavation of twin tunnels with different relative positions and the excavation of a single tunnel beneath a strip and a pile foundation. Their study is entitled "Rational interpretation of tunnelling considering existing tunnel and building loads". The results calculated with the modelling tools applied and the elastoplastic subloading t_{ij} constitutive model are in remarkable agreement with the centrifuge model tests. The relative position of the twin tunnels influences the surface settlement magnitude as well as the region of intense shear strain that occurs between the two tunnels, as displayed in Figure 3 for the condition of diagonal alignment.

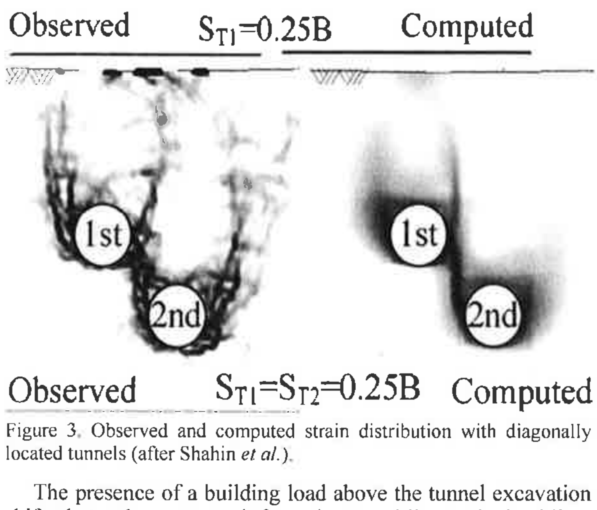

Figure 3. Observed and computed strain distribution with diagonally located tunnels (after Shahin *et al.*).

The presence of a building load above the tunnel excavation shifts the settlement trough from the tunnel line to the load line. In terms of strains distribution the study revealed the occurrence of a shear band from the building load, either for strip or pile foundation, to the closest side of the tunnel, as displayed in Figure 4.

Li *et al.* in their paper "An evaluation of influence factors that affect pressures in backfilled trenches" present the case for a rational approach to the design of conduits buried in trenches. The assessment of the vertical stress on the conduit based on analytical solutions may result in a underestimated value. A numerical analysis with FLAC was performed to reveal the relative importance of each soil and geometric parameter on the vertical stress distribution on the conduit. The results indicate that the geometric layout of the trench and the soil resistance parameters are the most influencing factors. It would have been of great value if these data were compared to the existing analytical solutions.

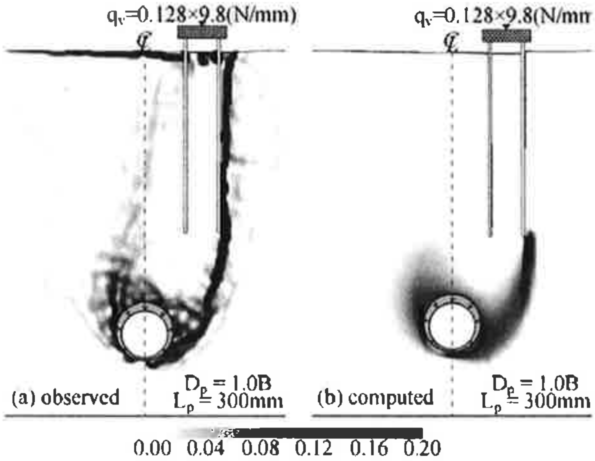

Figure 4. Observed and computed strain distribution for a tunnel beneath a piled foundation (after Shahin *et al.*).

Kobayashi and Matsumoto present an upper bound limit analysis solution in their paper "On the stability of a trap door evaluated by upper bound method". A typical roof failure situation is analysed with a parabola-shaped loosened soil zone, falling down vertically. The solution is displayed in design graphs. With these graphs it is possible to depict at what conditions the trap door is stable without support as well as the increase in the arching effect in case of narrow conditions.

Mazek and El Ghamrawy use data from The Greater Cairo metro for a thorough comparison of different surface settlements prediction methods. The results are presented in their paper "Assessment of empirical method used to study tunnel system performance". The study discussed that the empirical method proposed by Peck and Schmidt (1969) is unable to properly differentiate distinct sand conditions. An elastoplastic constitutive model with the elastic modulus as a function of the confining stress was employed in 2D FEA and resulted in a good agreement between FEA predictions and field measurements for different sand conditions, from loose to very dense sand, which is remarkable since the with FEA calculated troughs are usually too wide.

Köppl and Thuro propose a model for rational planning of hyperbaric interventions to change cutting tools of Mix-Shield TBMs that would avoid critical geological zones and reduce unnecessary intervention costs, as discussed in their paper "Cutting tool wear prognosis and management of wear-related risks for Mix-Shield TBM in soft ground". 18 TBM drives were analysed in terms of soil conditions and TBM characteristics in order to develop the empirical model for the service life of the cutter tools.

The results could not achieve a reliable correlation of one individual soil parameter to the wearing of the cutting tools. Therefore, the hardness of the soil, the stress at the contact surface and the shape parameter of the soil components were combined in a new parameter called Soil Abrasivity Index

(SAI). A non-linear relation between the SAI and the maximum serviceable cutting distance for the cutting tools was achieved and it is displayed on Figure 5. A linear relation was found between the ratio of the covered cutting distance over the maximum cutting distance and the ratio of number of tools to be changed in each intervention over the total number of tools in the TBM cutter head.

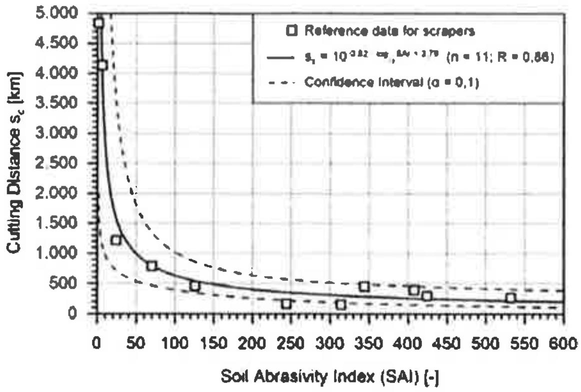

Figure 5. Correlation of the Soil Abrasivity Index (SAI) and the cutting distances of disc cutters (after Köppl and Thuro).

Sato and Kuwano in their paper "Effects of buried structures on the formation of underground cavity" present several model tests to investigate the consequences of an unfavourable water flow condition around buried structures. Such a flow may lead to an underground cavity and eventually a surface collapse. The observations suggest that the loss of confinement near the buried structured would increase local permeability and therefore the water flow around that area.

Xie *et al.* present a thorough analysis of induced settlements from immersed tube tunnel (IMT) on deep soft subsoil, as stated by the title of their paper: "Subsoil settlement feature of immersed tube tunnel in deep soft subsoil with heavy siltation in open sea". The study is based on the project of the Hong Kong-Zhuhai-Macao Link that comprises a bridge that will be more than 35 km long and a 6 km long IMT (Figure 6).

Figure 6. Location of Hong Kong-Zhuhai-Macao immersed tunnel (after Huang *et al.*).

Based on on-site CPTU test results and in-situ bored soil samples numerical modelling was performed to investigate the stress-path of the subsoil during and after construction of the IMT. To confirm the results tests were run in a geotechnical centrifuge to measure and analyse the whole process of consolidation, excavation, tube location, backfilling, siltation and re-excavation of channel.

The results indicate that in the process of excavation and backfill recompression, the stress and settlement distributions bellow the tunnel cross-section have a saddle-shape, as shown for the stresses in Figure 7. The measured settlement differences between the cross section and the longitudinal direction of the tunnel are small, as expected.

The papers in this topic went through several possible conditions were the soil behaviour has to be assessed and predicted for a proper design and construction of an underground facility. Köppl and Thuro properly discussed the importance of a proper selection of collected data for an empirical method. Shahin et al. showed us how the combination of a powerful constitutive method, with properly assessed parameters, with a model test can confirm the predictions of tunnels in special conditions.

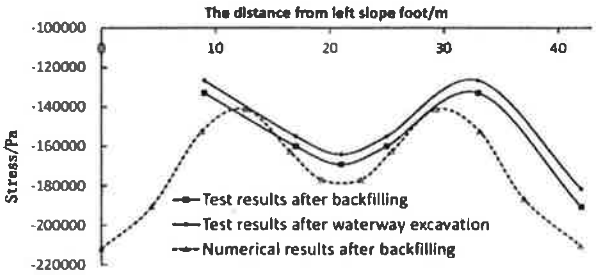

Figure 7. Stress distribution of the bottom a foundation trench section (after Xie *et al.*).

3 MITIGATION MEASURES

Seven papers were classified under this topic, the first three papers presented are about controlling deformations and ensuring stability of tunnels in special conditions, the other four papers are about surface settlements mitigation. The studies were based on real cases, numerical modelling and full scale field trials.

Aguilar *et al.* in their paper "Diametric deformations in the concrete segment lining of a tunnel excavated in soft soils. Criteria for their evaluation and mitigation actions for their control" present a graph (Figure 8) divided in five different zones based on the relation of the percentage of horizontal diameter increase to the time after the lining installation as a criterion for the mitigation measures recommended to ensure stability of the pre-cast reinforced concrete segmented rings that compose an 8.7 m diameter tunnel.

Each zone has specific recommendations for mitigation actions. For example, if the measurements reach zone 3 it is recommended that the ring's annular space is re-injected. Figure 8 shows the five different zones of intervention and three sets of measurements of horizontal diameter increase on different tunnel sections, the numbers at the end of the lines denote the section number of the tunnel lining. Note that one of the measurements resembles the measurement presented by Rangel-Núñez *et al.* There the consolidation caused the deformation, see Section 2, and reinjection is probably not the solution. The authors of the GR expect that for the situation of consolidation it is better to use the metallic frames in an earlier state.

Chang *et al.* in their paper "Application of ductile segments to tunnels in close proximity" analyse the mechanical behaviour of twin tunnels and the use of ductile segments to sustain the unfavourable stress conditions. The case of the Taipei MRT project, where a distance of 1.5 m occurred between twin tunnels, is presented. From 2D numerical analyses a vertical and lateral stress increase, as high as 50%, was calculated for the first tunnel during the excavation of the second one. This sort of behaviour was also observed with the automatic monitoring systems during the tunnel construction. The first tunnel lining went through a 70% increase in the bending moments and a 30% increase in the axial forces. The ductile segments are described as lining systems of favourable ductility and anticorrosion features. The analysis revealed that the ductile segments were able to resist the final stress conditions, where a precast reinforced concrete segment would have failed.

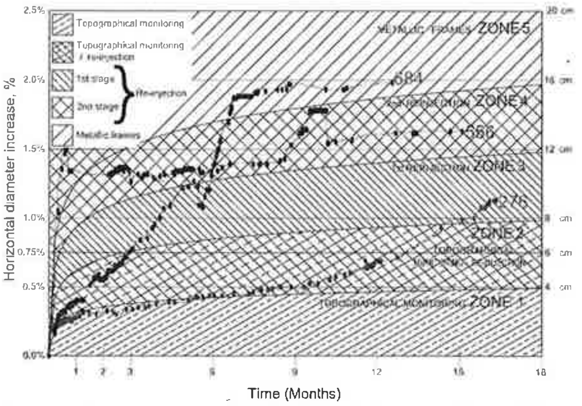

Figure 8. Time evolution of the horizontal diameter of three different ring sections over the proposed diagram for deformational control of tunnel segments (modified from Aguilar *et al.*).

Fang *et al.* in their paper "Construction of a cross passage between two MRT tunnels" defend the concept of several defence measures against water inflow in tunnels under high water head as the only reliable approach. They report the construction of a cross passage between two shield tunnels for the construction of Tu-chen Line of Taipei Rapid Transit Systems. Both jet grouting and chemical grouting were performed to ensure the construction safety under the 26.7 m of pressure head acting on the site. Water-leak tests were conducted, since any crack in the waterproofing system could cause major losses in the project.

Kummerer and Sciotti report how two compensation grouting works were performed to mitigate TBM induced settlements for structures founded on shallow and deep foundations in Rome. Their paper "Compensation grouting with shallow and deep foundations – case study from the metro B1 in Rome" describes how a full scale field trial was performed, for the piled foundation and the footing, in order to properly design the real interventions. Shafts constructed with soilcrete jet-grouting, for the lateral wall and the sealing slab, enabled the TAMs (*Tubes a Manchette*, the tubes by which the grout is injected) to be installed with Horizontal Directional Drilling technology. Figure 9 shows a schematic cross section of one of the buildings with a piled foundation close to Ionio Station with a TAM to pile distance of only 1.65 m, as obtained from the figure.

It was reported that no significant settlements were measured during the drilling operations. The water tightness of the shaft was assessed with pumping and thermal leakage tests, as the water table was just a few meters below the surface. The measured settlements were significantly below the tolerable values and confirm the efficiency of the compensation grouting technique both technically and economically both for shallow and deep foundations.

Cui and Kishida in their paper "Effect of pre-ground improvement method during shallow NATM tunnel excavations under unconsolidated conditions" analyse the layout of ground improvement prior to tunnelling for shallow NATM tunnels in Japan. This surface intervention creates a soil-cement mixture above the tunnel crown. 2D FEA were performed based on the t_{ij} constitutive model and indicated that surface settlements can be prevented by adopting the pre-ground improvement method, and that the method becomes more effective as the improved area becomes larger (Figure 10). The influenced area due to the tunnel excavation becomes narrow as the reinforcement zone intercepts the shear band generated by the tunnel excavation.

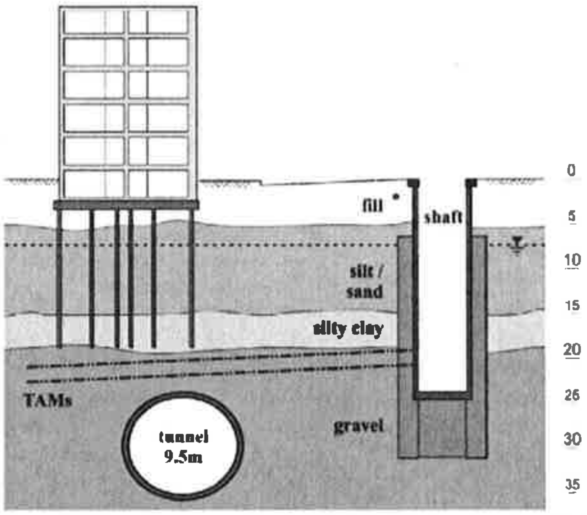

Figure 9. Schematic cross section for TAM installation close to a piled foundation at 'Ionio Station' (after Kummerer and Sciotti).

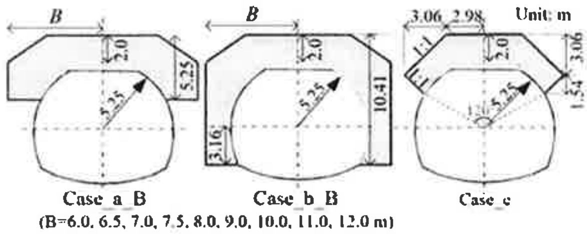

Figure 10. Analysed patterns for the ground improvement profile (after Cui and Kishida).

Ilyichev *et al.* presented the paper "Building deformations, induced by shallow service tunnel construction and protective measures for reducing of its influence" where empirical equations were derived from in-situ measurements of shallow shielded utility tunnels in Moscow to assess surface settlements and building deformations above the tunnel. The results are said to enhance the deformation estimates when in comparison with empirical methods for deep tunnels, but probably only for the local conditions in Moscow.

Petrukhin *et al.* in their paper "Refurbishment and underground space development of Moscow P.I. Tchaikovsky conservatory" present the case study of an historical building in Moscow in which underground service ducts had to be excavated without disrupting the building structure. An interesting assessment of the existing foundation and it's structural integrity allowed the protective measures to be analysed and planned in a reliable way, taking into account the real conditions in which this old structure was founded.

The papers presented in this topic show how it is always possible to build underground structures with safety for both the construction and the surface utilities. **Kummerer and Sciotti** show that full scale field trials are sometimes necessary for a proper design of mitigation measures and how they increase the efficiency of the actual intervention.

Cui and Kishida presented an analysis of the mechanism of reinforcement in terms of stress and strain mobilization. This enables a rational understanding of what are the most important parameters for the design of this type of pre-ground improvement method.

4 TUNNEL MAINTENANCE AND INSTRUMENTATION

Three papers were assigned to this topic. The first paper presents the general concept of inspection routines on underground structures. The other two papers are about specific instruments for monitoring tunnels.

In their paper "Engineering inspection and supervision of tunnels and underground stations of urban metro systems", **Katzenbach and Leppla** describe the negative effects of the lack a proper regulation for inspection of underground constructions. Both the general stability of the structure and the life cycle costs are jeopardized without a proper inspection routine. A concept with four different categories of inspection was developed and applied to the Frankfurt am Main metro system. Definitions of insufficiency and defect were stated and put together to generate a grade for the underground construction at the end of each inspection. The experience shows that the defined modalities and continuous procedures guarantee a sustainable preservation of the underground structures by early identification of insufficiencies and defects. Figure 11 presents an example of what was classified as the main inspection of a tunnel.

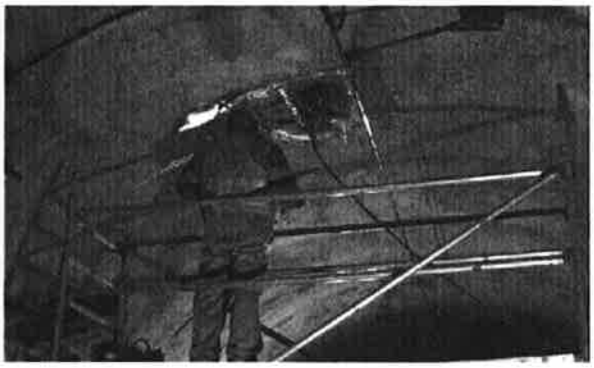

Figure 11. One of the procedures for a main tunnel inspection (after Katzenbach and Leppla).

Huang *et al.* present another study of the Taipei Mass Rapid Transit (MRT) in their paper "Field monitoring of shield tunnel lining using optical fiber Bragg grating based sensors". A strain monitoring instrumentation system was employed to confirm semi-empirical designs and to monitor especially problematic zones of the tunnel. Optical fibre was used to assess the strain evolutions from the start of the concrete pouring of the segment and to obtain results without disturbance by electromagnetic interference.

The optical fibre Bragg gratings (FBG) were installed in the centre of the reinforcement bars (Figure 12) and the readings were recorded from pre-cast concrete section production until installation and operation. The continuous readings enable the analysis of the lining reaction to each construction phase. The record also showed a strain fluctuation during the tunnel operation that was associated with variations in the internal temperature of the tunnel.

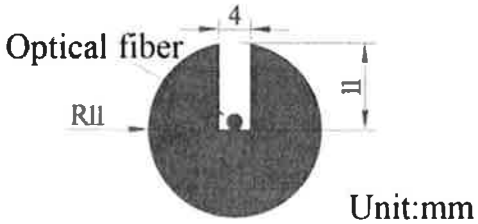

Figure 12. Placement of optical fiber in the reinforcement bar (after Huang *et al.*).

Gay *et al.* present a part of a project to evaluate the constructability and safety of cell preparation tunnels for radioactive waste storage on Callovian-Oxfordian clays, in their paper "Monitoring and Instrumentation of demonstrators storage cells (CMHM)". A set of innovative instruments were designed to monitor these 40 m long, 0.7 m diameter prototype tunnels. The devices enabled video footage associated with a geo-referenced trajectory and optical zoom to detect cracks of one tenth of a millimetre. Measurements of convergence, temperature and relative humidity of the tunnel were also recorded.

The metallic liner was also instrumented to obtain local and distributed strains, temperature and relative humidity. For that a series of laboratory tests was conducted to control the behaviour of different optical fibres under mechanical and thermal variations. Experiments are underway to simulate the presence of waste CMHM packages, by thermally loading the tunnels to 90 °C. The results obtained until now show a great performance of the instruments and could detect intriguing behaviours as anisotropic convergence of the tunnels. A schematic drawing and a picture of the convergence measurement device are on Figures 13 and 14.

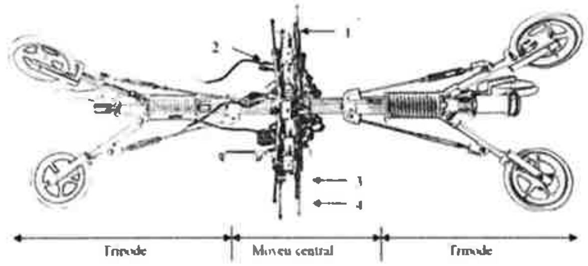

Figure 13. Overview of the device to measure the tunnel convergence (after Gay *et al.*).

Figure 14. Picture of the device, inside the tunnel, to measure the tunnel convergence (after Gay *et al.*).

The papers in this section present important messages for the session. It is important that we enhance our design concept of underground constructions beyond construction and early operation. Accounting for the life cycle and associated costs of the underground space, we can ensure technical and financial feasibility of the whole service life of the structure. The paper from **Katzenbach and Leppla** present a sight to that matter.

Huang *et al.* and **Gay *et al.*** remind us that is always possible to confirm design predictions for empirical designs and special tunnel conditions by measurements. Most important it shows how important it is to properly describe how field measurements are obtained, which instruments were used and how, so that the instrument's associated shortcomings and advantages are accounted for in the data analysis.

5 ROCK TUNNELLING

This topic gathered three papers of underground structures excavated in different types of rock. Stability of underground structures with different geometries and with account for post-peak strength degradation is presented. An empirical method for the prediction of TBM penetration rate is also presented.

Görög *et al.* perform several numerical analyses with four different codes of underground cellars beneath the city of Budapest, in their paper "Stability analyses of underground structures cut into porous limestone". The results focus on admissible surface loads, grouting and enlargement of a tunnel and interaction of different cellar systems, as in Figure 15. The restrictions and capabilities of each modelling tool are depicted and analysed in the results and conclusion.

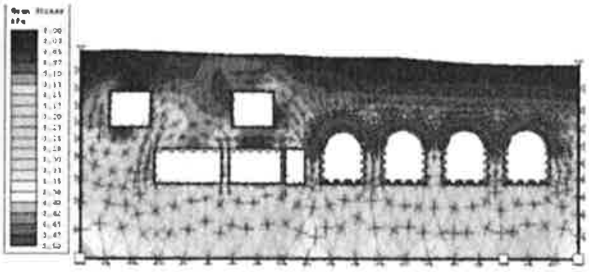

Figure 15. Mean stress distribution around the interacting cellars (modified from Görög *et al.*).

Hsiao and Chi in their paper "Effect of brittle failure on deep underground excavation in eastern Taiwan" investigate how post-peak strength degradation of metamorphic hard rock in Taiwan can affect deep tunnelling behaviour. The case study of a twin-hole tunnel with an excavation span of 12.5 m was studied with a finite difference package.

The study evaluated the tunnel at two different depths, 500 and 1000 m, and the rock mass by two different models, the Hoek-Brown model and the Hoek-Brown with the post peak degradation model of Cundall *et al.* (2003). A subroutine was created to account for the strength loss parameter as a function of the confining stress, adjusted from several tri-axial compressive tests (Figure 16).

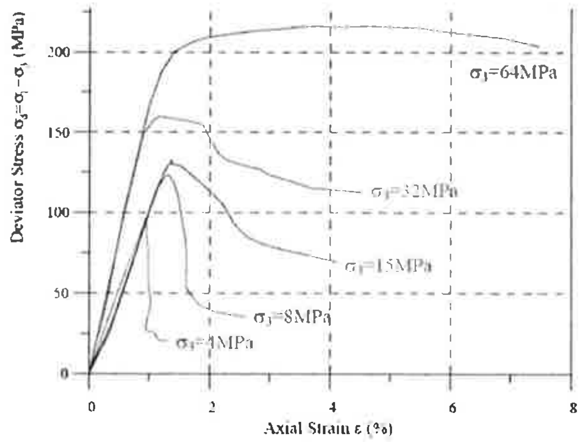

Figure 16. Typical stress-strain curves of triaxial tests under different confining stresses from the marbles in eastern Taiwan (modified from Hsiao and Chi).

This model diminishes the peak parameters by a factor of (1-β), β being the strength loss parameter that decreases with increasing σ_3/σ_c as in Figure 17.

The analyses show that the increase in tunnel deformations due to deeper excavation is more pronounced when the evolution of post-peak strength degradation with confinement loss due to tunnelling is accounted for. With a 1000 m depth the roof settlements can be three times larges when accounting for post-peak strength degradation.

Martins and Miranda in their paper "Prediction of hard rock TBM penetration rate based on Data Mining techniques" apply artificial neural networks (ANN) and support vector machine algorithms (SVM) on a database of rock properties and TBM penetration rate (ROP) to evaluate the relative impact of each rock parameter on the ROP. The artificial neural network algorithm resulted in more accurate predictions, as it can be seen in Figure 18. For this database that only included fractured rock masses, the PSI parameter that quantify the brittleness and toughness of the rock was the most influential parameter. On the other hand the uniaxial compressive strength was the least influential one. On a rock mass with less joints and faults one could expect a different scenario.

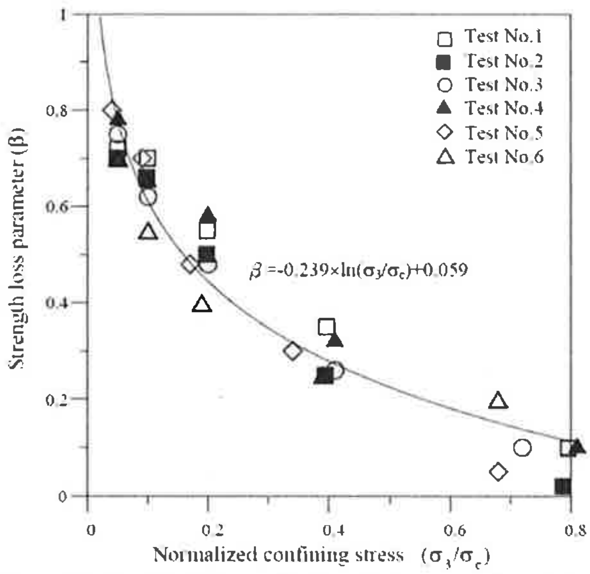

Figure 17. Correlation between the strength loss parameter and the normalized confining stress for the marbles in eastern Taiwan (after Hsiao and Chi).

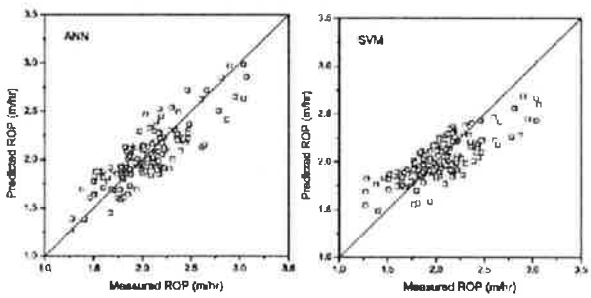

Figure 18. Comparison between the measured and predicted ROP for the ANN and the SVM models (after Martins and Miranda).

A reader of this topic that is mostly familiar with soft soil tunneling will be able to take a brief look at the challenges and interesting approaches that pervade rock tunneling. A solid study of constitutive modeling for special rock conditions is given by **Hsiao and Chi,** in the general rock mechanics sense and applied to tunnel case studies.

6 SEISMIC ANALYSIS OF TUNNELS

Three papers were classified under this topic. Analytical models and numerical models were derived based on in situ testing, model tests and real cases. There are also some interesting points over the short comes of design codes when it comes to seismic forces.

Tohda *et al.* in their paper "An elastic continuum model for interpretation of seismic behaviour of buried pipes as a soil-structure interaction" propose an analytical method for 2D analysis of buried pipes under seismic action, modelled as a simple shear action due to an earthquake. The objective was to overcome the current design code methodology that recommends the use of the seismic deformation method, based on spring models. This method assumes a governing stand for the tangential stress in the seismic behaviour.

The results were compared with the proposed model predictions with the results of a series of centrifuge model tests, as in Figure 19, confirming the validity of the analytical model. The results indicate that in most cases the tangential stress is almost null. The proposed model gives a rational interpretation for the seismic soil-pipe interaction with a proper account of the main stress components.

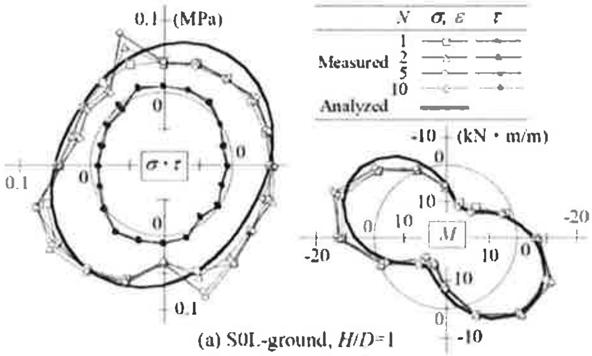

Figure 19. Comparison between measured and analytical results of normal and tangential stress and bending moment (after Tohda *et al.*).

Huang and Liu present a new modified response displacement method (MRDM) in the frequency domain, in their paper "Fast frequency-domain analysis method for longitudinal seismic response of super long immersed tunnels". The method is based on the theory of dynamic elastic Winkler foundation beam and is applied to analyse the longitudinal seismic response of a sea-crossing immersed tunnel between Hong Kong, Zhuhai and Macao (HZM) in China, as in the paper from Xie *et al.*.The proposed method considers the inertia of the tunnel, soil-tunnel interaction parameters and the dependence of dynamic stiffness coefficients on external loading frequency. The results are compared to the regular response displacement method (RDM), as in Figure 20. The HZM tunnel was modelled by 253 particles and the results indicate that the deformations of joints at both sides of the tunnel are much larger than those in the middle of the tunnel, which is analogous to that of the axial force. Nevertheless excessive tension and compression will not occur under proper design of segment joints.

Botero *et al.* in their paper "Effect of the subsoil conditions in the seismic interaction between two underground stations connected by a circular section tunnel" study a 50 year horizon of a 9 m diameter tunnel section connecting two metro station at about 22 m depth. They considered the seismic environment of the region scaled by the construction code of Mexico City. The present soil parameters as well as the prediction of their time evolution due to regional subsidence were evaluated in terms of CPT tests and empirical correlations to estimate the shear wave velocity. The results of a 3D finite difference numerical modelling indicate that only after 30 years the effects of the effective stress changes will present a considerable increase in the tunnels displacement and stresses. This would enable a better planning of future interventions and maintenance of the tunnel structures.

The papers present the challenges of the very complicated and potentially hazardous phenomena of earthquakes. Development of an analytical model, when confirmed by experimental data as in **Tohda *et al.***, is of great value for daily engineering practice.

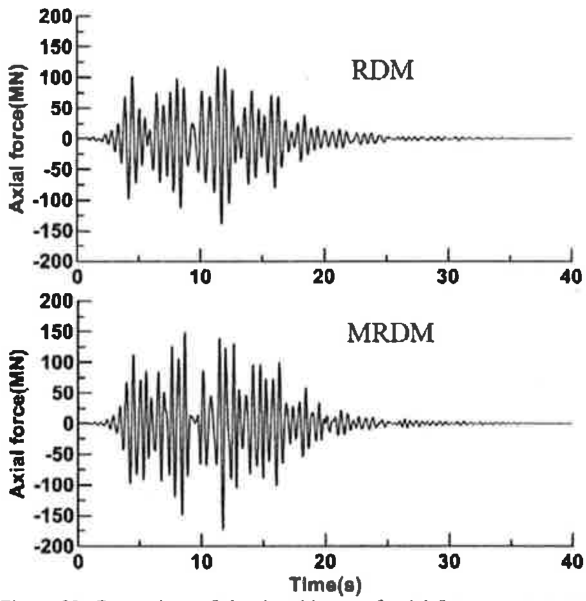

Figure 20. Comparison of the time history of axial force at one cross section of the immersed tunnel obtained by the RDM and the MRDM (after Huang and Liu).

7 CONSTRUCTION TECHNIQUES

Two papers were assigned to this topic. They present an evaluation of the selection procedure for construction methods and a new construction technique called modular approached tunnelling.

Yang and Yoo in their paper "Case studies of applicability for selection of construction method for highway underground crossing transit on the deposit soils in urban project in Korea" present a case history of the construction of a low depth road tunnel under a highway in Korea were the ground conditions were worse than predicted and remediation measures were necessary.

This case study underlines the argument that a rational guideline for the selection of the optimum construction method for an underground project is needed. Such a guideline would enable predictions of possible construction problems and improve the reliability of the financial budget. They also defend the case that design standards should specify the retention period of history files of structures, a standard coded system for underground failure types and a mandatory reliability analysis for geotechnical data assessment.

Komiya presents an analysis of a new construction method called modular approached tunnelling in his paper "Finite element modelling of construction processes of the modular approached tunnelling method". This method was developed to construct large scale tunnels for cross passages. The method consists of a cycle of small mechanized excavation followed by box-module insertion to form a lining frame in the soil that will sustain the excavation of the soil within the frame.

The process was analysed by modelling a real case in soft cohesive soil in Tokyo by 3D FEA (Figure 21). The mesh of the numerical model was updated at each time step and fictional elements to represent the cutting face of the TBM were employed.

The expected settlement of the numerical model was larger than the measured value, as in Figure 22, but the shape of the computed settlement trough at the top of the lining frame was similar to the measured results.

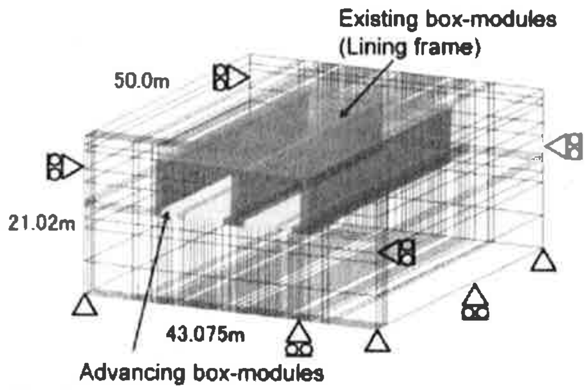

Figure 21. Three dimensional finite element model (after Komiya).

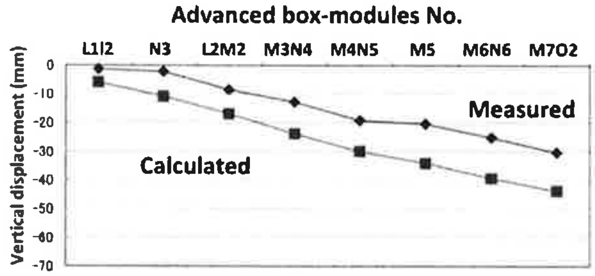

Figure 22. Vertical displacement against the evolution of the box-module construction (after Komiya).

The development of new construction techniques often raises doubts about the expected settlements and stress conditions of the structure. Numerical modelling and real cases monitoring, as in Komiya, assist the general engineering practitioner to better understand and trust the method.

8 CONCLUSIONS

This report presented an overview of the papers submitted for the TC204 session of the 18th International Conference on Soil Mechanics and Geotechnical Engineering. The papers covered several aspects of "Underground Construction in Soft Ground" and also some topics on rock tunnelling that were assigned to this session. The 27 papers were divided in six general topics and reviewed briefly.

The comments on this report are an image of the information displayed on the papers, the validity of the results and conclusions are responsibility of the authors of the papers. The board of the TC204 committee would appreciate the cooperation of all member societies were underground works are going on at the moment, no paper was submitted from South America, Eastern Europe, Africa, Middle East, Oceania, South and Southeast Asia. We would like to invite the member societies from these regions to take a more active part in the committee activities.

It is difficult to compare the papers with the papers presented in Alexandria 4 year ago, because by then the papers were in different themes. However, looking at the titles comparable subjects are dealt with than 4 years ago. There are new developments in underground construction: optical fibres are used more than is suggested from the one paper presented here, the increased computational power has led to complicated numerical models (FEM and DEM) to simulate the various interactions that play a role in underground construction and allows probability analyses using these models. These topics are already quite common on specialist conferences on underground construction and probably will appear in the next general conference.

Not all papers present the conditions for which the results and data analysis have to be depicted, as numerical method, mesh conditions, boundary conditions, calculation steps, numerical tools, model preparation procedures, adopted model scale, in flight actions etc. This complicates the application of the results in other studies.

Also the procedures currently employed as the official and correct tools to account for the underground construction related phenomena have to be described with the details. For example, the β method for 2D finite element analysis of tunnel construction that diminishes the excavation contour stress in steps. The β value as well as how it was estimated or calibrated should always be stated in the paper.

When more refined modelling procedures are used, even more effort should be put in to properly explaining the steps and boundary conditions of the model. For example, in hydro-mechanical analysis the initial conditions and especially how the hydraulic and mechanical equilibrium equations are solved radically affect how the results should be analysed.

The same lack of detailing can be said for the full scale or real case monitoring. As presented in the monitoring topic, the type of instrument, how and when it was installed, and how and how often it was measured completely defines the range of validity and reliability of the displayed results.

We expect that the this TC 204 session can bring significant contributions to the underground space research and practice fields, so that the important advantages of the use of the underground space for our cities can be fully exploited and not limited by our technical capabilities.

9 ACKNOWLEDGEMENTS

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