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# General Report - Session 5

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Commemorate the Legacy of Ralph B. Peck
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Case Histories in Geotechnical Engineering
and Symposium in Honor of Clyde Baker

# GENERAL REPORT - SESSION 5

## 5. Case Histories of Geological, Rock and Mining Enginering, Underground Structures and Excavations

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## INTRODUCTION

This General Report summarizes the papers submitted to Session 5 titled "Case Histories and Failure of Geological, Rock and Mining Engineering, including Underground Structures and Excavations, and Subsidence of Deltas, Anticipation, Characterization, Design and Construction in the Geological Complexity of Mélanges, Fault Rocks, Weathered Rocks, Boulder Colluvium, Lahars, and Similar Bimrocks (Block-in-Matrix Rocks) and Rock/Soil Mixtures."

A total of eleven papers covering the broad session themes described above were submitted. The geographic distribution of the case histories is listed in Table 1. Overall, five papers were submitted from Asia, two from Africa, two from North America, and two from Europe.

## SUMMARY OF PAPERS

**Paper #5.01 by Farid titled "Modified value of rock quality designation index RQD in rock formation"** is not a case history, but an attempt to modify the commonly used Rock Quality Designation (RQD) so that its definition does not include the arbitrary threshold core length of 10 cm. The mathematical formulation of the modified RQD is presented and subsequently calculations are made for a core log of one borehole. The author suggests that the advantage of the modified index is that it provides a better representation of the quality of the rock mass. A relationship is also presented between the modified RQD and the conventional RQD as originally proposed by Deere (1963).

**Paper #5.02 by Channabasavaraj and Visvanath titled "Influence of relative position of the tunnels - a numerical study on twin tunnels"** presents finding from a two-dimensional finite element analysis using PLAXIS computer program to analyze the interaction of two tunnels, with a particular focus on the impact of geometric configuration and construction procedure on the surface soil settlement.

The construction of underground transportation infrastructure facilities in increasingly congested metropolitan areas demands strict ground control measures to be adopted during construction in order to limit surface settlements within tolerable limits. Often twin tunnels are constructed at close spacing and at relatively shallow depth; hence, it becomes necessary to predict probable settlements with a relative degree of certainty.

In the present analysis, the location chosen is near Central College at K.R. Circle junction opposite to the mechanical department (Bangalore, Karnataka, India). Analyses were made between two newly constructed tunnels with three different alignments considering a horizontal, vertical and inclined alignment (separated by an angle, alpha). A 6.45m excavation diameter was assumed for bored tunnel alignments. The authors conclude that the highest soil settlement is obtained for vertically aligned tunnels, while horizontally aligned tunnels induce the lowest settlement, but with a larger lateral extension of the settlement profile. In the case of the inclined tunnel analyses, it was observed that sequencing the construction of the lower spatially-oriented tunnel first, leads to higher soil settlement, compared to when the upper tunnel construction is sequenced first.

**Paper #5.06 by Al-Mutairi, Dafalla, Al Fouzan and Al-Shamrani titled "Geotechnical and geophysical evaluation of the near surface faults and cracks in residential area underlain by semi-arid shale"** presents the results of an

investigation revealing the presence of expansive shale with a rather high swelling pressure and swell potential, which resulted in abnormal surface faults and distress extending more than two kilometers in an agricultural rural area to the northwest part of the Kingdom of Saudi Arabia.

The use of an electrical resistivity survey was selected to supplement traditional geotechnical exploration methods by borehole drilling and open test pits to assess the subsurface soil conditions. Ground deformation (surface faults and cracks) was found to relate to the highly moisture-sensitive nature of the soil. The authors present numerous figures illustrating various resistivity profile transects across the study area delineating moisture-sensitive areas in the expansive soil formation.

**Paper #5.08 by Haghi, Taheri and Haghi titled "Promotion of tunneling performance in locally semi-hard to hard conglomerate lenses, case of Esfahan historical city subsway project"** presents the experience of the authors from the construction of the Esfahan Subway Project using an Earth Pressure Balance Tunnel Boring Machine. The local site conditions include the presence of cemented soil particles due to a carbonate binder that leads to the formation of semi-hard to hard conglomeratic lenses that are generally known as Caliche and locally known as "Sovord" rock. This material is also classified as very to extremely abrasive to TBM excavation.

The earth pressure balance TBMs encountered significant challenges in tunnel excavation that involved tunnel face instabilities, low advance rates, cutter-head damage, and overall decreased performance. The authors assessed the improvement in excavation performance due to changes in supporting pressure, foaming agents and cutting wheel rotation speed. It was found that lowering the cylinder thrust force, and increasing the wheel rotation speed improved the performance of the TBM and optimized durability of the cutters. The use of anti-abrasive foaming agents was also beneficial.

**Paper #5.09 by Satyam titled "Support system design of power house and transformer caverns in Dickchu hydropower project, Sikkim"** presents analyses as part of the design of the support system of underground caverns that are excavated in quartzites and phyllitic quartzites of fair to good quality according to the RMR and Q classification systems. The horizontal stress was found to be significantly higher than the vertical stress. The original design was modified based on observations during excavation of the cavern and monitoring data. A finite element code was used in the analyses that first modeled the observed performance and subsequently was used to recommend the rock support scheme that involved 32-mm rock bolts at a 1.5 m spacing, and a 100-mm thick shotcrete.

**Paper #5.18 by Kashi and Nasri titled "Baltimore Red Line project, an overview of the Cooks Lane tunnel"** presents a two-dimensional finite element analysis that was performed using PLAXIS computer program in order to evaluate the deformation and stability of the tunnel excavation, the structural adequacy of 10-inch thick reinforced concrete liner, the impact on adjacent buildings and utilities, and finally the impact of excavation on the soil or rock pillar between the two parallel tunnels.

This paper presents the design approach for the preliminary engineering of the approximately 7,100 ft Cooks Lane Tunnel (CLT), as part of the Maryland Transit Administration's Baltimore Red Line proposed 14.1-mile east-west Light Rail Transit line. The authors also describe the current proposed design and construction methodology. The proposed CLT will be excavated below water table and in a variety of ground conditions ranging from soft ground to competent rock. Variable geotechnical conditions, mixed-face tunnel excavation, tunneling adjacent to the existing buildings and utilities, and cut-and-cover construction in urban environment characterize the design challenges.

Each TBM excavation sequence was simulated in the numerical model analysis in separate but consecutive stages to assess soil structure interaction effects at each stage. Different alternatives for the CLT including double-track large-diameter TBM-bored tunnel, single-track twin TBM-bored tunnels, and mined (NATM) tunnel are discussed. The paper also presents a discussion of ground water control during construction and tunnel muck removal.

**Paper #5.20 by Ota, Kuraoka and Takeshi titled "Numerical analysis to examine the effect of landslides on tunnels"** is not a case history but a numerical attempt to investigate the interaction effects between landslides and tunnel stability. The authors use the distinct element method and the software UDEC for the analyses. Analyses involved a number of models with different separation distances (which the authors refer to as offset distances) between the tunnel and the landslide, as well as different locations of depth of the tunnel. Impact on the tunnel was assessed by the amount of calculated subsidence of the tunnel crown. The influence on the interaction of the landslide with the tunnel was examined both during tunnel construction (assuming the presence of a pre-existing landslide) as well as after construction (assuming the occurrence of a new landslide).

The results indicate that as the offset distance increases, the impact on the tunnel decreases. An offset distance of 2*tunnel diameter appeared to be reasonable for a better rockmass, but that distance was not adequate for a poor rockmass. Thus, ground conditions (essentially modeled with different stiffness and Mohr-Coulomb strength) appeared to influence the results. The distribution of strain around the tunnel was also affected by the offset distance.

**Paper #5.21a by Huseini, Mehmeti, Bytyfi, and Hasani-Ziberi titled "Slope Stability Analysis of the Working Level and Final Slope in the Surface Mine of Marls near 'Hani i Elezit'"** deals with stability evaluation of deep cuts in

quarries excavated in marls, an important constituent of cement production of the country of Kosovo. The stability evaluations were performed to optimize open cuts, including cut face inclination and distance between benches using limit equilibrium and the Janbu and Bishop method. Input parameters were selected on the basis of laboratory testing.

**Paper #5.22 by Allahverdi and Nasri titled "Three dimensional numerical analysis for soft ground engineering"** presents the methodology and results of three-dimensional analyses performed to assess the impact of tunneling construction in the vicinity (only a few feet separation) of an existing subway tunnel as well as the piles that supported the piers of a bridge as part of the construction of an underground light rail transit project in downtown Los Angeles. The project is known as Regional Connector Transit Corridor (RCTC). The analyses used the MIDAS/GTS software program that allowed modeling the tunnel excavation using a shield-driven TBM and included modeling the staged construction, segmental lining installation process, tail void grouting, and the complex soil-structure interaction effects associated with construction next to the existing infrastructure.

**Paper #5.23 by Al Heib, Ngheim and Emeriault titled "Understanding sinkhole consequences on masonry structures using large small-scale physical modeling"** presents a reduced-scale physical model to study behavior of masonry structures subjected to ground subsidence or the collapse of underground cavities. The masonry structure model was constructed using small pieces of wood or sugar cubes, whereas the subgrade was constructed by the means of polycarbonate or silicon slab. The displacements and strains of the soil and the structure were induced manually and were measured using an imagery technique called DIC (Digital Image Correlation). Damage of the structure was pronounced when the structure was located in the zone of maximum tilt. No formal scaling factors (such as those used in centrifuge testing) were introduced, and the results were interpreted in a qualitative way (e.g., "damage of the masonry structure depends on its position on the subsidence area and its stiffness").

**Paper #5.25 by Bedal and Hassan titled "Numerical and rational analysis of shotcrete lining for rock tunnels under effect of explosion loads"** is not a case history, but a numerical exercise using the finite element model AUTODYN that aimed to investigate the impact of subsurface explosion loads occurring in the vicinity of a tunnel. The parametric analyses considered the impact of the rock mass properties, tunnel radius, charge weight and detonation distance on the stability of rock tunnels. The analyses considered the waves that propagate from the explosion source and calculated the compression and tensile stresses at the rock mass and the tunnel lining.

The results of the analyses indicated that the stronger the rock mass, i.e., the higher the rock mass rating (RMR), the higher the induced compression stresses were in the tunnel lining. The induced compression and tensile stresses in the tunnel lining reportedly decreased with increasing shotcrete lining thickness. The induced tensile stresses in the shotcrete lining increased with increasing rock mass rating, tunnel radius and charge weight and with decreasing detonation distance.

## SUMMARY

A total of 11 papers were submitted in Session 5. The papers cover various aspects of rock and site characterization, tunneling and underground construction, open-pit mining, and the stability of slopes and tunnels. A concise summary of each paper that includes a description and major findings is presented in this general report.

Table 1. Papers submitted to session 5.

| Paper # | Title of Paper | Authors | Country |
|---|---|---|---|
| 5.01 | Modified value of rock quality designation index RQD in rock formation | Ahmed T. M. Farid | Egypt |
| 5.02 | Influence of relative position of the tunnels a numerical study on twin tunnels | W.Channabasavaraj<br>B. Visvanath | India |
| 5.06 | Geotechnical and geophysical evaluation of the near surface faults and cracks in residential area underlain by semi-arid shale | Khaled Al-Mutairi<br>Muawia Dafalla<br>Fouzan Al Fouzan<br>Mosleh Al-Shamrani | Saudi Arabia |
| 5.08 | Promotion of tunneling performance in locally semi-hard to hard conglomerate lenses, case of Esfahan | Amir Hossein Haghi<br>Ali Taheri | Iran |

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| | historical city subsway project | A. Ehsan Haghi | |
| 5.09 | Support system design of power house and transformer caverns in Dickchu hydropower project, Sikkim | Dr. Neelima Satyam D | India |
| 5.18 | Baltimore Red Line project, an overview of the Cooks Lane tunnel | Mohsen G. Kashi,<br>Verya Nasri | USA |
| 5.20 | Numerical analysis to examine the effect of landslides on tunnels | Keiichi Ota<br>Senro Kuraoka<br>Toshiya Takeshi | Japan |
| 5.21a | Slope Stability Analysis of the Working Level and Final Slope in the Surface Mine of Marls near 'Hani i Elezit' | Idaver Huseini.<br>Nexhmi Krasniqi<br>Januz Mehmeti<br>Ahmet Bytyci<br>Semijal Hasani-Ziberi | FYROM<br>& Republic of Kosovo |
| 5.22 | Three dimensional numerical analysis for soft ground tunneling | Navid Allahverdi<br>Verya Nasri | USA |
| 5.23 | Understanding Sinkhole Consequences on Masonry Structures using Large Small-Scale Physical Modeling | Marwan Al Heib<br>Huu Luyen, Ngheim<br>Fabrice Emeriault | France |
| 5.25 | Numerical and rational analysis of shotcrete lining for rock tunnels under effect of explosion loads | Adel M. Bedal<br>Hazem Hassan | Egypt |