2nd EASTERN EUROPEAN TUNNELLING CONFERENCE

Tunnelling in a challenging environment

EETC 2014 ATHENS

ATHENS 28 September - 1 October 2014 Royal Olympic Hotel, Athens, Greece

PROGRAM

GREEK TUNNELLING SOCIETY
(E.E.Σ.Y.E.)
Member Nation of the International Tunnelling Association

http://www.eetc2014athens.org


FOREPOLING

The Greek Tunneling Society (GTS) is organising, with the official endorsement from ITA the **2nd Eastern European Tunnelling Conference** in Athens on September 28 – October 1 2014 (EETC2014, Athens).
The Eastern European Tunnelling Conference is a biennial regional traveling conference. It aims to promote the sharing of knowledge, experience, skills, ideas and achievements in the design, financing and contracting, construction, operation and maintenance of tunnels and other underground facilities among the countries of Eastern Europe, on an organized basis and with agreed aims. EETC2014 aims mainly to bring together colleagues from Eastern Europe but people from the rest of the world are also welcome.

The theme of EETC2014 Athens is:
"Tunnelling in a Challenging Environment"
Making tunnelling business in difficult times

The construction of underground projects is becoming increasingly demanding as new challenges are emerging in every aspect and sector of this multidisciplinary and multifarious business. Further to the usual geological, geotechnical, structural and operational challenges, we are now facing a difficult business and financial environment, which requires the deployment of even more intelligent and effective tools and solutions.
Greece in the last 20 years has undergone a Tunnelling golden era. Significant road, rail, metro, hydraulic tunnelling projects have been implemented, resulting in the accumulation of great experience and skills to the design, construction, consulting and public management sectors. The economical crisis has nevertheless affected tunnelling industry and of course tunnelling projects to varying degrees. Recently Greece meets an explosive recommencement of tunnel construction activities. The reactivated motorway concession projects include the construction of new tunnels of total single tube length 55 Km, and the upgrading of 17 km single tube of existing tunnels. Railway construction program includes the construction of new tunnels of total single tube length 43 Km. The works for new Metro Line 3 Aghia Marina to Piraeus, include 7.6 km long tunnels, with 6 modern Metro Stations, while in Thessalonica Metro 14,3 Km of tunnels are bored with 18 stations.

We really do hope that the EETC2014 Athens aims at creating a forum for further discussions for tunnels and tunnelling incorporating a series of issues and/or related organizations, designers, contractors, operators, researchers, manufacturers. We also seek for contribution and further facilitation on the growth of the tunnelling business and for a forum for scientific and professional collaboration.
We express our gratitude to the sponsors and supporters of the conference, to ITA and to all the authors and participants of the Conference, who contribute to share their experience.

Ioannis Bakogiannis
Chairman of the Organizing Committee of EETC 2014

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ATHENS 28 September - 1 October 2014 Royal Olympic Hotel, Athens, Greece

Conference Information

Conference Venue

Royal Olympic Hotel, 28-24 Ath. Diakou Street, Athens, Greece
Tel: +30 210 9288400, www. royalolympic.com

Official Language

English is the official language of the Conference

Conference Secretariat Opening Hours

Sunday, September 28th, 2014	13:30 – 17:30
Monday, September 29th, 2014	09:00 – 13:30 & 14.30 – 18.30
Tuesday, September 30rd, 2014	09:00 – 13.30 & 14.30 – 18.30

Technical Visit

Wednesday 1st October at Athens Metro line 3 extension to Piraeus-
8.30-13.30 (Depending on the number of participants)

Conference Secretariat

Triaena Tours & Congress S.A.
16 Kifissias Ave., 115 26, Ampelokipoi, Athens, Greece
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Conference Website: www.eetc2014athens.org

Kallirhoe Hall

Career Day for Tunnel and Geotechnical Professionals

Chairman: P. Fortsakis *Co-Chairman:* G. Prountzopoulos

14:00-15:15	**Company presentations - I**
14:00-14:15	**Opening Speech**
14:15-14:30	**Hill International**
14:30-14:45	**Dr Sauer Group**
14:45-15:00	**SYSTRA**
15:00-15:15	**GEOS Ingenieurs Conseils**
15:15-15:30	**Coffee Break**
15:30-16:30	**Company presentations - II**
15:30-15:45	**ITA-YMG Presentation**
	Petr Salak, *Vice-Chair of ITA-YMG Steering Board*
15:45-16:00	**GEODATA S.p.A.**
16:00-16:15	**VINCI CONSTRUCTION G.P.**
16:15-16:30	**OMIKRONKAPPA Consulting**
16:30-16:45	**Lombardi Group**
16:45-17:00	**Pini Swiss Engineers**
17:00-19:00	**Networking Event**
19:00-21:00	**Meeting of Eastern European ITA Member Nations Representatives**

Kallirhoe Hall

09:30-11:30 ***Session 1*** **Official Opening and Plenary I**

Opening speech
S. Raptopoulos, *President of Greek Tunnelling Society*

The Copenhagen Metro with a view to Environmental Challenges
S. Eskessen, *President of ITA-AITES*

Life cycle design of tunnels
K. Bergmeister, *O.Univ.Prof. Dipl.-Ing. MSc. Ph.D. Dr.phil. Dr.techn.*

World Tunnel Congress 2015, 22-28 May 2015 - Dubrovnic (Croatia)
D. Kolic, *ITA Croatia*

Athens and Thessaloniki Metro system - expanding with State of the Art technology
Dr G. Leoutsakos, *Attiko Metro*

11:30-12:00 **Coffee Break**

12:00-13:30 ***Session 2A*** **Mechanized tunneling**
Chairs: P. Marinos, A. Siemińska-Lewandowska

001 **Applied Research for EPB-shields in difficult ground conditions**
M. Thewes, M. Galli

002 **A 3D simulation for TBM-EPB tunnelling interacting with adjacent Buildings**
E.M. Comodromos, M.K. Papadopoulou , G.K. Konstantinidis

003 **NeTTUN project: how to increase the lifetime of TBM drag bits?**
V. Fridrici, M. Antonov, Ph. Dubujet, A. Taboulet, O. Marou-Alzouma, D. Katushin, D. - L. Yung, M. Méité, M. Chaze, Ph. Kapsa, R. Veinthal, I. Hussainova , Th. Camus

004 **Ground movements caused by Mechanized Tunnelling Works for the Athens Metro Elliniko extension**
S. Koukoutas, Al. Sofianos

005 **Development of Dual-mode TBMs**
F. Renault

Attica Hall

12:00-13:30 ***Session 2B*** **Innovative methods for analysis, design and construction**
Chairs: I. Fikiris, D. Kolic

006 **Design criteria for service life design of tunnel linings – focus on structural reliability and associated safety factors**
P. Spyridis, K. Bergmeister

007 **Assessing tunnel behavior and support in heterogeneous rock masses. The flysch formations in Padina tunnel, Serbia**
V. Marinos, A. Goricki, E. Malandrakis

008 **A simplified approach of the rock-bolting design based on the principles of NATM**
C. Jassionnesse, A. Tsirogianni, E. Vermoote

009 **A Method to Help prevent Errors In Steel Tube Jacking**
M. Shin, Y. Cho, E. Yee, L. Seongcheol

010 **Modelling Load Reduction Method in NATM - case study**
E. Zolqadr, F. Yazdandoust, A. Golshani

13:30-15:00 **Light Lunch**

Kallirhoe Hall

15:00-16:30 ***Session 3A*** **Safety**
Chairs: G. Tsifoutidis, E. Leca

011 **Quantitative risk and criticality assessment for tunnels under explosiv and fire threat scenarios**
G. Vollmann, I. Kaundinya

012 **Safety-related current state of knowledge of road tunnel users in Greece**
K. Kirytopoulos, K. Kazaras, P. Papapavlou, I. Tatsiopoulos

013 **Vision based Tunnel Inspection using non-rigid Registration**
A. Badshah, Shanullah, D. Shahzad

014 **Application of risk based approaches for road tunnels' safety in Greece**
I. Bakogiannis

Attica Hall

15:00-16:30	***Session 3B*** **Case Histories** *Chairs:* E. Pergantis, Y. Jinxiu
O15	**Jet Grouting - A solution to problems in Tunnelling - Examples from Europe** T. Kimpritis, W. Smon, P. Pandrea, G. Vukotic
O16	**Bucharest Metro Enlargement - a Future Aim** O. Arghiroiu, S. Călinescu
O17	**The challenging blasting approach for the construction of the three tunnels on the Motorway Athens - Salonica, Hellas** E. Baliktsis, A. Baliktsis, S. Baliktsis
O18	**Application of Iranian Traditional Tunnelling Method in Qhytariye-Ozghol cable tunnel** A. R. Taherian, A. Falahat Pishe
O19	**Conceptual design of ventilation system of Lorenzos Mavilis road tunnel – Experiences from design and construction of ventilation shaft** S. Tzarouchi
16:30-17:00	**Coffee Break**
17:00-18:30	***Session 4A*** **Case Histories** *Chairs:* G. Prountzopoulos, A. Gomes
O20	**Overview of the Longest Railway Tunnels** M. Hilar
O21	**Metsovo Tunnel-NATM Design for Squeezing Ground Conditions** A. Goricki, N. Rachaniotis
O22	**Niayesh tunnel Construction under Modares bridge abutment** E. Zolqadr, M. Pasdarpour, A. Golshani
O23	**Experience from the operation of hydraulic tunnels in PPC hydro projects** S. Raftopoulos, Y. Thanopoulos
O24	**Tunnelling under Existing Railway Roadbed using Pipe Roof Method** H. Park, M. Choi, S. Chang, S. Lee
O25	**Utilizing a Distributed Optical Sensing Technique in order to Continually Monitor the strain of a Forepole Temporary Support Element employed within an Umbrella Arch System** N. Vlachopoulos, B. Forbes

Kallirhoe Hall

17:00-18:30 ***Session 4B*** **Rehabilitation – Restoration of ancien tunnel**
Chairs: D. Nikolaou, O. Vion

O26 **Development of Tunnel Diagnosis and Maintenance Ontology**
J. Valdes, D. Thakker, V. Dimitrova, P. Thiaudiere, A. G. Cohn

O27 **Works for Metro Line Rehabilitation**
O. Arghiroiu, S. Călinescu

O28 **Survey, diagnosis and strengthening of a railway tunnel under aeronautical ways**
J. C. Beaucour

O29 **The geology of Eupalinos Aqueduct, Samos Island, Greece**
E. Lyberis, G. Dounias, A. Ntouroupi, L. Sotiropoulos, G. Angistalis

O30 **Outline of the Restoration Designs of Eupalinos Tunnel, Samos Island, Greece**
G. Angistalis, O. Kouroumli Arend

20:30 Conference Dinner

Will take place at "Ioannis Restaurant" in the roof garden of Royal Olympic Hotel at 20.30

DAY 2 Kallirhoe Hall

09:30-11:30 **_Session 5_** **Plenary II**

Tunnelling in Greece: Past, Present, Future
C. Tsatsanifos[1], I. Michalis[2]
Pangaea Consulting Engineers LTD, President of the Hellenic Society of Soil Mechanics and Geotechnical Engineering[1], Tunnels & Underground Structures Manager, Civil Works Department of Qatar Rail, Deutsche Bahn International[2]

Evaluating the application limits of the unreinforced concrete tunnel final linings
I. Michalis
Tunnels & Underground Structures Manager, Civil Works Department of Qatar Rail, Deutsche Bahn International

The Maliakos - Kleidi Motorway Tunnels - Geotechnical Conditions and Construction Experience
N. Koronakis[1], P. Kontothanassis[1], P. Mantziaras[1], D. Papakrivopoulos[2]
Omikron Kappa Consulting SA[1],
Maliakos-Kleidi Construction JV[2]

11:30-12:00 **Coffee Break**

Attica Hall

12:00-13:30 **_Session 6A_** **Mechanized tunneling**
Chairs: G. Dounias, T. Horvat

O31 **Efficient Mixed Ground EPB Excavation: A Study of Important Variables**
J. Roby, D. Willis, D. Jordan

O32 **Investigation of the influence of face pressure on surface settlements in EPB mechanized tunneling**
F. Chortis, K. Tzivakos, M. Kavvadas

O33 **Automated Replacement of TBMs Cutting Tools**
S. Moubarak, B. Girault, D. Lamont, T. Camus

O34 **Geotechnical Investigation Planning of Subway Projects in Urban Areas**
H. Ghodrat

O34A **3D Numerical simulation of shield tunnelling with emphasis on the influence of the tail gap**
D. Litsas, A. Rachmani, P. Fortsakis, M. Kavvadas

Kallirhoe Hall

12:00-13:30	***Session 6B*** **Numerical modeling and analysis** *Chairs:* V. Yiouta, V. Tashev
035	**Advances in numerical modelling for complex tunnelling projects** A. Nasekhian, A. Gakis, P. Spyridis, T. Schwind
036	**Simulation of the Pinheiros - São Paulo cavern-shaft system collapse** G. Saratsis, M. Stavropoulou, G. Exadaktylos
037	**Seismic fragility curves of shallow tunnels considering SSI and aging effects** S. Argyroudis, G. Tsinidis, F. Gatti, K. Pitilakis
038	**Pillar stability analysis using the finite element method at the Lavrion Technological and Cultural Park's underground hazardous waste repository** D. Papakonstantinou, A. Benardos
039	**Application of Statistical Analysis for Numerical Modelling of Tunnels** M. Hilar, T. Svoboda
13:30-15:00	**Light Lunch**

Attica Hall

15:00-16:30	***Session 7A*** **Innovative methods for analysis and design** *Chairs:* P. Fortsakis, Z. Tomanovic
040	**An indirect method for the design of reinforced tunnel faces** G. Prountzopoulos, M. Kavvadas
041	**Numerical modelling of an underground low and medium level radioactive waste repository in fractured rock mass** D. Borbely, T. Megyeri, P. Gorog
042	**Investigation of Tunnel Face Stability and Deformation using Critical State Plasticity** P. Sitarenios, G. Kallivokas, G. Prountzopoulos, A. Kalos, M. Kavvadas
043	**SFRC for cast-in-place (CIP) Permanent Linings: Thames Tideway Lee Tunnel Project in East London, UK** S. Psomas, C. Eddie, R. Sutherden, C. Matta
044	**Time-dependency issues associated with rock tunnelling** C. Paraskevopoulou, M. Diederichs

Kallirhoe Hall

15:00-16:30	***Session 7B*** **Innovative methods for analysis and design** *Chairs:* C. Tsatsanifos, E. Akis
045	**Stresses and Deformations around Tunnels of different Shapes due to Incident SV-Waves** E. Pelli, A. Sofianos
046	**Seismic Behavior of Shallow Tunnels Accounting of the Surface Structures Interaction Effects** G. Tsinidis, A. Leanza, K. Pitilakis, M. Maugeri
047	**Seismic response of deep tunnels: comparison of different existing methods** D. Vlachakis, M. Pescara, C.G. Lai
048	**Influence of the change of cross section in the seismic design of 'Qaf Murrizi' tunnel** E. Paçi, A. Bidaj, H. Cullufi
049	**Dynamic response of square tunnels: Centrifuge testing and validation of existing design methodologies** G. Tsinidis, E. Rovithis, K. Pitilakis, J. - L. Chazelas
16:30-17:00	**Coffee Break**
17:00-18:30	***Session 8*** **Contractual – Performance evaluation – Closing Ceremony** *Chairs:* S. Raptopoulos, M. Hilar
050	**The performance of motorways' concessions contracts under construction in Greece** I. Bakogiannis
051	**Strategic design considerations for long transportation tunnels. The case of the Trikokkia Railway Tunnel (Greece)** A. Alexandris, M. Abarioti, I. Katsipi Griva, K. Mouroudelis
052	**Can be a contract type crucially best or worst? (One "Turnkey Contract" is much favorable than the fragmented into several parts and separate contracts, - isn't it?)** L. Frigyik
053	**Stochastic Cost Estimation of Road Tunnels** K. Ioannidis, K. Kirytopoulos, G. Doulis
054	**An insider's approach to concurrent tunnel engineering with inadequate data and strict construction schedule** N. Koronakis, P. Kontothanassis, G. Prountzopoulos

Posters Presentations

P01 **Application of the Spatial Rock Mass Behaviour into 2DFEM Model**
J. Pruška[1], J. Vrbata[2]
[1]Czech Technical University in Prague - FCE, Prague, Czech Republic
[2]Metrostav a.s., Prague, Czech Republic

P02 **Preliminary analysis of tunnel face stability for risk or back analysis**
C. Jassionnesse, M. Cahn, A. Tsirogianni
Geos Ingenieurs Conseils, Archamps, France

P03 **The Albanian Motorway – Rreshen Kalimash Section Thirra Tunnel**
A. Kosho, E. Kalluci, A. Malaj, L. Harizaj , B. Xhagolli, P. Sheperi
Altea & Geostudio 2000, Tirana, Albania

Life-cycle design of tunnels

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Keywords: Service life, Life-cycle, Safety and Reliability, Robustness.

The paper focuses on major issues regarding the life cycle design of tunnel projects. Life-cycle design for new infrastructure and life time extension of existing structures have become very important on a worldwide scale. Impressive progress has been made in the field of design optimization, service life design and global monitoring, but nevertheless real applications on tunnels and important structures are limited in their number. The most common approach is to analyze existing structures through a life cycle assessment in order to increase their life time. For the life-cycle design, specific structural detailing (concrete cover etc.), increased partial safety factors (material) and periodic inspection and monitoring programs must be considered.
As an example, the design of the Brenner Base Tunnel, a project of European significance, will be presented. The Brenner tunnel will become the longest underground railway infrastructure world-wide with a length of 64 km. It forms the central part of the high-capacity railway between Munich and Verona, and in general the link along the Trans-European Corridor no. 5 between Helsinki-Finland and Valletta-Malta. The design and the structural detailing of this important infrastructure in order for it to comply with defined life time limits is of high importance. Through a specific safety evaluation, partial safety factors for the dominant material parameters were worked out for a life time of 200 years, aiming at the rather small probability of failure of the order 10-7 per year. Finally, a novel "gradient limit state approach" considering gradually serviceability, ultimate loads, durability and robustness will be presented as a basis for future life-cycle design of tunnels.

The Maliakos – Kleidi Motorway Tunnels - Geotechnical conditions and Construction Experience

N. Koronakis[1], P. Kontothanassis[1], P. Mantziaras[1], D. Papakrivopoulos[2]
[1]*Omikron Kappa Consulting SA, Athens, Greece*
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Keywords: Bored Tunnels, NATM, Observational Method, Pilot Tunnel, Unreinforced Final Lining

The alignment of the Motorway Maliakos – Kleidi (MMK) BOT project stretches in the underground in order to bypass the famous Tembi gorge (tunnels T1 & T2 - the longest highway tunnel in Balkans) and the Platamon area (tunnel T3), both amongst the most significantly disturbed areas in Greece, from geological point of view. The MMK tunnels constitute the application of the NATM under demanding construction requirements as posed by: the nature of the project (BOT), the dimensions of tunnel section (two traffic lanes and an emergency lane, 120-180m^2), the underground lengths (totaling 21.5km in length), the underground facilities designated to intersect the tunnels (ventilation galleries, shafts and escape cross adits) in conjunction with the quality and spatial variability of the involved geomaterials and the anticipated geotechnical hazards.

According to the traffic & safety requirements the tunnels were designed with two traffic lanes of 3.75m width and an emergency lane of 2.50m width, in each direction. The distance between the tunnel axes depends on the alignment, but it is not less than 25m, resulting in the remaining rock mass pillar between the tubes with a minimum width of 11.50m. Design & construction calls for fully drained tunnels to be bored in line with the NATM principles whereby: the tunnels are designed as dual lining structures with an initial shotcrete lining, for the temporary support of the excavated tunnel and a permanent cast-in-situ concrete lining for the final state (12.50m standard blocks of C30/37 steel reinforced or unreinforced – satisfying fireproof requirements). A geotextile fleece (600g/m^2) and waterproof membrane (>2mm) located in the vault, between primary and the permanent linings along with a drainage system at the bottom of both side walls are the components of the fully drained tunnel concept, protecting the structure from water inflows. Construction also included development of complex underground spaces for the implementation of the ventilation facilities such as: ventilation shafts and chambers and galleries and application of cutting edge designs such as the inner lining of unreinforced cast in-situ concrete. The geotechnical risk included tunneling, under: extremely low (<10m) but also very high overburden heights (>280m), mixed face conditions in geomaterials of dramatically different geomechanical behavior, water ingress, very long fault zones, persisting, severe face instabilities, high convergences rates and delayed deformations. Certain troublesome situations were encountered during construction that required modifications in the construction methodology and establishment of special methodological approaches to cope with. Close collaboration between the Designer and the Client ensured quick adaptations of the E&S methodology and processing of efficient solutions to address the arisen geotechnical hazards. The Geotechnical Design of underground excavation & primary support (E&S) was based on: the Rock Mass Types, the E&S Classes and well defined Application Criteria in linking the anticipated Rock Mass Behaviour with the E&S classes. To address the variety of underground conditions from the most favourable to the most adverse ones, nine (9) E&S classes have been designed for the main tunnel. These are grouped in open as well as closed bottom sections, in correspondence with the typification adopted for the permanent cast-insitu lining. Two closed bottom sections were designated (one with a deep invert foundation and one with a shallower invert geometry) for better efficiency and matching to the temporary as well as permanent stability requirements. The primary support elements consisted of: sprayed concrete, reinforced either with steel fibers or steel mesh, bolting (Swellex or fully grouted), steel ribs (lattice girders to heavy HEB 180 profiles). To address the anticipated, increased likelihood of squeezing conditions the key decision towards bringing the primary support into equilibrium was by allowance for adequate over-excavation to accommodate the convergence and use of dual primary support shells instead of finding recourse to a flexible initial support concept. The key features of the NATM tunneling to be presented herein regard: the methodology to effectively in harness the systematic face instabilities the wide excavation areas (by means of the short pilot tunnel concept), the variety of tunnel rehabilitation schemes developed and the unreinforced final lining concept. **Special conditions at ch.10+730 of T2 tunnel – The “short pilot tunnel” method.** A novel method called the “short pilot tunnel” method was devised so as to provide pre-reinforcement and increased confinement conditions of the very weak and unstable masses ahead of the face. The hazardous conditions were first encountered as the T2 tunnels advanced through a 50m long zone of shattered phyllites (GSI10) under medium overburden (70m). The zone was represented by heavily tectonized geomaterials (completely fractured and sheared), exhibiting soil behaviour under an adverse stress regime and the fully unfavourable orientation of the quasi-schistosity planes to the excavation. In essence, the triggered enormous face instabilities on advancing the tunnels excavation caused inability to implement the support measures (bolting and temporary invert) as foreseen. This delay turned out responsible for the poor performance of the initial support shell, by means of early development of high convergences of the shell immediately behind the face, associated with evolution of overstress phenomena in the shell and strong evidence of interaction between the two bores had led to cracking of the temporary invert. In this event, the need to seek for methods to stabilize the wide excavation faces of the three lane tunnel more effective than would be by dense fibreglass rock bolting was of utmost importance. With the “short pilot” method, in lieu of dividing the excavation by means of side drifts, the face was stabilized by the formation of a forepolling (Φ114/140) protected pilot tunnel which was designated to excavate at the core of the face from the main tunnel and presenting always a maximum 5m advance ahead of the main tunnel. The “short pilot tunnel” method proved very efficient way to negotiate face instabilities by deploying the same equipment used for the main tunnel excavation and support. And thereby, it was incorporated to a new E&S class appointed to address similar geotechnical hazards which were evolved very frequently along the 21.6km tunnel driving.

Special Conditions at ch.12+400 of the T3 Tunnel – Tunnel Rehabilitation. An abrupt, very severe cave-in incident occurred around the low overburden area (<20m), while both tunnels were advancing in top heading section through very weak peridotites (GSI<15). The detrimental relaxation of the surrounding weak due to uncontrollable straining of the cavity brought about full collapse of the primary support and blockage in a 40m long section of the NB (to Thessaloniki) tunnel as well as severe deformation in the SB tunnel (to Athens), which was though protected against full collapse by immediate backfilling. The cave-in has progressed up to the ground level, thus creating a wide subsidence area (6,000m^2) and disclosing a small part of the Nat. Gas Pipeline running at small depth below the ground surface. Re-instatement of the tunnel cross section in the blocked NB presented a quite demanding task design as well as construction wise, due to the additional restrictions set by the involvement of the Nat. Gas Pipeline in the collapse area. The design of rehabilitation for the blocked NB tunnel, relied on an extensive site investigation around the tunnels. The solution was sought after ground improvement options of the surrounding mass had been scrutinized and rejected. Advancement of a pilot tunnel to pass all the way through the 40m collapsed materials was finally promoted to be the first, key phase of a two phases' construction. Rehabilitation B phase regarded the demolition of the pilot tunnel structure and the re-instatement of tunnel cross section wide enough to accommodate the induced convergences and an adequately thick final lining. Both phases were constructed under the

protection of overlapping standard forepoling umbrellas (Φ114/140). Pilot tunnel design was based on a very competent composite shotcrete shell (35cm thick with embedded steel sets HEB160 per 80cm) so dimensioned to sustain the most conservative assumptions on the anticipated dead weights combinations. The advancement of the E&S of the pilot tunnel was designed to complete in a single stage to be followed by immediate invert closure, while no bolting was adopted. Rehabilitation B phase was split in a top heading – bench – invert process for the installation of a stiff initial lining 50cm in total thickness at the top heading (by means of a double initial shotcrete shell), 30cm in the sidewalls and 40cm in the invert. The double primary support in the top heading was applied in short rounds with an outer shell (with LG140/30/200) which is subsequently supplemented by an inner shell (with HEB180 profiles), each 25cm thick. Bench and invert closure were systematically kept 8m behind. Very strict thresholds for the deformations to be recorded in the underground as well as at the surface completed the framework of the design. The rehabilitation objective has proceeded in close cooperation with the Nat. Gas Pipe Authority (DESFA) and had as prerequisite the disclosure of the pipeline for the length under consideration to facilitate monitoring of the facility. The pilot tunnel work has started 18 months after the disastrous incident and took 3 working months to get through the collapsed zone with another 3 months for the rehabilitation B phase. Design anticipations were fully verified by the recorded very limited deformations in the underground (4.5cm) as well as on the ground surface (2cm).

The Unreinforced Final Lining. In the elaborated typical sections for the permanent lining the foundation (either foundation beams or invert) was designed to be standard steel reinforced, while the vault could be either reinforced or unreinforced. The implementation of non-reinforced final lining possesses the state of the art to latest safety standards in Europe (Directive 2004/54). The contractual documents of the project provided the contractual basis for the design of the unreinforced concrete permanent lining for the MMK tunnels. In principle, the intersection blocks as well as the crossings were designed as steel reinforced, while the standard blocks of the main tunnel bores are either reinforced or unreinforced. Also, for the unreinforced concrete blocks the ones with a niche (Emergency or Drainage) the reinforcement was restricted only around the niche area. Of the three main final lining types the concept of unreinforced vault was designated for the open section type (I) and under conditions for the shallow invert section (II), with thickness 0.45m at the crown. In principle, application was adopted in strong and adequately competent rock-masses (E>1GPa considered to be the threshold value between the reinforced and the unreinforced). Instead, sections in questionable as well as poor rock and / or sections with acknowledged vulnerability to seismic forces (such the portals and the low overburden areas) were excluded from application. At certain cases dilatometer testing was conducted for the validation of the prevailing Young modulus. Design basis for the adequacy checks was based on the requirement for maximum crack width of 1.0mm, while the calculated crack width evolution should be restricted to less than one half of the section. Formwork removal was allowed at minimum compressive strength of 2MPa, alongside specific curing process. Certain restrictions were, too set to address cases of excessive over-excavation with the actual thickness not exceeding 150% of the nominal thickness (0.45m). The application of the concept included mainly tunnels T1 (1,46km out of the 3,85km) and T2 (3,37km out of 11.94km), with its application generally restricted by the inherent geometry of the vault (to accommodate the three lanes' traffic requirements) as well as the unfavourable geotechnical conditions (weak masses and prevalent mixed face conditions for long stretches). It is essential to note that in the 5,58 km of twin tunnels T3 none section was casted as non-reinforced.

O01

Applied research for EPB-shields in difficult ground conditions

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Keywords: EPB, difficult ground, conditioning, face support

As a result of growing urbanisation, subsurface space is developed and has to be expanded. New and bigger tunnels are required to meet the infrastructural needs. The ground is the decisive factor regarding the type of tunnelling method and its efficiency. The bigger such projects the greater the chance to encounter inhomogeneous in situ ground conditions. This makes an adequate and economic choice of the process technology more difficult, especially in mechanised shield tunnelling.

A clear differentiation based on the grain-size distribution between the field of application of an EPB shield and a hydro shield nowadays is hardly possible. An application of a hydro shield machine in fine soils is just as feasible as tunnelling with EPB shields in coarse soils.

In this article, the authors explain selected geological conditions, which represent challenging and difficult situations for the application of EPB shields. Therefore, it is particularly focused on overconsolidated cohesive soils, highly permeable non-cohesive soils and sedimentary rock as well as areas of mixed face conditions (rock and soil). Moreover, test methods and tools for the planning and the construction phase are presented. This conference contribution is based on a recently published reviewed journal paper by the authors (Galli & Thewes, 2014).

Fig. 1: Examples for Difficult Ground in EPB tunnelling:

O02

A 3D simulation for TBM-EPB tunnelling interacting with adjacent buildings

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The aim of the paper is a profound investigation of all relative parameters involved in the TBM-EPB tunnelling. A 3D numerical model simulating a twin tunnel excavated by a TBM-EPB is presented, allowing for all the components that influence the induced ground settlements. The sensitivity to variations of the face support, the pressure applied to the steering gap slurry and the tail gap grouting were also evaluated within the framework of parametric analyses. Furthermore, a full soil-structure interaction using 3D numerical analysis was carried out to evaluate the ability of numerical methods in providing accurate prognosis for buildings adjacent to tunnels excavated by the TBM-EPB method. Full soil-structure interaction using 3D numerical analysis was carried out, including a 7 storey building founded close to the tunnels. The methodology is validated by comparing the numerical results to in situ measurements recorded during the excavation of the on going Thessaloniki subway with a TBM-EPB. Figure 1 illustrates the settlement development in soil and the adjacent building at the instrumented cross section.

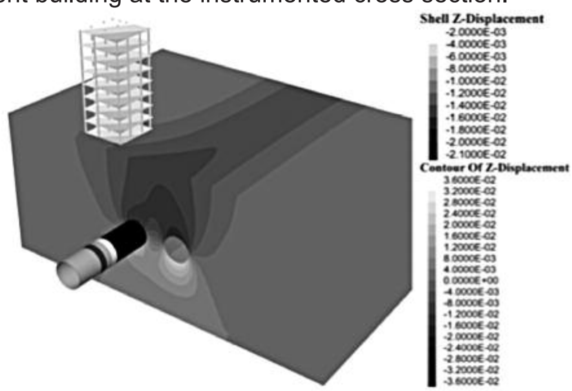

Figure 1. Numerically established progressive development of settlement with excavation advancement.

The application of the proposed method to the on going Thessaloniki subway and the good agreement acquired from the comparison of monitored data and numerical results has led to useful conclusions regarding the effects of relevant parameters on an accurate design and construction of shallow tunnels by the TBM-EPB method. It was found that, apart from the face supporting pressure, the steering and the tail gap pressures notably affect the ground movement. It has also been deduced that an accurate application of the TBM-EPB method limits the development of surface settlements to the region between 2.0*D* behind and 4.0*D* ahead the excavation face. It has also been found that the effect on adjacent buildings is rather limited at a distance higher than 3.0*D* from the tunnel centreline. Therefore, an accurate application of the method assures the safety of closely founded buildings, limiting the effects to acceptable settlements and tilting.

O03

NeTTUN project: how to increase the lifetime of TBM drag bits?

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Keywords: Damage, wear, drag bits, materials, modelling

NeTTUN is a collaborative integrated R&D project, aiming at developing New Technologies for Tunnelling and UNdergroung works. Since Sept. 2012, it is funded by the 7th Framework Programme of the European Commission. It involves 21 partners (from universities, SME and large companies) from 9 European countries.

In this project, a work package is dedicated to increasing the lifetime of the drag bits used on Tunnel Boring Machines (TBM). The wear of such parts represents a significant cost and waste of production time because of the related maintenance operations, with associated personnel risks that NeTTUN aims at reducing.

To achieve this goal, we combine different tasks related to:

- the analysis of damaged drag bits for the understanding of the phenomena that occur in the carbide inserts and body of the drag bits, in order to guide the development of materials that will overcome these phenomena;
- the numerical modelling of the material flow around a drag bit and of the contact between the drag bit and the ground (by FEM and DEM), in order to optimize the geometric arrangement of drag bits on the cutter head;
- the strategy of development of new optimised materials with improved wear resistance, by working on mixing different hard phase types, improving the binder behaviour, using new sintering techniques… in order to find ways to violate the law of nature concerning the relationships between hardness and toughness;
- the tribological testing of the newly developed materials, in comparison with existing materials, in order to understand the wear phenomena, to rank the materials, and to further improve the development of materials.

The final goal is to develop improved drag bits that would exhibit a lifetime extended by at least 20% over current drag bits. These new drag bits will then be tested on a TBM at the end of the project.

In this paper, the results obtained in modelling, and development and testing of new materials will be presented.

O04

Ground movements caused by Mechanized Tunnelling Works for the Athens Metro Elliniko extension

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Keywords: Tunnel Boring Machines, Surface settlement, Data base management

Athens Metro line 2, southbound extension "Agios Dimitrios–Elliniko" is an underground 5.5km long project, connecting 4 municipalities. The tunnel is constructed below one of the main road arteries of the city, Vouliagmenis avenue, with 4 new stations and one underground depot near its southern end. The tunnel overburden along the alignment ranges from 9.5 to 16.5m and the water table is found at 4 to 11m below the ground surface; it is constructed by a EPBM capable of applying a thrust force up to 70900kN and a torque up to 20000kNm, which achieved a penetration rate of 60mm/min.
The surface settlements are measured on ~6000 installed levelling pins. Measured settlements started to develop at the rear end of the EPBM shield at a distance 10 m behind the cutter head; there, the tunnel diameter excavated by the machine and that of the segmental lining create a 20 cm annular gap, that is filled with primary grout. Settlements continue for a period of approximately one month until final stabilization. The maximum ground settlements created by the machine passage at lot C were below 20mm, which is the alert limit for normal buildings.
The usual design procedure to evaluate settlements, due to shallow metro tunnelling, accounts for the local conditions and the pressure exerted by the machine on the face. Such a procedure employs assumptions for the local ground conditions and properties, the local geometry, and the face pressure distribution on the machine.
However, in-situ tunnel boring employs many more machine related parameters, of which major, affecting ground surface settlement, are considered to be the face pressure, the thrust force, the cutter wheel torque, the volume of the excavated material, the volume of the primary grout, and the rate of advance. These parameters have variability in precision; however, they are interrelated and therefore contain redundant information. Thus, face pressure and thrust force is observed to have simultaneous peaks and lows, and this is similarly observed between cutter wheel torque and the rate of advance.

Table 1. Specified EPBM operational parameters

Face support earth pressure	Thrust force	Wheel Torque	Penetration rate	Excavated mass	Primary grouting
(bar)	(kN)	(MNm)	(mm/min)	t/advance	lt/advance
0.6	12500	5.0	40	180	4575

At chainage 13+075, where the overburden is at 9.5m, we observe that the EPBM thrust and penetration obtain low values, whereas face pressure, primary grouting and excavated mass quantities obtain the specified values shown in Table 1. This interrelation attributes the creation of ground movement there to the ground formation. However, generally no such single or pairs of operation parameter may predict quantitatively the ground response. A more thorough combination of EPBM operation parameters with geometric and ground parameters improves the value of any prediction.

O05

Development of Dual-mode TBMs

F. Renault

O06

Design criteria for service life design of tunnel linings – focus on structural reliability and associated safety factors

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Keywords: Codes of practice, Service life, Structural reliability, Tunnel linings

Tunnels are typically large scale infrastructure projects, where a requirement for an increased service life is present. In order to meet such requirements – except for a sophisticated design detailing, advanced material and construction quality, and a well specified structure monitoring plan – the appropriate adjustment of safety factors is necessary. Paradigms of non-standard service life are discussed in (BTS-ICE, 2004), (Bergmeister, 2013), and have been seen among others in the Brenner Base tunnel (200 years), the Koralm tunnel (150 years), the London Crossrail and the Doha Metro (120 years), or the Niagara tunnels (90 years).
The service life of a structure may be expressed in conjunction to its time-dependent performance level and be processed in the reliability discipline, as discussed by Frangopol et al. (2004) and as integrated in codified performance based assessments (fib, 2012). In Eurocode 0, “Basis of Design” (CEN, 2002) a structure’s service life is defined as the “assumed period for which a structure or part of it is to be used for its intended purpose with anticipated maintenance but without major repair being necessary”. The structure’s service life ends when the minimum acceptable (terminal) target reliability β_{TARGET} is reached.
The present paper discusses a simplified methodology to support the evaluation of the design service life of a tunnel lining through an engineered scaling of the involved ULS partial safety factors. This is achieved through considerations of the reliability level inherited to the structure at the very beginning of its lifetime, during design. Furthermore, this solution does not contradict the Eurocodes (CEN 2002, CEN 2004) but complements their use, i.e. this methodology is consistent with the reliability concepts indicated in Eurocode 0, while similar approaches have been applied in the design criteria of other large infrastructure projects with non-standard service life requirements, as for example the Brenner Base Tunnel (Bergmeister, 2013). This design concept is then presented in a combination with special SCL design assumptions indicating the load sharing between the two linings (primary and secondary) and the primary lining degradation in long term situations.

O07

Assessing tunnel behaviour and support in heterogeneous rock masses. The flysch formations in Padina tunnel, Serbia

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Keywords: Tunnel, Flysch, Ground types, Tunnel Behaviour, Support

The paper describes the geological and geotechnical conditions for the excavation and support of Padina tunnel in Servia. Subject of this work is to assess the geological and engineering geological conditions along the tunnel, to evaluate all the possible ground types along the tunnel branches, to assign the geotechnical parameters of the probable ground profiles and to consider the probable tunnel failures (behaviour types). Moreover, the philosophy of the primary support measures is suggested in order to contain and control the probable failure modes.

Padina tunnel is located on the E-80 Highway, Belgrade - Niš – Dimitrovgrad, section: Dimitrovgrad Bypass – Border crossing. The tunnel is driven in two twin tunnel tubes (one for each driving direction), with total length of around 1080m. Tunnel overburden generally ranges from 15m to nearly 40m, while the axial distance of the two tunnel bores is 30m. The Padina Tunnel is constructed with conventional excavation in accordance with the principles of the NATM using the top heading and bench method. Due to the poor ground conditions and its shallow position, the tunnel was expected to be a difficult one. The twin tube, two-lane highway tunnel was successfully constructed without significant problems. A comparison between the predicted and encountered geotechnical conditions and tunnel behaviour is presented in the paper.

The bedrock in the wider area of Padina Tunnel consists of flysch sediments and more particularly sandstone beds with siltstone intercalations with some Neogenic deposits. The area is disturbed by several faults. One of these tectonic surfaces is located perpendicularly to the exit portal and generally determines the boundary between the flysch sediments and the Quaternary and Neogenic deposits. Limestone masses may be occasionally met inside the flysch strata but in thin zones. It must be noted that there are cases, where sandstones can be calcitic due to the high presence of the limestones in the area. The significance of this calcitic presence to the tunnel design lies on the higher intact rock strength that is developed but also on the dissolution phenomena inside the sandstone mass. This karstification though, is met along some fault planes with insignificant length and without filling presence.

In general, the formation is moderately fractured, but along fault and shear zones it is sheared and heavily folded. These zones are found perpendicular to the tunnel direction, since they have a NW-SE and NE-SW direction. These faults have disturbed the rock mass in a zone of 3 m - 5 m but are not very frequent in number as it is evident from the fresh cuts in the area. In addition, shear zones are also presented with sub-horizontal direction, with less, though disturbance. In order to investigate the properties of flysch, rock mass has been classified with the geotechnical system of GSI (Marinos, 2011). Flysch formations are classified here into 4 rock mass types (I to IV) according to their tectonic disturbance and sandstone-siltstone participation. A certain range of GSI values

for every rock mass type are proposed. The sandstone rock mass ranges from blocky (I) - very blocky (II), folded-disturbed (III) to sheared (IV).
Several behaviour types were considered. To determine the ground behaviour, the Ground Type is combined with the predicted ground conditions affected by factors such as tunnel geometry, primary stress condition, and water conditions. From the geotechnical point of view five different ground types were proposed. Flysch can be stable, exhibit wedge sliding and wider chimney type failures, or cause deformation even under low overburden. Its behaviour is controlled by its main geotechnical characteristics, as well as by the in-situ stress and groundwater conditions. The tunnel behaviour of rock mass types I and II is purely anisotropic and is controlled by the orientation of discontinuities, mainly the bedding, in relation to the orientation of the tunnel. As a result, there is a possibility of wedge formation and sliding. Sliding can occur along thin siltstone layers with low shear strength that are often present on bedding planes, especially in Type II. Similar lower properties are presented along the shear zones or faults. The behaviour of the rock mass type III can be well considered as isotropic. It is controlled by the low strength of the intact rock and limited deformation starts to develop under medium overburden. Yet, there is a possibility of local wedge formation and sliding, enhanced by the siltstone layers, if the geometry of joints favors it. As a result of the relatively good “interlocking” of the rock mass due to its folded structure, no extended falls are expected, except only in weathered zones close to the surface. The behaviour of the rock mass type IV is clearly isotropic, controlled by its low strength and high deformability that are responsible for the development of deformation.
These classified Behaviour Types were the basis for the design of appropriate measures (excavation and primary support) to achieve stable tunnel conditions. The temporary support measures that were designed according to these Behaviour Types are presented in the paper.

O08

A simplified approach of the rock-bolting design based on the principles of NATM

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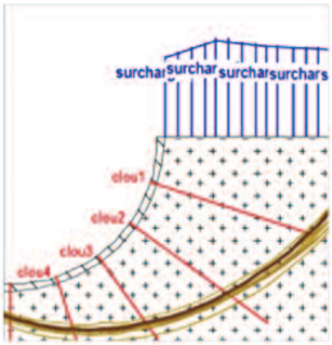
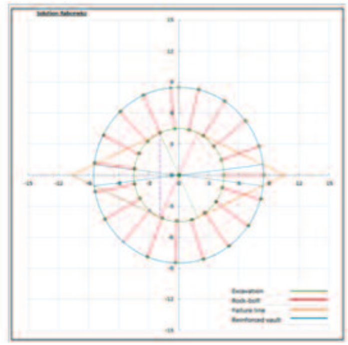
Keywords: rock-bolting, simplified approach, limit equilibrium, GEOSTAB

A simplified approach is presented in this article in order to evaluate the efficiency of rock-bolting in underground excavations. The basic principles of the approach are based on the NATM as it was been described by Rabcewizc in the 60’s, with the bearing capacity of the reinforced rock arch depending on the development of shear lines through the support system (rock-bolts and shotcrete) and the appearance of a sliding body that under the influence of the geostatic stresses is extruded towards the interior of the tunnel. According to NATM, but with more rigorous and modern formalism, the design of rock-bolting is

based on the limit equilibrium, where the shear strength of the reinforced arch is performed to determine the global stability in terms of a safety factor.





General stability of a bolted section, GEOSTAB ©

The equivalent simplified approach is a typical 2D computation, realised with GEOSTAB, slope stability software, where the rock-bolting should verify the stability of the sliding body, subjected to an overload. The overloading varies from the residual strength of the rock at the tunnel wall, to the initial stress at the infinite without considering a fictitious internal pressure as in the convergence-confinement method but a real state of stresses at a certain distance of the face.

O09

A Method to Help prevent Errors In Steel Tube Jacking

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Keywords: Jacking, Steel Tube, Tunnel, Weld, excavation

The steel tube jacking method, which uses powerful hydraulic jacks to horizontally push moderately sized steel tubes through the ground behind a shield, is commonly used to install underground pipelines, ducts, and culverts. This technique is also known as micro-tunnelling when the diameter of the steel tube is relatively small. Steel tube jacking provides a flexible, watertight, finished pipeline as the tunnel is being excavated. One major problem with steel tube jacking is the connection of steel tubes as they are being pushed into the earth. Steel tubes are typically welded together end-to-end, sometimes with steel plates as connectors, but deformations due to overburden and earth pressures make welding extremely difficult. This study proposes the use of a portable modular steel ring that acts as a type of reinforcement liner to help maintain the steel tube shape during jacking and tunnel excavation. Numerical simulations were conducted to ascertain the level of stresses that the steel ring would experience during jacking under varying rock conditions. Results suggest the steel ring reinforcement method is promising for soft rock conditions.

O10

Modelling Load Reduction Method in NATM - case study

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Keywords: NATM, load relaxation factor, 2D model, 3D model

The New Austrian Tunnelling Method (NATM) has been adopted extensively as a method of tunnelling in Iran. The NATM philosophy stated that a certain amount of ground deformation should be allowed to take place to reduce the pressure acting on the tunnel and mobilize a ground arch while maintaining the integrity of the ground mass, but deformations must be minimized. Usually, 2D and 3D numerical models are developed to predict performance of tunnels and surrounding ground during and after construction. The excavation steps include both sectional and longitudinal stages that cannot be simulated in 2D modelling without considering force reduction factors.
A number of 2D methods that can be used to account for 3D effects within finite element analysis framework have been presented in many references. Probably the most popular method is the so-called load reduction method. Studies demonstrated that the 3D ground response to tunnelling could be analyzed with a plane strain approach, provided a fictitious pressure was introduced on the tunnel surface in the 2D model. The objective of this study is to estimate of relaxation factor considering the factors controlling the 3D effects in 2D plane strain analysis of AmirKabir tunnel, an urban tunnel in Tehran. For evaluating this parameter, 2D load reduction models are used and comparison with fully 3D simulations for a section in the tunnel, focused on the predictions of displacement field is done. According to different methods and considering various dimensions of excavations' steps in the tunnel, the amount of relaxation factors for excavation rate of 1m are proposed.

O11

Quantitative risk and criticality assessment for tunnels under explosive and fire threat scenarios

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Keywords: Combined hazards, fire, explosion, quantitative risk, criticality assessment

Tunnels are key elements in modern traffic networks often crossing rivers and city regions with a high traffic density and with important, highly frequented buildings and infrastructures in close distance. Against these background economical and societal

consequences of large scale accidents and malicious threats such as fires, explosions, etc. are potentially very high. This is the reason why the German Federal ministry for Education and Research launched two very large national research projects (SKRIBT and SKRIBTPlus) with the purpose of tackling all issues for infrastructural tunnels resulting from accidents as well as man-made hazards. First results from these projects were already presented at the last ISTSS in New York.
Since a comparatively small initial damage to the structure might lead to a disproportionate effect for the tunnel itself, the whole urban infrastructure system or structures which are founded above or beneath the tunnel a more precise and holistic approach has to be taken for the overall assessment. That said it is necessary to assess not only the possible structural risks in terms of vulnerability of specific components to malicious threats but to get an idea of how the structure may react to and interact with its surrounding infrastructural network and/or the user. The project has shown how the research partners determined bedding reactions for typical soils in combination with tunnel constructions on a scaled and on a full scale basis. Then, first results of how these soil models can be implemented in numerical FEM-modeling for tunnel constructions, with a combined load of explosion and fire, were delivered.
In this paper the authors show how the evaluation model is developed onto the next level be implementing a newly developed quantitative assessment approach for structural risks under fire and explosive loads. In the following the authors will sketch how results for a specific structure can then be transferred into a holistic assessment methodology, which combines the structural assessment with aspects of user safety and network criticality, leading up to a criticality assessment of the structure as a whole.

O12

Safety-related current state of knowledge of road tunnel users in Greece

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Keywords: Tunnel Safety, Survey, Tunnel users' behaviour, Risk analysis

Road tunnels are regarded as a key element of transportation systems. However, the increasing number of these infrastructures is a double-edged sword also raising upfront an endogenous problem, which is the severity of accidents that may occur. Correct user behaviour may smooth the adverse outcomes of a potential accident but the diversity of tunnels makes it difficult to promote a universal, ultimately correct behaviour, therefore, information campaigns imposed by law (e.g. Directive 2004/54/EC) are usually requested to be designed on a local/regional basis. Before designing such a campaign or introducing

educational initiatives, it is vital to evaluate road tunnel users' awareness and current state of knowledge on safety issues.

This paper presents a study conducted in Greece aiming to evaluate road tunnel users' awareness and to identify potential knowledge gaps that should be addressed. In the framework of this study, road tunnel users are regarded the drivers of the private or commercial vehicles passing through a tunnel.

A large survey has been undertaken through an internet based questionnaire open to the public and advertised through social media and relevant websites. At the end of the three months survey, 1243 individuals participated in the research. The results revealed that there are several misconceptions concerning the recommended behaviour that tunnel users should adopt, both in normal conditions and emergency situations. The results validate the sense existing among road tunnel safety practitioners that the knowledge of users for safety issues in road tunnels is limited. It is interesting that the vast majority of responders do not know that a tunnels' radio frequency exist and a considerable percentage of them indicates that in the incident of a fire, they would close the windows and stay inside their cars. Rules such as 'try to get out of the tunnel if possible in case smoke is emitted from your vehicle' are familiar to less than half of the responders and a remarkable share of them do not comply with tunnel closure systems.

Taking into account that tunnel users are agents who influence other people behaviours, it is important to note that even a small improvement on their performance might greatly enhance the overall safety of these critical infrastructures, should an incident occurs. The aspects highlighted in this paper are to be utilised for the creation of an educational software programme funded by the Competitiveness and Entrepreneurship operational programme under National Strategic Reference Framework 2007-2013. It will also help to highlight recommendations that need to be taken into consideration by upcoming information campaigns on the issue, undertaken either by the State or highways Concessionaires.

O13

Vision based Tunnel Inspection using non-rigid Registration

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Growing numbers of long tunnels across the globe has increased the need for safety measurements and inspections of tunnels in these days. To avoid serious damages, tunnel inspection is highly recommended at regular intervals of time to find any deformations or cracks at the right time. While following the stringent safety and tunnel accessibility standards, conventional geodetic surveying using techniques of civil engineering and other manual and mechanical methods are time consuming and results in troublesome of routine life. An automatic tunnel inspection by image processing techniques using non rigid registration has been proposed. There are many other image processing methods used for image registration purposes. Most of the techniques are processing of images in its spatial domain, like finding edges and corners by Harris edge detection method. These methods are much time consuming and fail for some or other

reasons like for blurred or images with noise. Due to use of image features directly by these methods in the process, are known by the group, correlation by image features. The other method is featureless correlation, in which the images are converted into its frequency domain and then correlated with each other. The shift in spatial domain is the same as in frequency domain, but the processing is order faster than in spatial domain. In the proposed method modified normalized phase correlation has been used to find any shift between two images. Before processing the tunnel images i.e. reference and template are divided into small patches. All these relative patches are registered by the proposed modified normalized phase correlation. Relative pixel movement between the two sub images are calculated by the proposed method, which is much faster than the other methods. These pixels shifts are converted to measuring units like millimetres, centimetres etc. Any shift or deformation in tunnel is pointed out after the application of the proposed method on the whole tunnel.

O14

Application of risk based approaches for road tunnels' safety in Greece

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Keywords: tunnel safety, risk analysis,

In the past five years the use of risk analysis methodologies in operation of road tunnel in Greece, has been a standard part of safety management. Risk analysis methods were formalised, adopted by the Greek Administrative Authority and became part of the national legislation. The two adopted methods, one for investigating the risks associated with the transport of dangerous goods through road tunnels and other one to scrutinize the risks from all other vehicles, have certain limitations and restrictions that have to carefully consider when applied. No risk analysis method exists capable to deal with all possible problems and questions. Restrictions and limitations when applying a risk analysis method have to be completely explicit and clear.
The Directive 2004/54/EC introduces the possibility to move from traditional prescriptive standard to a partial risk based approach. This partial risk based approach is a complement to the prescriptive standard and has to be applied in specific cases, as mentioned in the actual text of the Directive. In this respect risk analysis is a valuable tool in decision making, when performed by experts and used by acquainted with risk analysis decision makers, always as a complement to the prescriptive standard.
Risk analysis methodologies have to be considered as a “live” text and not as an “once and for all” regulatory document. Collected data from different significant incidents provide valuable information and inputs in various tunnel safety management tools, strategies and procedures, including risk analysis. In Greece, the existing scenario risk analysis methodology for analysing risks without involvement of dangerous goods, it would be useful to be supplemented by a systemic risk analysis approach. In order to achieve this, a sound and reliable statistical data basis for both frequencies and consequences of significant incidents is required. Furthermore, this information would improve also the outputs of existing risk analysis methods.

There were some problems with applying the DG QRA model and the adopted method for evaluation of risks from DG's transport.

- T**he lack** of flame traps or any other provision to prevent fire and flammable and toxic liquids from spreading inside tubes and between tubes cannot be evaluated with this method
- The composition of the DG's traffic volume is not always a measurable parameter but rather an outcome of admissions and assumptions, that are often a matter of debate
- The selection of alternative routes is not a straightforward procedure. Problems of twenty-four-hour or yearlong availability of the routes, mountainous routes with poor characteristics, refusal of local communities to allow the passage of DG's vehicles (mainly as an outcome of risk aversion), are some of these.
- The projection of different values and indexes to the future (at least six years from the year of elaboration) is very questionable, specifically in conditions of the current economical crisis.
- The incidents rates (incidents per veh. Km) that are required in DG QRA are not directly available for the most Greek tunnels, as the covered vehicle kilometres are not reliably available.
- Incident rates directly coming from raw data have to be used very carefully, as many parameters may influence and warp resulting values.
- Although some traffic arrangements or managerial measures (e.g. the distribution of DG's vehicles in specific "quite" traffic time windows) may result in acceptable situations, these are often restricted only into design office environment, because of practical problems in their implementation and/or failure or inability to enforce the measure.
- **DG QRA requires** substantive update and upgrade of the model

For the risk scenario analysis, the determination of reference tunnel gave rise a lot of debate. Some items that are faced and are issue can be summarized as in the following:

- The scenario analysis is only applied in self resque phase.
- The dimensioning of ventilation system and its smoke extraction capacity is not something that is specified in the Presidential Decree or the Directive.
- For some older tunnels some systems are not in compliance with most recent specifications. How these systems are introduced into the model
- There is a debate on the characteristics of the typical evacuating person. How the persons with reduced mobility or other disabilities are coming into the simulation of evacuation procedure
- The number of drivers who continue to enter the tunnel ignoring all relevant signs (tunnels without closing barriers
- Time required for activation of different parts of tunnel equipment.
- The determination of reference tunnel, namely a tunnel of same characteristics with tunnel under consideration and complying to all minimum safety requirements introduced by the Directive 2004/54/EC, is not always a straightforward procedure.

The very procedure of both risk analyses methods will be susceptible to some risks that can impair the contribution and the outcomes of risk analysis and risk evaluation. Such risks may be as follows:

- ➢ Inadequate resources (e.g. time, money, information, and knowledge)
- ➢ Risk analysis has to be incorporated into design procedure in order to avoid discrepancies and complications in decision making
- ➢ Improper mixture of experiences of a risk analysis and risk evaluation team.
- ➢ Introduction of risk management team in improper time.

- Inappropriate risk management procedures and methods can cause confusion and pass over the real problem.
- Loosely defined interfaces and interdependencies between involved parties
- Risk on oversimplification and uncritical trustfulness on existing codification. Uncertain and rulesless straightforward procedures into risk management team.
- Not well-defined or ambiguous risk assessment strategy.
- Misuse (intended or not) of risk analysis methods to justify and enforce decisions regarding construction or contractual options.
- Risk analysis approach needs all involved parties to be acquainted with risk analysis. This is specifically boiling point for politicians and decision making authorities.
- No risk analysis method exists capable to deal with all possible problems and questions. Restrictions and limitations when applying a risk analysis method have to be completely explicit and clear.

O15

Jet Grouting – A solution to problems in Tunnelling – Examples from Europe

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Keywords: Tunnelling, Jet Grouting, Ground Improvement, Projects, Shafts

Jet Grouting is a well-known method which was introduced to the field of geotechnical engineering more than 30 years ago; it primarily acts in the ground either as a mean of stabilization or as a sealing structure. With the aid of high pressure cutting jets of water or cement suspension, having a nozzle exit with a velocity ≥100 m/sec, sometimes air-shrouded, the soil around the borehole is eroded. The eroded soil is rearranged and mixed with the cement suspension. The result is a structured element ‘Soilcrete’ column, which has improved mechanical characteristics compared with the original soil.
Jet-Grouting has been introduced to the European market in the 70ies of the last century. Its versatility and flexibility together with its applications, in almost every soil formation, makes it a perfect solution for complex geotechnical problems. It is effective in open field as well as in confined space with limited headroom, since the column diameter does not correspond to the size of the rig. The salient feature of this technology is that from relatively small boreholes, columns in the range of several metres can be formed and almost arbitrary geometries can be composed out of them.
Over this long period of application, a lot of experience was gained with this technology and enormous progress was made pushing back boundaries and limitations for its application. Nowadays, it is used for various depths, even more than 70 m, and column diameters of more than 3 m are often common.

In the last decade, the unique features of this technology were used in all high profile tunnelling projects in Europe in order to facilitate the building process and to improve the level of safety and efficiency. The current paper presents projects in Thessaloniki, Barcelona and London where Jet Grouting solved complex problems in tunnelling.

Figure: Jet Grouting excavated column

O16

Bucharest Metro Enlargement – A Future Aim

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Keywords: metro, expansion, public transport.

In 1989 The metropolitan area of Bucharest city has in excess of 2 million people. In order to meet the public transport demand in Bucharest Municipality, in the 70’s a new public transport has been developed, the metro, as an electric underground public transport mode. This solution was capable of decongest surface traffic and, thanks to its higher average speed, save time for its users, reduce pollution, increase passenger comfort and safety. The planning and development of the metro system have kicked off simultaneously as a result of preliminary studies conducted during 1972-1975.
The metro operator, METROREX SA, has been established in 1977, placed under the authority of the Ministry of Transportation. The scope of activity of S.A. is “metro passenger transport using the underground and surface railway system, under traffic safety conditions in order to meet the public, social and civil defence interest”. Developed, equipped and put into operation in several stages starting with 1979, the current metro system totals are: double-track 70 km, 4 lines, 51 stations and 4 depots. Currently, some 50-59 (6-car) trains service Bucharest public transport system, carrying daily over 750,000 passengers in a safe, comfortable and reliable transport system, with a commercial speed about 33-36 km/h. Though the metro system accounts for about 2-3% of the overall Bucharest Municipality public transport system, metro passengers account for more than 25% of the total passengers and it is likely to further go up in the near future as a result of an improved harmonisation, based on complementarity, with surface transport.
As a result of the development of the metro system, the main public transport operators

in Bucharest are the following:

- S.C.T.M.B. METROREX S.A. - placed under the direct authority of the Ministry of Transportation – responsible with the management and operation of the metro system,
- RATB (Regia Autonomă de Transport Bucureşti) – placed under the authority of Bucharest Municipality General Council – responsible with the administration and operation of surface public transport system made up of trams, buses and trolleys.

The basis for the a study was the estimation as of 2000 of a population of 2,009 thousand people, which was supported by reality; the slowdown in the population decline starting with 2005; an annual average increase 0.2% rate for the period 2005-2010, while for 2010-2020 period an 0.4% annual average increase rate. The estimated population for 2010 is 2,034 thousands people, 2,165 thousands people in 2021 and, respectively, 2,550 thousands people in 2030.

In view of the aforesaid premises, starting 1991 a set of measures aimed at redressing and improving the metro operation has been developed. The following main strategies have been considered in the preparation of the metro rehabilitation and development strategy: a/. Improvement of the overall management system; b/. Institutional measures for the purpose of coordinating all surface and underground public transport aspects; c/. Developing investment plans to enable the development and modernisation of metro; d/. Improve user-friendliness of the existing metro system; e/. Modernise facilities currently in use on lines in operation; f/. Rolling stock acquisition.

O17

The challenging blasting approach for the construction of the three tunnels on the Motorway Athens – Salonica, Hellas

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Keywords: blasting, tunnel, construction, motorway

The Athens – Salonica Motorway is perhaps the most commonly used road of Hellas linking the capital city Athens with the co-capital Salonica. Its route, among others, regard the difficult crossing of Tempi – Platamonas area (Central Hellas), with the construction of three twin tunnels, of 22 km total length. The demanding blast design as well as the implementation of a vibration monitoring program regarding the tunnelling blastings were both assigned to our company EXORIXI S.A. The challenging conditions of the project, the increased risks, as well as various delaying incidents rendered the blast monitoring program decisive. Installation positions concerned risk factors such as the main gas pipeline (in close proximity to the tunnel), nearby settlement houses, archaeological and historical findings – structures, fresh-concrete structures inside the tunnels, as well as water vibration monitoring in the aquifer. Additionally, all these were in accordance with the rockfall risk from the adjacent slopes of the operating Motorway, providing valuable correlation and statistical analysis with the implemented crack-monitoring. This paper highlights the challenging management, blast planning and crack-vibration monitoring program, in relation to the elevated and acute damage risks.

O18

Application of Iranian Traditional Tunnelling Method in Ghaytariye- Ozgol Cable Tunnel

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Keywords: Utility Tunnel, Tehran, ITTM, Elevated Bridge

This paper discusses the overall challenges to construct a 6.0K m Utility cable (63/230KV) tunnel in Tehran greater city during 6 month by Iranian Traditional Tunnelling Method (ITTM). The goal of the project is to rapid remove the high voltage cables of aloud towers to tunnel. Removing of towers provide possibility for construction of 11.0 Km length Sadr elevated bridge in north of Tehran. Due to urban restrictions for tunnel course, lack of sufficient time and encountering to buried urban facilities the ITTM has been used instead of shield tunnelling. In this project, the ITTM with 34 m/day progress represented the most rapid upgrade ever undertaken in Tehran heterogeneous urban texture. The paper describes the efficiency of ITTM and measures taken to negotiate these difficulties. Due to time restrictions, the geotechnical parameters of soils have been determined through direct observation of high building trenches and experienced gained from tunnelling in similar materials. Tehran is defined as a complementary located in one of the most earthquake prone areas in Iran. The tunnel route excavated through GC,CL-SC and GW-GM soil types.
During excavation by ITTM, the following major extraordinary difficulties have been encountered: encountering of tunnel with Qantas, buried urban facilities, huge boulders and under passing of 3th line of metro.
Experienced gained from application of ITTM indicated that, this method with respect to ground water control, dealing for unforeseen, tunnel alignment, ground movement and urban restrictions is more flexible and effective than shield tunnelling method.

O19

Conceptual design of ventilation system of "Lorentzos Mavilis" road tunnel – Experiences from design and construction of ventilation shaft

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The road tunnel Lorentzos Mavilis (former Driskos) is part of Egnatia Highway, with a total length of about 4.560m, located between Ch.: +166.06 6 & 10 730 and geographically between the River Arahthos and Ioannina. This consists of three Axial Fans Ventilation and 2 Fire Dampers. Ventilation of Lorenzo Mavilis Tunnel under normal operation is achieved with a longitudinal ventilation system, consisting of 38 Axial Fans. In emergency cases, such as an accident or fire ventilation is accomplished through the Ventilation shaft. The

latter consists of 3 Axial Ventilation Fans and 2 Flame Retardant Baffles that only 2 of the 3 Axial Fans will be in simultaneous operation, while the third serves as backup. The shaft is located about in the middle of a connecting gallery between the two tunnel tubes, focusing on the Ch. 8 +250, circular in cross section and excavation diameter from 6.5 to 6.66m.

During construction of the shaft due to the geotechnical conditions in combination with the possible location of joints of pilot casing, took place pilot's blockage and breaking off of the casing and after the consolidation grouting program, the excavation works of the shaft continued and completed successfully. In this specific case, the initial design concept for excavation of the shaft with the removal of excavated material through the pilot was proven problematic. In general this method is not advisable for weak sheared and water bearing rock masses but only for healthy rocks with relatively high RQD values.

In conclusion, in order to avoid unforeseeable developments, when drilling deep shafts it is proposed:

1. In cases of "bad geotechnical conditions" the suggested method involves excavation without using a pilot, but transport and removal of materials of excavation from the roof of the shaft. This method requires necessary special and relatively expensive equipment for the safe and effective removal of excavated material (special wagons).
2. In cases of "good geotechical conditions" appropriate shaft excavation method is the one using pilot (cheaper method compared to the above one).
3. Finally, shafts using pilot can be excavated in case of "bad geotechnical conditions", but under certain conditions, related to the possibility of execution a proper consolidation and stabilization rock mass grouting program before the shaft excavation.

It is underlined that the shaft's' excavation method depends on all these factors, and the combination of these factors can give the most suitable method for each case.

O20

Overview of the Longest Railway Tunnels

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Keywords: Tunnel, Railway, TBM, NATM

The 25 km long high-speed railway tunnel was designed for the new railway route between towns Prague and Beroun in the Czech Republic. The project would be very exceptional within the Czech tunnelling industry and there are not many longer tunnels worldwide. An unusual character of the project led to a review of similar projects, which was namely focused on the major technical aspects of extra long railway tunnels.

The presented paper brings some interesting outcomes from the provided review. Overview of the longest modern railway tunnels in the world is presented. The overview includes completed tunnels (eg. Seikan, Eurotunnel, Loetchberg base tunnel, Guadarrama, Hakkoda, Iwate-Ichinohe, Wushaoling, Vereina, Vaglia, Qingling, etc.). Also projects under construction are considered (eg. Gotthard base tunnel, Koralm, Pajares,

Iyame, Ceneribase tunnel, etc.) and prepared tunnels are considered (Brenner base tunnel, Lyon – Turin, Gibraltar, etc.). A comparison of the basic parameters of major long railway tunnels is provided (length, basic concept, profile, distance of cross-passages, safety concept, method of excavation, etc.). Also interesting features of long railway tunnels are generally discussed and approach to various problems in different countries are highlighted (comparison of single-track and double-track concepts, layout and location of underground stations, requirement for crossover connections within the tunnel, bifurcations, location of cross-passages and emergency exits, internal diameter of single-track tunnels, etc.).
The decisions about tunnel concept, tunnel diameter, and distance of emergency exits have to be done in early stages of the design process. These decisions are crucial and they have a marginal impact on the final cost. It can be seen from the presented data that main features of very long tunnels vary very significantly. There are many reasons of this situation: missing standards (long tunnels have to be treated individually), amount of money available for the project, time available preparation and design, safety requirements in various countries, etc. In each case maximum effort should be made to optimise the design and to reduce final cost with retained safety.

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O21

Metsovo Tunnel – NATM Design for Squeezing Ground Conditions

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Keywords: Tunnel Design, Squeezing, NATM

The Egnatia Odos motorway is one of the largest civil engineering projects in Europe at the current time. The 670 km long motorway is situated in northern Greece and leads from Igoumenitsa at the Ionian Sea in the west to Kipi at the Turkish border in the east. The main highway has been opened in 2009, major construction works for the nine perpendicular feeders providing connections to Albania, FYROM, Bulgaria and Turkey are still under construction.
Significant parts of the alignment are in topographically difficult mountainous areas, which resulted in the demand for 76 tunnels and 1.650 major bridges. 30% of the project costs are dedicated to the tunnels with a total combined single bore length of 99 km. Most of the mined tunnels are located in the western part of the route, where the Egnatia Odos crosses the Pindos Mountains, which are the southernmost extension of the Alps. In this area the ground conditions are dominated by heavily sheared flysch, ophiolites with a high degree of serpentinisation and the occurrence of major thrust zones in combination with tectonic melanges.

The paper describes the design and construction of the Metsovo tunnel. The 3.5 km long tunnel with an elevation of 1.100 m is the summit of the alignment of the Egnatia Odos. The left tunnel tube has already been finished in 1992 where large displacements, stability problems and collapses caused significant construction problems and delays.
The combination of unfavourable ground conditions with an overburden of up to 600 m results in severe squeezing potential. To face these squeezing ground conditions a yielding primary tunnel support has been designed for more than one half of the tunnel. Three of the nine Support Categories are designed for squeezing ground conditions. The installation of yielding elements (Lining Stress Controllers) in the shotcrete lining in combination with sliding joints of the tunnel arches allowed a radial displacement of the primary tunnel lining of up to 100 cm. After the construction of the cross passages from the existing tunnel the excavation of the second Metsovo tunnel was finished within less than two years with up to 8 simultaneous excavation faces. During the construction the yielding support proved to be a robust and flexible system for the treatment of the heterogeneous and squeezing ground conditions. In most tunnel sections displacements of 30 – 50 cm have occurred as predicted, with a maximum of approximately 70 cm.
Additionally to the description of the NATM design for squeezing ground conditions the paper focuses on the application of the design during construction by using the observational method. Predefined design criteria, which can be observed on site during construction, are applied to successfully select the proper support categories for each excavation step.

O22

Niayesh tunnel Construction under Modares bridge abutment

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Keywords: Urban Tunnel, Numerical modeling, Monitoring

The demand for more travel facilities in major cities has led to a significant increase in the interest in development of underground rail or road systems in Iran. The New Austrian Tunnelling Method (NATM) has been adopted extensively as the method of tunnelling. Niayesh northern tunnel is an urban tunnel in Tehran with the width of about 14 meters and the height of about 11.5 meter that constructed by The NATM. The project site is located at Tehran. Part of the tunnel passes about 6.5 m under abutment of the Modares Bridge that is part of a crowded highway. Figure 1 Presents plan view of Modares Bridge and location of the Niayesh tunnel.

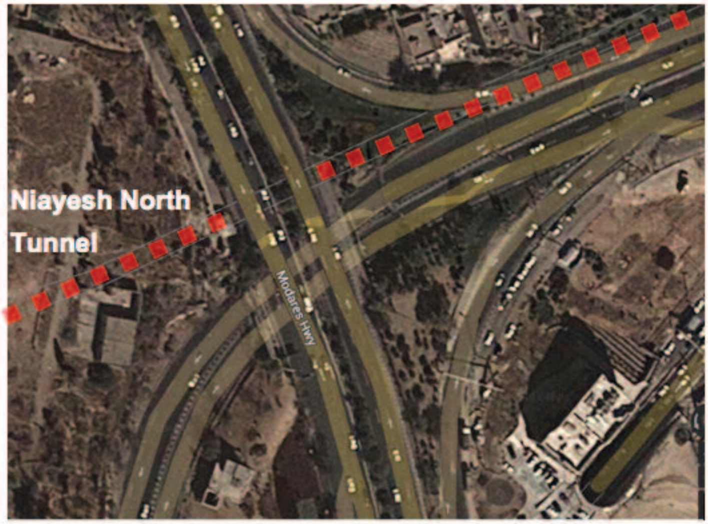

Figure 1. Location of Modares Bridge

In this study, some numerical models were developed using three-dimensional Finite Element software to analyze behavior of tunnels and surrounding ground and effect of construction on the abutment of the bridge. Stage construction is considered in models. Stability and performance analyses carried out for initial conditions, during and after construction conditions. The modeling results are compared with monitoring results which provided by several settlement point on the surface of the highway and some convergence stations placed in the initial lining of the tunnel. The modelling results are generally larger than the monitoring results during excavation and after construction of initial lining of the tunnel.

O23

Experience from the operation of hydraulic tunnels in PPC hydro projects

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The article discusses the performance of hydraulic tunnels operating in Public Power Corporation of Greece hydro project installations for many decades. The main problem encountered is erosion of the concrete lining. Cases of repair interventions are also presented.
Examples of a number of projects are given including Ladonas and Polyphyto headrace tunnels and Messochora diversion tunnel which is operating for an unusually long period of time without the reservoir been impounded.

More specifically in Ladonas HEP where the headrace tunnel is about 8.650 m. long with a diameter of 3,90 m , five inspections have been totally done up to nowadays . The findings always consisted of some cracks and rather scarce cavities in the concrete mass combined with calcareous stalactite features through them. Additionally a thin clayey layer always covered the lining.
Respectively in the case of Polyphyton HEP, the 4.500 m long with a max. diameter of 8,50 m. headrace tunnel, was inspected and repaired for the very first time during operation, 29 years after the completion of construction. Numerous cracks crossing the roof and the sides of the tunnel were recognized, as well as small in their majority erosive cavities at some parts with the steel reinforcement uncovered and exposed. Following a rehabilitation program the surface of the concrete was repaired by applying synthetic materials.
In the case of Messochora 10m dia diversion tunnel serious erosion of the tunnel floor and sides has been developed during an unusually long operating period of two decades. Transported material during floods is causing abrasion of the concrete lining and the tunnel floor has been almost completely destroyed in some areas. Special repair work has to be envisaged to rehabilitate the lining in view of the operation of the plant.

O24

Tunnelling under Existing Railway Roadbed using Pipe Roof Method

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This paper has dealt with a case history of design and construction of an 80m-length mined tunnel with unfavourable ground condition and closely located existing transportation facilities. Major issues in the design of pipe roof method (PRM) and ground responses during tunnelling are presented and discussed. Conclusions of this study can be deduced as follows:

1. Results of 3-dimensional numerical analyses indicated that full reinforcement of PRM along entire crown and bench may not ensure required bearing capacity of abutment in weak ground condition. In this study, a combination of elephant foot and leg piles was proposed to acquire larger bearing capacity and global stability in bench cut. Its effectiveness for protecting adjacent pier foundations and railway roadbed was successfully verified based on numerical calculations.
2. Even though PRM was proved to restrict tunnel displacements during the heading, PRM was found to induce considerable settlement during its own construction process. In particular, considerable subsidence was monitored when pipe advancing was carried out through mixed ground condition, i.e. border of weathered soil-rock layer in this case, while less ground settlement was measured during advancing of pipe within homogeneous rock/soil layer. Hence, care should be taken to the construction of PRM in the ground composed of weathered soil and weathered rock.
3. The monitored settlements of railway roadbed during tunnelling indicated larger settlement of ground than settlement at tunnel crown. The measurement was identified to be much larger than predicted settlement obtained from back-analysis. Possible reason for that can be severe ground water flow occurred during tunnelling. Two kinds of mechanisms were considered: the first one is suffusion of fine particles within ground

and consequent volume contraction of ground and the second one is compaction of ground induced by persistently imposing seepage force. Because there was no significant muddy flow during construction, seepage-induced deformation of ground over long period was supposed as the main cause of the excessive settlement of railway roadbed. Hence, when applying PRM for the ground with high ground water level, it is recommend to minimize outflow across temporary wall or tunnel section for preventing seepage-induced ground settlement.

O25

Utilizing a Distributed Optical Sensing Technique in order to continually monitor the strain of a Forepole temporary support element employed within an Umbrella Arch System

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Keywords: Fibre Optics, Forepole support, Continuous Monitoring, Support Sensor, Tunnelling

Temporary support for a tunnel excavated in weak rock can involve (but is not limited to) the utilization of a combination or steel-sets, rock bolts, shotcrete, spiles/forepoles and/or face stabilization technologies. These support elements combine to construct the overall temporary support structure. The purpose of such tunnel support is to maintain confinement for the rock mass in order to help the rock mass support itself. This research is concerned with the forepoles as components of this system; Forepoles are used ahead of the face, adding stabilization ahead of the plastic zone created due to tunnelling effects. They are installed longitudinally in order to allow for stable excavation underneath the structural umbrella formed by an arrangement of multiple forepoles. In terms of their mechanistic behaviour, forepoles support in the radial direction, however, they also react in the longitudinal direction. This bi-directional nature of the forepole support and reaction warrants the determination of the continual mechanistic behaviour / response of these support elements in three dimensions. The in-situ stress-conditions, rock displacements, and other complex interactions involved in tunnel excavations (among other factors) combine to provide an overall uncertainty as to the specific response of such forpoles to such conditions. Within this context, this paper summarizes a monitoring technique that has been developed in order to measure the continuous strain profile of a forepole element of support monitoring in order to capture the behavior of forepole elements. The procedure employs a distributed optical sensing technique using optical fiber that is based on Rayleigh backscattering. Determining a technique within working conditions and at the resolution as well as the operational accuracy is non-trivial. This technique has been successful in being employed with grouted rock bolts. The paper summarizes the technology employed for monitoring of such support elements as well as how it has been adapted for forepoles.

O26

Development of Tunnel Diagnosis and Maintenance Ontology

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Keywords: Tunnel Diagnosis, Tunnel Pathologies, Decision Support System, Ontology

Maintenance management of tunnels and underground structures involves the need of guaranteeing the operation under full safety conditions while optimising the overall maintenance costs. When managing a large set of tunnels, because of their high heterogeneity (geological environments, construction methods, lining materials, etc.), this cost is directly related to an optimised prioritisation of tunnels for maintenance works. This paper presents recent work, carried out as part of the EU project NeTTUN, on building a Decision Support System (DSS) to facilitate the decision-making process concerning tunnel diagnosis by assisting maintenance experts in defining appropriate inspection actions and maintenance operations. The DSS captures the diagnosis process conducted by tunnel experts, providing a knowledge-driven approach to tunnel maintenance where decisions for each tunnel are based on consistent criteria, using predefined facts and rules. The decision support process consists of analysing data from visual inspections in order to identify tunnel pathologies and possible risks of further degradation; it can help identifying tunnel priorities and deciding of what maintenance operation is needed. The work carried out utilises state-of-the art Semantic Web and Artificial intelligence technologies to capture, present, and retrieve expert knowledge about tunnel maintenance for developing an intelligent decision support system.

The paper presents the initial stage in DSS development - constructing a knowledge base that represents domain knowledge captured from tunnel maintenance experts. This includes the existing decision process concerning the maintenance of tunnels which will provide a context model for automated decision support. The first step in building this knowledge base was to capture the diagnosis process into a conceptual model, based on knowledge elicitation with tunnel experts and by consulting the relevant tunnel maintenance regulations. This conceptual model represents a valuable resource that includes tunnel disorders observed during inspections, common tunnel pathologies, influencing factors that influence the pathology's development and evolution. The conceptual model was converted into a modular ontology following a widely-used ontology development methodology, as proposed by the METHONTOLOGY framework. The ontology is implemented with state-of-the-art tools such as ROO and Protégé, and is published using well-established W3C recommendations such as Web Ontology Language (OWL) and Semantic Web Rule Language (SWRL). The first of its kind, this ontology is computer-processable and reusable due to its encoding using standardised languages. A case study of a DSS to support tunnel maintenance at SNCF is the current instantiation of the model; however, the approach and model and fairly generic suitable for a range of tunnel maintenance practices based on tunnel inspections.

O27

Works for Metro Line Rehabilitation

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Keywords: metro, rehabilitation, commissioning

In 1989 began the construction works on Line 4 splited in two sections (expansions on the existing Lines 1 and 3). Section 1, from Nicolae Grigorescu Station to Anghel Saligny Station, located in the south-eastern part of the city, has 4.7 km long and 4 stations. Section 2, located in the north-western part of the city, has 6.6 km long and 7 stations. This paper is focused on Section 1. Design for implementing Section 1 started in 1988. Due to the lack of funds, construction works stopped in 1993. Since 1993, only a controlled monitoring program continued.

Figure 1. Bucharest Metro Network.

After 2000, for continuing and completion the works, rehabilitation of the structures and further operation of Section 1, the Bucharest Metro Company has signed a loan agreement with European Investment Bank, basing on a Consultant Report and Expertise made by Prof. André P. Assis. Complementary investigations pointed out to: cracks and crushes of lining segments, severe geometry changes from original circular shape of the support rings and loss of stability, sand sediments inside the tunnel indicating leaching segment joints and consequently ground loosening around the tunnel, severe surface ground settlements and variations of hydrostatic level. The structural works continued, also the other works in order to put into operation the line: cleaning, waterproofing, railway system, installation, finishing, safety traffic control, fire prevention, ticketing etc, so that on the 19-th of November 2008 this metro section was commissioned. This paper will present all this aspects of rehabilitation and operation works, with all problems which were occurred during construction phase.

O28

Survey, diagnosis and strengthening of a railway tunnel under aeronautical ways

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Keywords: Railway tunnel, Airport context, Survey, Diagnosis, Strengthening

The railway tunnel of Regional Express network serving Paris-Charles de Gaulle Airport, is a 600m long tunnel with rectangular sections on both sides of an arched one, 11.5m wide and 9m high, at a depth of about 9m under two major aeronautical ways of the airport. It was built in trench in 1975, and for several years has been presenting mild fissuring centred under the two aeronautical ways, among which a longitudinal crack in vault.

His monitoring and regular survey by Aéroports de Paris Laboratory highlighted moderate but evolutionary deformations, which, in a proactive approach, led to conduct a diagnosis in order to evaluate the necessity for strengthening, and if necessary, define the process of buttressing works. This diagnosis made the best use of in situ instrumentation, regular and long-term survey of the tunnel, completed by various historical data mining, and combination of targeted investigations taking into account the specific context of an international airport and especially the imperative of guaranteeing the continuity of service.

Those studies explained the tunnel's behaviour by a combination of different factors, regarding the design and the execution of the tunnel, aging, and growth of airplanes' traffic. They concluded that there was no imminent risk of sudden collapse, but that in order to optimize safety, strengthening of the tunnel was nevertheless required in the short term, because of the pursuit of deformations with a threshold effect observed during winters.

The choice of strengthening method, mainly conducted considering both the efficiency objective and strong logistical constraints (because the rail traffic had to be maintained), was armed shotcrete clipped into the vault wall. The work was organized and conducted exploiting short time slots allowed by the railway operator, by nights, during winter time, and including special procedures in order to allow reopening of the railway traffic after each phase of the strengthening operations. Although it was impossible to go beyond the short deadline that had been imposed, the works were successfully completed.

Figure 1. Worksite views: construction worksite (1974), geotechnical survey (2011) and strengthening worksite (2013)

O29

The geology of Eupalinos Aqueduct, Samos Island, Greece

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Keywords: Eupalinos, Tunnel, Geology, Monuments, Samos

Eupalinos Aqueduct, built circa 550 BC, is not only a unique ancient monument and an astonishing pioneering achievement of engineering, but also an outstanding evidence of the timeless interaction between humankind and geological formations. The famous tunnel, 1036m long, is bored through the hill of 'Kastro' and is preserved in a good condition. The tunnel suffers locally from geological instabilities of varying severity. A detailed geological study was undertaken as part of a multi-disciplinary design campaign to protect and restore the monument. Main aspects of the geological conditions characterizing the aqueduct were studied, such as lithostratigraphy, tectonic structure and groundwater conditions, in order to provide data for the design of the rehabilitation measures. The paper focuses on the geological structure of the monument and on the relation between the structure and the engineering geological conditions. Geological mapping was prepared in two scales, one detailed (1:50 – 1:25) for the interior of the main tunnel and one broader (1:500) for the surface mapping of the whole aqueduct. A longitudinal section was prepared along the aqueduct combining the tunnel and the surface mappings. Along the northern part of the tunnel, where the presence of ancient Greek and Roman lining in the tunnel does not permit the direct observation of the rockmass for many meters, this correlation was assisted by geophysical investigations.

Geological studies

The purpose of the geological study was to investigate, to record and to analyze the geological conditions characterising the ancient structure, both on the surface and in the interior of the underground section, in order to determine its engineering geological model. One of the main scopes of the study was also to identify and describe, in terms of qualitative and quantitative detail, the potentially unstable geological structures along the underground section of the aqueduct. In order to feed the geotechnical – restoration design with precise data about the mechanism, the volume and the possibility of the potential failures within the Eupalinos tunnel, a codified system of engineering geological hazard ranking was established and customized according to the requirements of the particular project.

The Pythagorion and Hora formations in the tunnel zone dip towards NNE with a mean dip/dip direction of 20°/025° (Fig. 8). Folding and faulting have developed during the dynamic tectonic regime of the final orogenetic stages and faulting during the Pliocene - present extensional regime. Although the mean dip of strata remains constant, these structures bend and deeply dissect the strata in mesoscopic and macroscopic scale, which is significant for the scale of the specific study.

The orientation of the discontinuities (faults and joints), regardless of their age and movement characteristics, is more or less similar to the fold axes. NW-SE to E-W trending discontinuities dominate, whilst NNE-SSW are the main subordinates. Dip angles of 60-85° are prominent, but smoother angles are not uncommon. Most of the large discontinuities that were examined show very little or no displacement. The larger faults show offsets in the order of 0.5-5m and it is appreciated that the offset is very rarely larger than 10m. The exception is the Pythagorion fault that forms the boundary between the Kastro hill-range and the Hora plain, which is considered to be active and according to Meissner (1995) its vertical offset is in the order of 200m. Likewise, the offset of a large fault located at ch. 400 of the tunnel is appreciated to be between 10-50m.

The mode of tectonism is in close relation with the type of the involved formations. The harder and more homogenous massive to medium-bedded limestones deform in a more rigid way, forming broader folds and zones of intense cataclasis. In cases, the fracturing of the limestones obviously coincides with bending of strata. The much weaker thin-bedded and fissile horizons show frequent chevron or asymmetric folds, accompanied by smaller and close-spaced faults. Differential tectonic or sedimentary deformation occurs along the contact between fissile horizons and benches of limestone, frequently forming structures like small-scale folding, striations on the bedding planes, secondary cleavage and boudinage. These structures significantly degrade the geotechnical characteristics of these surfaces.

Some examples of tunnel Geological structure

Longitudinal and cross sections were prepared in order to describe the structure and modes of instability and to assist in the design of the restorative measures. The following figures present some examples and show the great diversity of structure and tunnel instabilities. The chainage of each section is indicated, starting measurements from the northern portal following an accurate update on the Kienast's measurements.

Figure 10. Tunnel in colluvium. Damage of the archaic lining (ch. 1034).

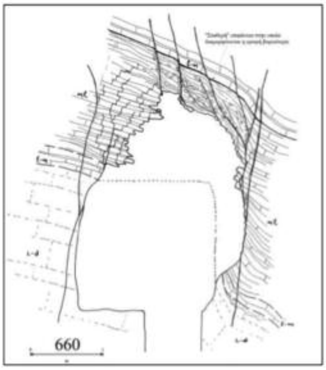

Figure 12. Instability on the roof in thin-bedded horizons (ch. 660).

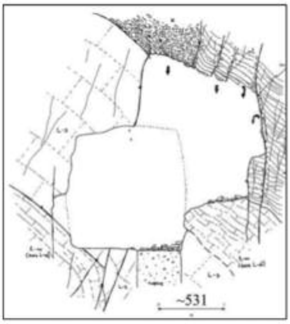

Figure 14. Roof and wall instability in thin-bedded folded and faulted horizons (ch.531).

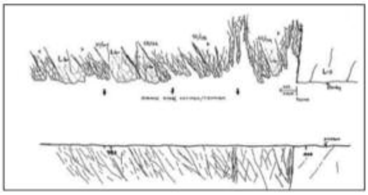

Figure 16. Longitudinal tunnel section across the fault zone at ch. 400.

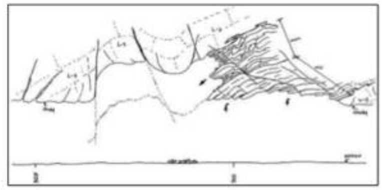

Figure 17. Instabilities along the contact between massive limestones and weak fissile layers (around ch.310).

O30

Outline of the Restoration Designs of Eupalinos Tunnel, Samos Island, Greece

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Keywords: Herodotus, Eupalinos, ancient tunnel, lining, restoration

The Aqueduct of Eupalinos has a total length exceeding 2,5 kilometres involving a bored tunnel 1036m long, ~1.8mx 1,8m wide under a 170m overburden of mount Kastro. Its purpose was to supply the city of Samos with water and was built in the mid- sixth century B.C, on the island of Samos that lies in the archipelago of north Aegean Sea. Herodotus (481-425 B.C.) was the first historian to refer to the monument. He mentions Eupalinos, son of Naustrophus, born in the city of Megara as the engineer responsible for the design and construction of this ancient project. He also describes the method of construction that makes this monument unique: "…One is a tunnel, under a hill one hundred and fifty fathoms high, carried entirely through the base of the hill; its excavation started from two portals (ἀρξάμενον, ἀμφίστομον) …". Part of the aqueduct was constructed as an open trench ~60 cm wide and of a variable height of some metres. Parts of the trench are covered with big orthogonal hewn stones and parts with an arched shaped roof. Another part of it was constructed using the qanat method which involves the construction of underground interconnected vertical shafts. The most interesting part of the aqueduct is the main and 1036m long bored tunnel that "hosts" the canal and the water conveying ceramic pipeline. Almost 230m of it are lined with a dry masonry made of high quality hewn stones. The roof is made of big slightly curved stones that form a triangular roof. Today parts of the monument suffer from deterioration and instabilities. Egnatia Odos S.A. (see note 1, chapter 7) in cooperation with the Prefecture of Samos and the Ministry of Culture initiated a multi-discipline design study to protect and restore the monument. In the context of the surveying design works the monument was mapped in a three dimensional space using both conventional and laser scanner techniques. The surveying data produced were processed with an advanced state-of-the-art software. The geophysical survey has given insight to the geological structure behind the lined part of the main tunnel and provided information on the thickness of its lining. The geological

and geotechnical designs involve a detailed engineering geological mapping and reporting of the area along the monument. It also includes the dimensioning of the support measures proposed to strengthen the rock mass around the tunnel's excavation perimeter where potential ground instabilities have been recorded. These measures include rock reinforcing systems with the use of stainless steel rock bolts and flexible netting of a different capacity. The structural design includes the works to restore the stability of the monument's structural elements mainly those on its lined parts. The electrical and mechanical design includes the lighting design, the illumination plans and the equipment so as to provide a comfortable environment in the tunnel and to highlight its engineering and historical features. Finally, the architectural design combines elements such as accesses, parking areas, footways and restrooms, information places, etc along the monument.

O31

Efficient Mixed Ground EPB Excavation: A study of Important Variables

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Keywords: Mixed ground, Soft ground, Metro, EPB Performance, Tunnel Boring Machines, Ground Conditioning

Earth Pressure Balance (EPB) tunneling in mixed ground conditions is a challenging prospect, as it often includes excavation in boulder fields, sections of rock, and/or sticky clay, under high water pressure or changing water pressure. In today's projects these challenging conditions are often compounded by urban tunneling near sensitive structures, strict settlement limits, and buried foundations and artifacts. Maintaining a rapid advance rate in such conditions is a function of many factors—from adequate cutting tools to cutterhead design, pre-planning and execution of an appropriate ground conditioning regime as well as proper maintenance and operation of the TBM. This paper analyzes recent record-breaking and high-performing projects, seeking to identify factors that contribute to fast machine advance. These factors will then be discussed and an effort made to form simple, high level guidelines for optimal TBM excavation in mixed ground conditions.
For this paper the authors reviewed 25 projects in 10 different countries which employed 40 different EPBMs on projects for which we deemed the geology to be "mixed". Obviously, the geology of some of these projects was decidedly more challenging than others but all contained at least some sections of geology that included coarse sands and gravels that wouldn't form a plug, or they contained large boulders or hard rock. Many of the tunnels contained some combination of these "difficult to excavate with an EPB" geologies.
For the 40 EPBMs reviewed the diameter ranged from 5.9 to 10.2 meters, though the vast majority were in the 6 to 6.5 m range. Thirty-one of the machines were employed on metro projects, eight on sewerage projects and one on a train tunnel. They were supplied by three different manufacturers. The face pressure under which they worked ranged from 0 to 13.5 bar with an average of 3.6 bar, with seven projects not reporting the ground pressure. Forty-seven percent of the machines were fitted with variable frequency electric cutterhead drives and the balance were driven hydraulically. The geology on which the machines operated varied widely from sedimentary rock and weathered rock through glacial till, gravel, sands, soils and clays, however all had encountered mixed conditions.

The single factor that had the strongest correlation to machine performance appears to be ground conditioning. The best performers nearly all had soils tested in a laboratory in advance of the start of boring and had established an initial ground conditioning regime in coordination with the contractor, the machine manufacturer and the chemical supplier. Even those projects that merely brought in the chemical supplier at the start of boring had more success than those who did not employ chemicals or did so only late in the project. In conclusion ground conditioning, as the main factor explored here affecting advance rate, is the first line of influence for the contractor/additive supplier/equipment supplier to influence how material is excavated. The GC plan, implemented in front of the cutterhead, impacts the entire operation as the material must flow through the machine, out the heading, over the surface and off the site. It affects every part of the job from the number of tool changes required to the amount of cleanup in the heading and on the surface due to spillage. When this global impact of ground conditioning is taken into account, it makes good sense that advance rates are closely correlated. The authors believe that it is this overarching influence that makes a good GC plan, in combination with an EPBM properly designed for executing the plan, one of the most powerful tools available in achieving good project success.

O32

Investigation of the influence of face pressure on surface settlements in EPB mechanized tunnelling

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Keywords: Mechanized tunnelling, EPB, 3D numerical analyses, Face pressure, Surface settlements

The excavation of a shallow tunnel with an Earth Pressure Balance (EPB) Tunnel Boring Machine (TBM) is effective in terms of limiting unfavourable consequences in the urban field, such as excessive ground surface settlements. During excavation, the tunnel face suffers loss of confinement resulting in extrusion (horizontal displacement), redistribution of the stress field, development of plastic strains and pre-convergence of the tunnel wall. This response can lead to excessive extrusion, even to face instability and thus contribute to the development of excessive surface settlements. The prevention from such an event is achieved with the stabilization of the tunnel face with the application and maintenance of a face pressure by the EPB-TBM during the excavation process. The problem was investigated via 3D numerical analyses with the finite element code Abaqus for two values of the overburden height (H=16m=2D & H=32m=4D measured from the tunnel axis level).
The excavation of the tunnel was carried out with a step sequence procedure that aims to simulate precisely shield-driven tunnelling with an EPB-TBM. The scope of this procedure is the numerical simulation of the cutterhead, the shield, the pressure that is applied on the tunnel face and the geometrical annular gaps that exist in shield-driven tunnelling. Particularly, the excavation process with an EPB-TBM through the numerical process is performed with the simulation of the following parameters: (a) the gap between (i) the cross-section of the tunnel excavation and the shield (shield tail gap or gst) and (ii) the cross-section of the tunnel excavation and the segmental lining

constructed by the EPB-TBM (annular gap or ga), (b) the pressure of the grout which is imposed on the cross-section of the excavation and the segmental lining, (c) the filling of the annular gap with the grout when the latter has become solid and has acquired its ultimate strength.
The results of the numerical analyses demonstrated that the reduction of face pressure leads to the increase of extrusion at the tunnel face, pre-convergence at the advance core and consequently surface settlements. However, the degree of increase is larger for extrusion. The influence on surface settlements is dominantly determined by the geotechnical conditions and the shield tail gap. For stable, if unsupported, tunnel faces, the effect of support pressure is negligible, since the arch effect of the surrounding geomaterial is created sufficiently, regardless of the shield tail gap value. For unstable, if unsupported, tunnel faces, the increase of surface settlements is strongly determined by the value of the shield tail gap, due to the different mechanism and causes of volume loss and redistribution of stress and strain field, that is developed. The percentage increase is: (i) up to 10% for non zero g_{st} and (ii) up to 30 % for zero g_{st}, in comparison to surface settlements for p_{fs}/σ_{ho}=1.00, where p_{fs}/σ_{ho}: ratio of face support pressure to geostatic horizontal stress at the tunnel axis level. The increase of overburden ratio (H/D) restricts the effect of face pressure on the induced ground surface settlements. The critical value of face pressure should be oriented to p_{fs}/σ_{ho}=0.50, in the sense that further increase does not lead to decrease of the examined parameter. However, for p_{fs}/σ_{ho}<0.1 development of excessive extrusion and surface settlements is observed. Particularly, the larger values of surface pre-settlements appear at and ahead of the tunnel face which lead to the development of unfavourable values of settlements as tunnel excavation advances.

O33

Automated Replacement of TBMs Cutting Tools

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Keywords: Pressurised tunnelling, Robotised maintenance, Risk reduction

Since the introduction, several decades ago, of the first concepts of tunnel boring machines (TBMs), the unremitting increase of mechanised and automated tasks and the reduction of manual tasks carried out by human operators have gone hand in hand with the continuous improvement of these machines. In the present state of TBMs, the replacement of worn cutting tools is a critical, tedious, and dangerous manual operation especially for earth pressure balanced (EPB) and slurry TBMs. Furthermore, hyperbaric interventions increase risk to the operators and require long decompression procedures that increase the idle time of the machine and reduce its efficiency. Tunnel boring contractors are therefore increasingly interested in automating these operations to reduce the risks to human workers and improve the TBM's performance. Moreover, the demand for new, ambitious and challenging tunnelling projects (very deep, high pressure boring) is ever increasing, but the supply of suitable TBMs is limited and the risk from working in the hyperbaric environments becomes increasingly unacceptable. This paper presents the development of an automatic and remotely operated robotic system dedicated to the replacement of worn cutting tools on TBM cutter heads. If successfully developed, it will considerably reduce the need for manual operations and human presence in the excavation chamber, and presents a viable solution for future tunnelling challenges. The results of market and technical studies through surveys with tunnelling contractors (partners in the European project NeTTUN) and feedback from field operators and experts in hyperbaric environments are presented. They highlight the need for automated cutter head maintenance and the advantage of a robotised system. The operational concept and design of the system under development are presented and discussed.

O34

Geotechnical Investigation Planning of Subway Projects in Urban Areas

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Keywords: Geotechnical Investigation, Planning

It is clear that geotechnical data gathering is one of the basic and important issues of subway tunnels and stations design. Proper and sufficient data collection from underground circumstance makes the designers stronger in order that they can decrease the design and construction risks. As there are several constraints in geotechnical investigations in urban areas especially for drilling and sampling or in-situ tests, organizing a geotechnical investigation plan will play an important role. Also, economical limitations of the projects should be considered in the mentioned planning but with no defects in technical issues. On the other hand, proper definition of investigation stages will influence the quality of the investigation and results accuracy. Since, subway projects are the combination of linear and concentrated projects from geotechnical studies point of view, therefore, an optimal planning is required to prevent extra costs. Geotechnical investigation planning, especially for subway projects, has plentiful and important points, based on mentioned issues. In this paper, the authors try to present some guidelines for geotechnical investigation planning, especially for subway projects. Required geotechnical parameters, number, depth and location of boreholes, type of in-situ and laboratory tests, which have been optimized in several subway projects in Iran and other geotechnical hazards are studied in this paper.

O34A

3D Numerical simulation of shield tunnelling with emphasis on the influence of the tail gap

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Keywords: Shield Tunnelling, Tail shield gap, Annular gap, Settlements, Tail void grouting, FEM

Shield tunnelling is a commonly used construction technique because it is very effective in reducing ground deformations and thus damage to urban infrastructure. This paper presents a 3D simulation of the Earth Pressure Balance (EPB) mechanized tunnelling using the finite element code ABAQUS. All the components of the TBM are simulated in detail including the gaps due to the overcut of the cutterhead and the difference of the radius between shield and segmental lining. Tail void grouting is modelled as an equivalent pressure in fluid state, while the hardened grout is modelled with 3D solid finite elements. The differences among tunnelling machines could have significant influences on the disturbance of the surrounding ground and ground surface settlements.
Therefore, this paper investigates the influence that the tail shield gap has in a mechanized tunnelling procedure via parametric analyses for various soil formations and tail shield gap values (g_{ts}=0, 2 and 4cm), while the tunnel face pressure remains constant. The surface settlements show a strong correlation with the value of the tail shield gap, according to the prevailing ground conditions. As depicted in Figure 1, surface settlements in poor geotechnical conditions show a high sensitivity to the tail shield gap values, while as the geotechnical conditions are becoming more favorable the influence is diminished. Regarding the tunnel depth the results show that increase of the H value leads to smaller surface settlements due to the stronger arching effect (Figure 1).

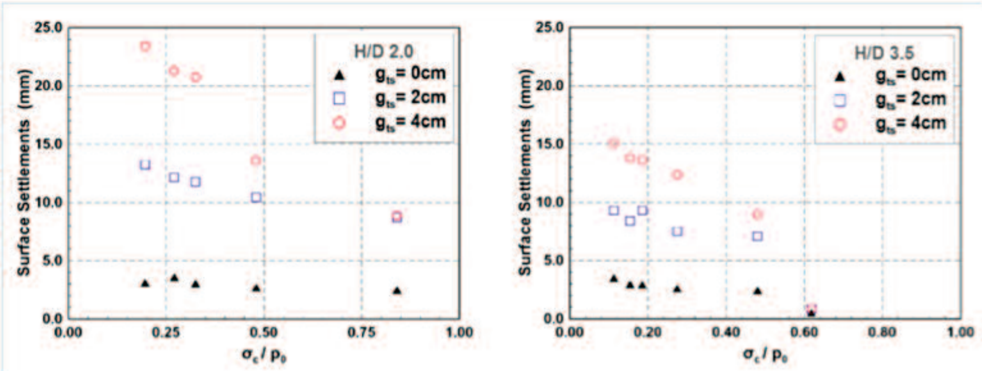

Figure 1 Results of the surface settlements relative to the geotechnical conditions for the three different tail gaps

O35

Advances in numerical modelling for complex tunnelling projects

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Keywords: Shallow tunnels, sprayed concrete, junctions, FE modelling, existing structures – impacts.

As computer technology has evolved in the recent years, numerical modelling appears to be an increasingly preferable solution in all engineering fields, including tunnelling. The finite element method has become one of the standard tools and proves to indeed be very useful for the analysis of complex underground structures. Besides the advanced constitutive models for soil and rock materials, numerical modelling is of significant aid in complex geometries. For example, this becomes evident in urban tunnelling having large platform size tunnels with several cross-passages, inclines and shafts, and/or in close proximity to utilities and other infrastructure. In such cases, sophisticated three-dimensional modelling can give a good and communicable description of the structural behaviour, indicate risks, and highlight issues deserving additional attention during design or construction, providing substantial aid to the project development. This has been shown in various recent design and consulting experiences of the authors. This paper presents recent experiences of numerical modelling campaigns in major urban tunnelling projects and discusses critical aspects of the modelling procedure and the verification of results through monitoring of the actual construction. The present paper attempts to shed light on the state-of-the-art use of numerical modelling in projects with high complexity, on the basis of case studies of recent urban underground projects in London.

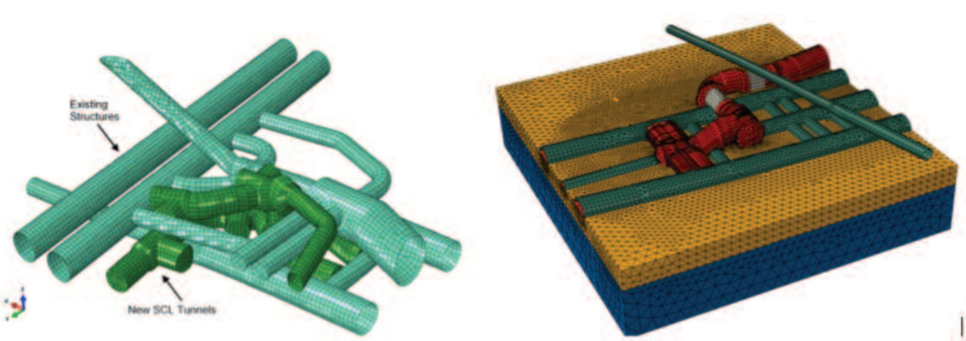

Figure 1. FE-Modelling of existing tunnels and new SCL tunnels in the Bond Street Station Upgrade

O36

Simulation of the Pinheiros - São Paulo cavern-shaft system collapse

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Keywords: NATM, strain softening, strain localization, shear bands, ground-support interaction.

This work is devoted to the numerical simulation of the conditions that have lead to the collapse of the Eastern cavern of the Pinheiros station in the city of São Paulo, Brazil (2007) constructed with the Conventional Tunnelling Method (CTM) or the New Austrian Tunneling Technique (NATM). The Pinheiros station where the incident occurred, is located in an area known as the Caucaia Shear Zone, resulting in highly fractured and heterogeneous rock masses. The main observed lithologies were biotite gneiss and granite gneiss displaying spatially varying weathering. According to the Bieniawski's RMR classification system, there were observed II,III,IV (partially corresponding to saprolite), and V (partially corresponding to residual soils) rock mass classes in the vertical plane from down to top. It is remarked that in addition to two-dimensional numerical analyses used in the design phase of the station, the installed vertical extensometers have not promptly indicated the incipient collapse phenomenon.

Herein the shaft-cavern construction was simulated by virtue of a numerical code that may model the evolution and propagation of shear bands in three-dimensional continua. After evaluating the in situ geological conditions presented in the open literature, a kinematic simultaneous cohesion-friction softening model of the "equivalent" continuous rock mass was employed. A preliminary model without considering the ground-support interaction has shown that failure is manifested with the evolution of shear bands starting from the corners of the cavern periphery as this approaches the shaft while retreating. Before this, another cylindrical shear band initiates from the bottom of the shaft and also propagates upwards to connect with the former and hence producing the final collapse or caving of the overlying rock mass along a distance of 40 m from the shaft. Based on these preliminary results, a second upgraded model was prepared and is presented here that takes into account the type and time of installation of the temporary support measures, as well as the appropriate configuration of extensometers that could have captured the initial stages of the collapse.

O37

Seismic fragility curves of shallow tunnels considering SSI and aging effects

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Keywords: Seismic risk assessment, Fragility analysis, Lining corrosion

The paper presents a numerical approach for the construction of fragility curves for shallow metro tunnels considering soil-structure-interaction (SSI) and the aging effects due to corrosion in the lining behaviour. In particular, the proposed methodology is presented and applied on a representative soil-tunnel system. Tunnel dynamic response is evaluated through 2D non-linear dynamic analyses, for increasing levels of seismic intensity. An elasto-plastic model is used to simulate the soil non-linear behavior during shaking, while the effects of lining mechanical properties, soil conditions and ground motion characteristics on the soil-structure system response are accounted for. In particular, two circular tunnel sections, two soil profiles (C and D according to EC8) and six real acceleration time histories are considered in the analyses. The aging effect to the tunnel lining behaviour is simulated through the modification of strength properties. Damage state thresholds are defined based on the exceedance of the lining capacity due to the developed lining forces. The fragility curves are estimated in terms of peak ground acceleration at the free field, for different time periods (i.e. initial construction, 50, 75, 100 years) based on the evolution of damage with increasing earthquake intensity considering the associated uncertainties (Fig. 1). As expected, the fragility of the structure is modified due to different soil conditions and due to the assumed change of strength properties over time. The proposed fragility models contribute towards an advanced vulnerability and risk assessment of transportation systems and infrastructures.

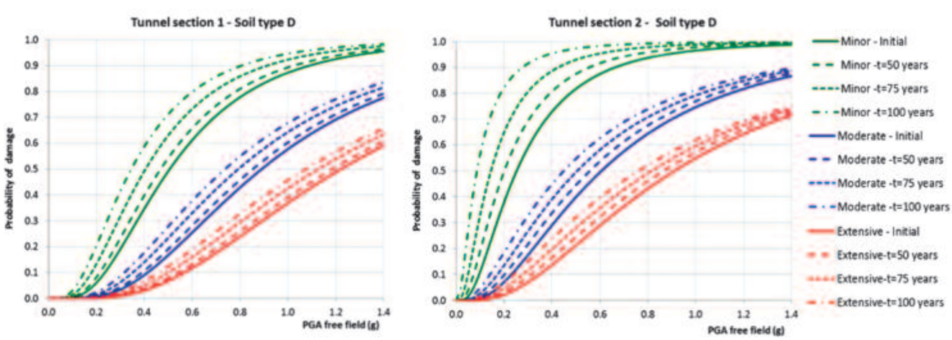

Figure 1. Time dependent fragility curves for shallow circular tunnels in soil type D

O38

Pillar stability analysis using the finite element method at the Lavrion Technological and Cultural Park underground hazardous waste repository

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The stability analysis and its performance assessment is an integral part of the design of underground structures. The restrictions and prerequisites for the development of special underground projects like underground hazardous waste repositories are stricter as their structural stability in a long term period is a key element to the success of the project.
In the paper is presented the assessment of the pillar behavior of the underground hazardous waste repository that has been developed at the site of the Lavrion Technological and Cultural Park. The design employed there follows the principles of the room and pillar mining method, leaving a number of pillars of the host rock to support the underground openings. A prerequisite for a safe working environment is that pillars support the overburden and pillar ribs and room remain stable during mining. The main design considerations of the projects are given and the analyses of the structural stability of the pillars are presented. The analyses, beyond the utilization of empirical formulae regarding pillar strength, are focusing on the use of two different finite element software programs (Phase2, Plaxis) that reproduce the actual geological and geotechnical conditions that have been encountered during the construction, where an unforeseen local geological anomaly affected part of the repository. The detailed analyses performed identify possible failure phenomena, evaluate the support measures and finally assess the pillar's stability. Moreover, based on the findings, the similarities and differences between these finite element programs are given, followed by their assessment with respect to the analysis type and calculation options that each program use.

O39

Application of Statistical Analysis for Numerical Modelling of Tunnels

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Keywords: Tunnel, Numerical modelling, Statistics, FEM, Geotechnical parameters

Geotechnical parameters of rock mass obtained from site investigation for the purpose of designing tunnels (or other geotechnical structures) often display significant scatter. This fact follows not only from the properties of the geological environment, which usually is not homogeneous, but it is also caused by inaccuracies in the executed laboratory or field tests.

Uncertainties in input parameters are allowed for in deterministic calculations in the geotechnical practice by means of safety coefficients. They enter the calculations to Eurocode 7 (EC7) in the form of partial coefficients applied to material parameters, loads themselves, their effects, or both of them. In a standard model calculation the results may be significantly conservative; a model with reduced input parameters may substantially differ from the real behaviour. The EC7 permits the use of probabilistic methods, which take into consideration the variability of input parameters and loading cases. A probabilistic calculation is formulated as an alternative, which should be verified by a standard calculation using partial coefficients. By using probabilistic methods it is possible to determine the probability of a defect and the index of reliability, the minimum values of which for the ultimate limit state and individual reliability classes are determined in the EC7. The result of the probabilistic approach is then not only the information whether the structure will or will not satisfy requirements, but also the determination level of the risk of a failure connected with the designed structure.
Probabilistic calculations have been becoming an ever more attainable tool for solving geotechnical problems. Their spreading in the common praxis is prevented first of all by the higher time consumption for executing the calculations, requirements for outputs from geotechnical investigation and, in addition, due to the absence of the implementation of probabilistic methods in a commonly used software. The paper will be focused on the Latin Hypercube Sampling reduction probabilistic method, which is an alternative to the time-intensive Monte Carlo simulation method. The paper content will comprise first of all the description of the method algorithm, its development, current state of knowledge and its application.

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O40

An indirect method for the design of reinforced tunnel faces

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Keywords: Tunnel face, Reinforcement, Design Method

Tunnel face reinforcement via fibreglass (FG) nails has been the most commonly used method for the enhancement of face stability and the control of deformation in front of and above the tunnel during conventional construction of underground works in the past 3 decades. However, the design of the fibreglass nails pattern is still mainly based on experience and in situ observation during construction, as no relevant widely recognised rational method exists. On the contrary, there is an important number of proposed methods for the estimation of the required retaining pressure σ_T on the tunnel face that ensures a certain value of the safety factor against failure. In that concept, a methodology that could relate the geotechnical and geometrical tunnelling parameters (soil shear

strength and deformability, tunnel depth H and diameter D) with an equivalent retaining pressure p_{eq} that gives the same face extrusion with a set of face nails with a density d, can be used for an indirect but rational estimation of the required nail density d, for given tunnelling conditions and $p_{eq}=\sigma_T$. Additionally, such a methodology could be used to perform equivalent, but simpler, 3D numerical analyses, where the fibreglass nail pattern is substituted by a retaining pressure on the excavation face.
The present paper proposes both a simplified and a detailed methodology to estimate the equivalent retaining pressure p_{eq} that results in the same average face extrusion as a set of fibreglass nails of a certain density d, using an extensive series of 3D finite element analyses. The equivalent pressure p_{eq} is given as a fraction of a reference pressure p_{ref}, which is determined as the maximum distributed face pressure that would result if all face nails reached their yield limit.

$$p_{ref} = \frac{n \cdot F_y}{A_{tun}} = d \cdot F_y \qquad (1)$$

with n being the number of nails, F_y the nail's bearing capacity, A_{tun} the tunnel face area and d the density of the fibreglass nails pattern. It is obvious that p_{eq} cannot be higher than p_{ref}. The value of p_{eq} and therefore of the ratio p_{eq}/p_{ref} depends mainly on the normalised tunnel depth H/D and the soil friction angle φ and secondly on the deformability of the soil and the axial stiffness of fibreglass nails. Therefore, a simplified methodology was proposed, which correlates the ratio p_{eq}/p_{ref} with the simple factor $(H/D)^{0.75}/\tan\varphi$ that includes the normalized tunnel depth H/D and the ground's friction angle φ, using the following linear relationship:

$$\frac{p_{eq}}{p_{ref}} = 0.065 \cdot \left(\frac{H^{0.75}}{D^{0.75} \cdot \tan\phi} + 1 \right) \qquad (2)$$

The simplified methodology is proposed for an initial, rational estimation of the FG nails' pattern density, in combination with one of the available analytical methods that estimate the required face pressure for a predetermined safety factor, during the early stages of the design. When the correlation between the face pressure and the face reinforcement pattern is to be used for the execution of more simple numerical analyses, application of the following, detailed methodology is advisable.
In the detailed methodology, the effect of the ground modulus E_{soil} and the axial stiffness of the nails E_{nails} are also taken into account. The ratio p_{eq}/p_{ref} can be estimated as a function of a new factor F_{eq}, using the following linear relationship:

$$\frac{p_{eq}}{p_{ref}} = 0.095 \cdot F_{eq} + 0.075 \qquad (3)$$

where

$$F_{eq} = \left(\frac{H}{D} \right)^{1.05} \cdot (\tan\phi)^{-0.75} \cdot \left(\frac{E_{nails}}{1000 \cdot E_{soil}} \right)^{0.32} \qquad (4)$$

The detailed methodology is proposed both in comparison with an available analytical methodology of estimation of the required face pressure for a predefined factor of safety, in order to rationally design the FG nails' pattern, as well as for the execution of 3D numerical analyses, using an equivalent pressure instead of modeling each nail separately.
Based on the proposed simplified methodology and a widely used method for the estimation of the required retaining pressure σ_T on the tunnel face in order to achieve a certain value of the safety factor, a design example and an indicative design chart are given that can be used for a rational design of tunnel face reinforcement.
Summarizing, the effect of face reinforcement via FG nails can be well approximated by an equivalent retaining pressure. The use of the proposed methodologies can offer a rational design concept for the most commonly used method for the enhancement of face stability during conventional tunnelling.

O41

Numerical modelling of an underground low and medium level radioactive waste repository in fractured rock mass

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Keywords:Radioactive waste repository, numerical modelling, distinct element modelling, long term rock mass behaviour

The first underground radioactive waste repository in Hungary is being built in the village of Bátaapáti. The tunnels were driven in fractured granitic rocks. Based on the discontinuities the host rock of the repository can be considered as an assembly of blocks, therefore the discontinuum modelling approach can be used to provide representative results of its behaviour. This paper focuses on the prediction capability of the discontinuum modelling code 3DEC, and the long term behaviour of the rock mass. Convergence monitoring was carried out in the modelled section that offers the ability to check the validity of analysis results. Furthermore back analysis was carried out to improve the prediction capability of the model. A hybrid continuum-discrete model is presented, where the near-field is modelled as a blocky rock mass, and the far-field is modelled as a continuum using the built in deformable blocks in 3DEC. The run time of the model was significantly reduced, to facilitate the time consuming back analysis procedure, requires multiple runs. The long term (thousands of years) behaviour of the rock mass was examined using 2D finite element models made by Phase2. The short term (tens of years) was modelled both 3DEC and Phase2, and the results was compared.

O42

Investigation of Tunnel Face Stability and Deformation using Critical State Plasticity

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Keywords: Tunnel Face Stability, Face extrusion, Modified Cam – Clay

This paper investigates the deformational behavior and stability conditions of an unsupported tunnel face. In doing so, three-dimensional numerical analyses were conducted, using the ABAQUS finite element code. The analyses simulate the excavation of a circular tunnel using the Modified Cam-Clay (for the stress–strain relationship of the surrounding geomaterial) to examine the effect of ground strength and deformability as well as the effect of tunnel overburden in the developed extrusion (horizontal deformation) of the excavation face. The outcome of the analyses was used in quantifying the stability of the tunnel face in terms of face extrusion, in a similar fashion to the proposal by Prountzopoulos (2012). In that respect, the average normalized extrusion $\Omega_{f,Area}$ was related to a modified unsupported tunnel face stability factor Λ_F^{MCC} (see fig.1a). Finally, a methodology of assessing the factor of safety FS of an unsupported tunnel face is proposed.

The obtained results indicate that the final extrusion depends mainly on the value of parameter κ, the slope of the swelling curve in the v-lnp' plane. Additionally, it was observed that in normally or even lightly overconsolidated soils (OCR<2), excessive plastic deformation accumulate in the face core, with face support pressure reduction, and thus face extrusion depends mainly on the slope of the critical state line M. As expected, in better geotechnical conditions face extrusion is smaller, while the calculated extrusion increases with decreasing tunnel depth assuming the same ground shear strength conditions.

On the other hand, for heavily over-consolidated soils (OCR>2), the face area remains mainly within the elastic region, and thus its extrusion is primarily affected by the compressibility parameters, while at the same time it increases with increasing tunnel depth. Finally, regarding the stability of the excavation face, it was observed that in normally or slightly over-consolidated soils (OCR<2) the calculated factor of safety is in most of the cases below unity, corresponding to an unstable tunnel face (see fig.1b).

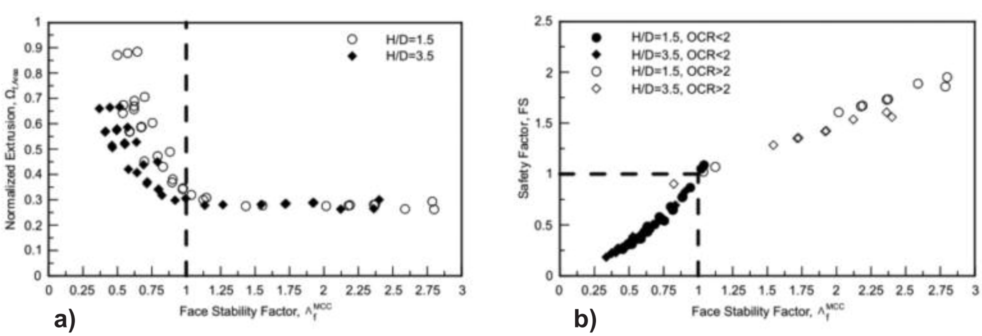

Figure 1. a) The normalized face extrusion ploted versus the Face Stability Parameter Λ_F^{MCC}, and b) the estimated Safety Factor versus the modified Face Stability Parameter Λ_F^{MCC}.

O43

SFRC for cast-in-place (CIP) Permanent Linings: Thames Tideway Lee Tunnel Project in East London, UK

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Keywords: Steel Fibre Reinforced Concrete, Shaft, slipform, tunnel lining, value engineering

The Lee Tunnel project comprises an important aspect of the Thames Tideway improvements, which aims to improve the quality of water of the River Thames and ensures the enhancement of the sewage system of London for following generations. This is a £635M Thames Water (Design & Build) scheme that will store and transfer storm sewage by gravity flow through a 7.2m ID, 7km long tunnel to a pumping station shaft for delivery to the surface for treatment with. The Lee Tunnel underground works were predominately constructed in Chalk and Thanet Sand formations, under water pressure reaching up to 8 bar. The successful Partnership between Client's Consultants, the Contractor and the Contractor's Designer enabled Value Engineering, which in turn ensured significant optimisation in construction.

This Paper focuses on the innovative design and construction method of the inner shaft lining of the largest shaft of the scheme and on the Inner (secondary) Main Tunnel Lining. Both have been designed as Steel Fibre Reinforced Concrete (SFRC) Structures. The Pumping Station Shaft, which enables the pumping of extracted effluent, is the largest shaft on the project, with an internal diameter of 38m, and 84m deep (the diaphragm walls 98m deep) and with an inner SFRC lining 1000mm thick. The Secondary Tunnel Lining is a 7.2m ID 300mm thick, SFRC lining, cast in place inside a precast segmental SFRC 7.8m ID Primary Lining.

In the case of the Pumping station shaft the Design Team successfully pioneered a new method in the UK of internally lining the deep shafts using a SFRC slipformed chimney, isolated from the base and with a confining concrete grout annulus taking into consideration pressurised annular grouted fill and subsequent composite action. The design verification of the Limit states of SFRC was carried out from first principles deducing a stress block that can be adjusted for different strains. A non-linear FE analysis was performed to assess the robustness and the degree of damage to the SFRC lining of Emergency Event. Significant amount of testing was carried out to validate the performance of SFRC and its suitability for slipform construction.

In the case of the Secondary Tunnel Lining the design has been carried out according to EN 1990 principle, 'design-assisted by testing. Watertightness requirements necessitate the assessment of crack widths. Large scale (full depth) wide-beam bending tests enabled the determination of the tensile strain capacity, crack development and ductility of SFRC. Post-processing of the strain development enabled the deduction of crack widths at the

working tensile strains. This performance-based design approach was justified by the fact that the verification of the governing Limit State required that the SFRC exhibited deflection hardening characteristics in order to satisfy strain compatibility and crack control.

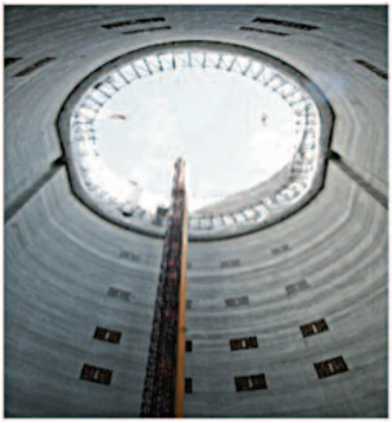

Figure 1. Internal view of pump shaft slipformed SFRC lining wall

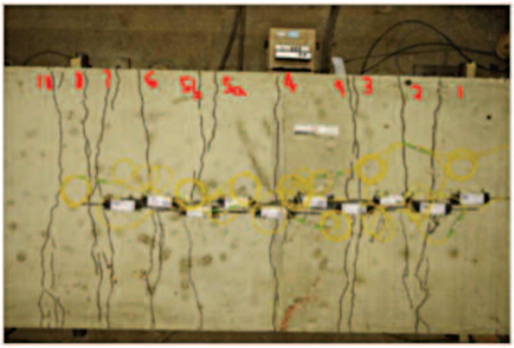

Figure 2. Wide beam testing exhibiting multi cracking for the SFRC tunnel lining

For the Pumping station Shaft the Value Engineering led to the development of an innovative construction methodology that resulted in substantial savings in cost, programme, and risk. For the Main Tunnel Lining the innovative design enabled savings of hundreds of tonnes of reinforcing steel and accelerated the construction element of this part of the works thus reducing cost and the associated materials' CO_2 embedment, reducing waste and enhancing durability to achieve a service life of 120 years.

O44

Time-dependency issues associated with rock tunnelling

C. Paraskevopoulou, M. Diederichs

O45

Stresses and Deformations around Tunnels of different Shapes due to Incident SV-Waves

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Keywords: Seismic waves, Ovaling, Racking, soil structure interaction

The increased construction and use of underground facilities requires, in the case of countries with seismic zones, safety provisions against motions caused by earthquakes. Generally, underground structures are less vulnerable in comparison than surface structures in case of an earthquake. Nevertheless, due to their importance, even slight damages can harm, e.g. leakage of hazardous materials incurring environmental disasters. Serious damage to transportation networks endanger human life and hinder transport.
The purpose of this work is the calculation of the stress field as well as the deformations occurring around Underground Tunnels with various shapes, unlined and lined, situated in a linear elastic ground, due to seismic excitation and the comparison with results occurred by Analytical Method. The theoretical model concerning the calculation of the stress field and the deformations in the sections of underground structures subjected to seismic excitation of shear wave SV type, is achieved through the method of infinite series expansion of Bessel & Hankel type for the estimation of the incident and scattered waves, in combination with the Muskelishvili method of complex functions.

The numerical solution is achieved by the implementation of the finite difference code Flac 3D, in order to perform a series of dynamic parametric analyses such us: the frequency of the input wave, the thickness of the soil layer above the structure (full & half space), the shape of the cavity, damping and the flexibility ratio. This finite-differences code is applied in Geotechnical Engineering for the exact numerical solution of the differential equation of motion. The model is subjected to seismic excitation, simulated by an harmonic vertically propagating shear wave, of SV type. SV waves cause ova ling or racking motion of the cross section of the Tunnel. The results of the analyses showed that the sectional stresses and deformations depend on the different shapes of the sections, the structure depth, the flexibility ratio and the existence of the liner.
A comparison between the analytical and the numerical method in the elasticity range entailed to satisfactory results. Due to the fact that the analytical solution doesn't take into account the soil-structure interaction results are more accurate when the soil and structure stiffness are similar.

f=4.6(rigid), lining thickness 0.20m

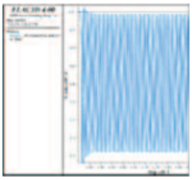

Fig.1. Displacement u_x, full space, circular tunnel of 1m radius, at the crown of the cavity

O46

Seismic Behavior of Shallow Tunnels Accounting for the Surface Structures Interaction Effects

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Keywords: Seismic behavior, Structure-Soil-Tunnel interaction, Dynamic analysis

Tunnels are commonly designed under seismic loading assuming "free field conditions". However, in urban areas these structures pass beneath buildings, often high-rise ones, or are located close to them. During seismic excitation, above ground structures may cause complex interaction effects with the tunnel, altering its seismic response compared to the "free field conditions" case. The paper summarizes an attempt to identify and understand these interaction effects, focusing on the tunnel response. The problem is investigated in the transversal direction, by means of full dynamic time history analyses that are performed on representative tunnel-soil-above ground structures systems (Fig. 1). Both circular and rectangular tunnels are investigated, while above ground structures are modelled in a simplified way as equivalent single-degree of freedom oscillators with proper mechanical properties. Crucial parameters, controlling the response, are accounted for in this parametric study, namely: the soil to tunnel relative flexibility, the tunnel dimensions, the tunnel burial depth and the soil properties and nonlinearities during shaking. Tunnels response characteristics are discussed, in terms of tunnel deformations, dynamic earth pressures and lining dynamic internal forces. Results indicate that the presence of the above ground structures may have a significant effect on the seismic response of the tunnel, especially when the latter is stiff and located in shallow depths.

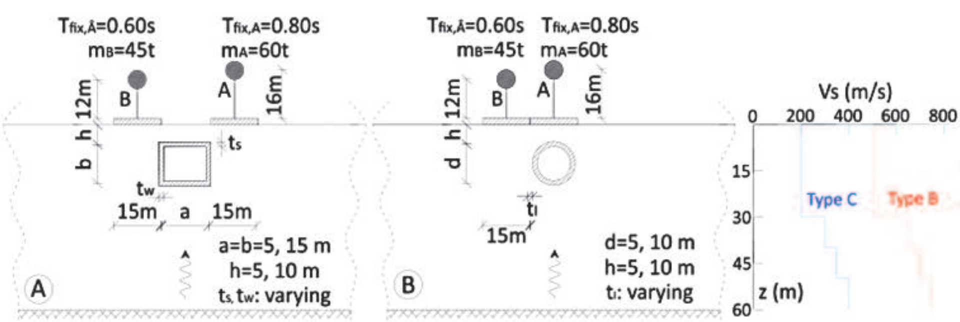

Figure 1. Test cases and parameters for analyses, (a) rectangular tunnels, (b) circular tunnels

O47

Seismic response of deep tunnels: comparison of different existing methods

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Keywords: pseudo-static, time-history, seismic design

The task at the present study was the verification of the current methods used in a conventional manner so as to estimate the behaviour of a tunnel against ground motion but also the investigation and suggestion of additional methods. To accomplish this objective, the study analyzes a real project that had been designed by the engineering team of Geodata. Moreover there is a review of what has already been applied to the case (pseudo-static methods) and in parallel there is a consideration of various other existent procedures: analytical, dynamic time-history and a different numerical model again in pseudo-static condition. The time-history method is highlighted in particular as it is a rigorous scheme that needs prudent consideration. In the end, the comparison brought out both advantages and drawbacks but as well as the contrasts of the distinct proceedings and made the associated proposal for future performance issues.

Creating a model for a pseudo-static approach has a simplicity that makes it advisable as the primary way to characterize the situation. On the other hand it is the only way among all those that were described at the study and can exist on its own. The model itself is capable of enclosing sufficient results provided that the configuration guarantees a reliable representation of the surrounding mass conditions (in the present case, the project adopted pure material homogeneity and a detailed grid around the tunnel). Shear deformation is the dominant value that plays the role to define the level of the response and therefore the dynamic analysis was also a tool to detect the relative strain levels. Even so, a thorough search among past ground motion scenarios brings the suitable records (the key parameter here is the PGA of the region) that can more or less set the stress-strain framework to strengthen the reliability of the numerical model.

The use of time-history (dynamic) analysis requires a suitable record selection (three or more) and a number of accompanying checks. The record time-histories must be compatible to the site response spectrum and were scaled to the relevant PGA. Further checks have to do with the frequency propagation ability offered by the model but also with the energy content of the input. Even the damping issue is considered in more than one ways. Consequently, this method turns out to be a useful, representative and exceptional tool as it is the only one that inserts dynamic loading. The basic topic is the interaction and the coexistence of the dynamic analysis with any simplified numerical approach. Such a combination is to be further examined at a large group of deep elements. This study demonstrates that, the two methods, if put together, can set the analyses to the same strain levels and consequently the correlation between them will be considered much more valid so as to evaluate the seismic response of the structure.

O48

Influence of the change of cross section in the seismic design of "Qaf Murrizi" tunnel

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Keywords: Tunnel, Seismic design, Cross section

The tunnel cross section change will bring changes to internal forces in the tunnel lining. The size of these forces is limited by soil-structure interaction effects. If the seismic design of the tunnel will be done as in free-field approach and the coefficient of flexibility for both sections would be more then 20, the section change would not have any effect since the deformation of the tunnel will be as in the surrounding ground. In other cases the cross section change will have concentration of the stresses and increasing internal forces.
The article analyse the modelling of the section change in homogeneous and heterogeneous environment, gives the design principles, design methodology and practical methods for structural detail construction.
From the longitudinal model we can estimate the deformation and curvature based on which we can judge for applying plastic hinges or seismic joints. In our application, from the longitudinal model we have also concluded that using an estimated scale factor that can scale the internal forces or time history of acceleration gives unrealistic results. We have also generated in longitudinal model a time history at the level of transversal model which serves as input for the transversal models. Different continued sections which pass through heterogeneous geological formations bring large additional forces near the plan of changing sections connection. Using a plastic hinge at the lining connection zone is a very efficient way but not sufficiently studied. A simple way to solve the problem is to do seismic joints in order that the sections work separately.
This solution is more problematic because of the possibility of permanent deformations at connection zone but also is a very practical solution for the problem.
After analyzing the deformation shape and internal forces from the results of longitudinal model, at the tectonic zone, we make 2 seismic joints which divide the tunnel on three segments that behaves like separate parts during the earthquake. With this new configuration we recalculate the longitudinal model and take strains, deformations and forces in the lining in the axial direction.
We have also recalculated transversal models with seismic input that we have generated from modified longitudinal model. Transversal models calculated separately for each segment now depends only on the modification of the time histories of seismic action due to heterogeneous geological configuration and ground-structure interactions for each segment separately. In the tunnel lining did not appear inertial forces due to the change of section and influence of sections on each other.
The influence of heterogeneous geological formations especially the contact zone plan can be taken into account by generated time histories of acceleration in the longitudinal model and not by applying a scale factor to time history of acceleration or internal forces in the linnings
Based on the results obtained by seismic numerical calculation of the Qaf Murrizi tunnel are given the recommendations for effective methods of design of the section change and the environment treatment to overpass this difficulties.
The study of the use of plastic hinges at connection zone will be one of our objectives in the future.

O49

Dynamic Response of Square Tunnels: Centrifuge Testing and Validation of Existing Design Methodologies

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Keywords: Rectangular tunnels, Dynamic centrifuge testing, Dynamic analysis, Simplified analysis methods

A series of dynamic centrifuge tests performed on rectangular tunnel models embedded in dry sand is presented. The tests were carried out at the geotechnical centrifuge facility of IFSTTAR in Nantes, within the DRESBUS II TA action that was offered by the SERIES research project (http://www.series.upatras.gr/DRESBUS_II). Among the innovative features of the experimental campaign is the implementation of a real earthquake recording as the base motion. The effect of salient model parameters, such as soil-to-tunnel relative flexibility, soil-structure interface properties and characteristics of the input motion is explored. Representative test cases are numerically modelled by means of rigorous finite-element configurations of the coupled soil-tunnel system. Numerical results are validated with experimental data and compared with simplified design methods in terms of soil and tunnel acceleration and tunnel deformations.

Generally, numerical models reproduce reasonably well the recorded response. Horizontal acceleration amplification is slightly affected by the tunnel presence, while experimental and numerical results confirm the theoretical expected racking distortion of the tunnels. Side-walls deformations are amplified from invert to roof slab, being increased in case of flexible tunnels compared to the rigid ones. Increase of the input motion amplitude result in an increase of the side-walls deformations. In addition to the racking deformation of the tunnel, a rocking mode of vibration is also observed.

Comparisons between the experimental data and simplified analysis results indicate that with properly selected parameters and modelling hypothesis, numerical and analytical models can reproduce the seismic racking distortions of a shallow rectangular tunnel within the engineering acceptable margin.

O50

The performance of motorways' concession contracts under construction in Greece

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The Greek State's original design of Concessions Contracts has proven as very optimistic and failed to recognize and manage important risks and issues involved into contract implementation. This design had closed eyes to important factors that could affect the overall performance of the contracts. Many of these factors had already been activated before the onset of the economic crisis, which undoubtedly was the most aggravating factor in the destabilization of the evolution of contracts. The economic crisis and resultant decrease of traffic volume and toll revenues bring up for discussion the long term viability of the projects. The problems which have suffered the concession contracts are summarized in the following:

- The size and distribution of concession projects throughout the Infrastructure Construction Sector - Establishment of the mechanism of Concessions as the dominant system for the national construction program.
- The design, project feasibility, the hierarchy construction program did not arise as an integrated programming approach to the rational basis of the public interest, but rather as a means of maximizing the economic and political benefits
- The non-involvement of local communities in project design
- Improper distribution of the scope and the inefficient structure of some projects
- The size of the projects and the choice for such projects of very large budgets did not weigh the relevant requirements and side effects
- The Toll Policy minelaying social acceptance of projects and created major problems
- Unrealistic provisions of State contractual obligations
- The project design did not meet the requirements of projects of this magnitude
- The Allocation of Risk: On certain issues the basic rules "for the parties of contract with similar risk aversion perception, the risk should be allocated to the party that is responsible (and can manage better) or has more control to the risk factor" and "for the parties of contract with similar responsibility or control, the risk should be allocated to the party that has the lesser risk aversion approach" and their combination have been ignored.
- The financial models and funding.

Regarding the tunnels have proved less affected by these inherent problems of the contracts, mainly because land requirements for the construction activities are limited.
In the course of some tunnel final lining design the disputes arisen from the Greek State have been resolved by the Dispute Resolution Panel. All findings from Dispute Resolution Procedure and relevant documentation represent valuable sources and concern issues important for tunnelling in Greece. The most significant discussed issues related to the:

- Design values for hydrostatic pressure of drained tunnels
- Computational proof of non-implementation of a chain collapse of the tunnel final lining in case of fire
- The influence of differing thicknesses of the unreinforced tunnel lining (due to overecavations or in forepolling umbrellas areas) in stress regime and bearing capacity of the lining
- The calculation of thermal-hygrometric effects for the load case Removal of Sliding Formwork.
- The loading case due of potential rock wedges
- The earthquake resistance of tunnel unreinforced lining.
- The allowable thickness of the compressive zone of the unreinforced tunnel final lining.

O51

Strategic design considerations for long transportation tunnels. The case of the Trikokkia Railway Tunnel (Greece)

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Keywords: Tunnel Design, Value analysis, Performance evaluation, Balanced scorecard

The conceptual and preliminary design of long transportation tunnels is a critical stage for the accomplishment of a successful and economical tunnelling project. All the strategic decisions related to the engineering, operational and financial aspects are settled during the first design stages, with limited allowance for later modifications. It is also widely recognised that the most significant opportunities for project value improvement are at those early design stages and decline rapidly with project advancement. This paper outlines the analysis methodology and decision making procedure applied during the outline design of the Trikokkia long railway tunnel.

The first step of the preliminary design was to define the project's objectives and identify all constrains and risks. The most critical issues for the particular tunnel proved to be: a) the definition of the optimal tunnel's routing with respect to the ground relief and geotechnical conditions, b) the selection of the most efficient construction method and c) the planning of an effective emergency evacuation system.

Multiple alternative design options were designed, evaluated using balanced scorecards and optimised, examining each one of the above issues. The performance of all the alternative designs was verified and evaluated on the basis of a series of quantitative and qualitative criteria set by the designer and the investor, reflecting all project perceived objectives. The performance criteria regarded a wide spectrum of variables from basic construction cost/time and related risks, up to environmental impact, both during construction and operation, impact on local societies as well as operational service level, safety and respective residual risks.

The procedure contributed considerably to the value improvement of the project. Starting with a 8.3 km long running tunnel, with a 8.3 parallel escape gallery, interconnected every 1000 m, we ended up with a section of bored tunnel 4.0 km long, a section of cut and cover tunnel 1.2 km long and 1.6 km of escape galleries, providing access to the safe every 500 m in the middle section of the running tunnel and every 1000 m at the remaining sections.

The analysis methodology presented herewith proved to be an efficient tool to guide the design effort and provided a sound basis for proper decision making. The procedure does not require more data than those usually available at the early design stages, it is simple and traceable and most importantly it can be easily modified to focus on the most critical design issues. It can be implemented on other tunnelling projects although the establishment of a standardized tunnel planning methodology, seams not to be an easy task due to the significant diversity of geotechnical, structural as well as economical and social conditions forming the framework within which each project is to be planned, designed and constructed.

O52

Can be a contract type crucially best or worst?
(One "Turnkey Contract" is much favorable than the fragmented into several parts and separate contracts, - isn't it?)

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FTBM Pty. (Ltd.) Design Consulting and Engineering Co, 2049 Diósd, Hungary

Key words: Contract, risk sharing, finance

The contractual system fundamentally determines the relationship of the Parties and the process of implementation. Each of the subsurface projects usually unique, different from previous samples and beside of the contract typically includes a vast contractual documentation. What are the necessary components of a good contract document? What are the main issues for the sake of the successful project completion? Typical characteristic of the underground projects the geotechnical environment and it has decisive importance the quality of the Geotechnical Baseline Report. The underground projects (especially the tunnels) require special equipment, special organized human resources (experienced specialist teams), unique technologies and methods as well as large amount of capital. The contract has to supply the appropriate answers for this challenge specifying the terms and conditions. The professionally prepared contract documents are the fundamental basis of a successful project. But is it enough to compose all these factors into a subsurface project's contract, will it be automatically successful and efficient? No! The real partnership in good faith between the contractual Parties is more important same as their committed and honest cooperation. It doesn't mean that they can't have different interests but need to respect the other party's aims. Trying to save money on the time-consuming, very accurate and detailed preparatory works is an own goal. Most of the dispute issues in the construction phase of projects are based on the mistakes or the lack of good preparatory works. One of the well recoverable investment is to choose the best (and often not the cheapest) professional Consultant for the position of the Employer Representative. Any type of contract can be successful or failed. The type of the contract has to be fit to the characteristics of the project but not the type of the contract is the determinant. Only the fair and well balanced contract can be efficient and successful.

O53

Stochastic Cost Estimation of Road Tunnels

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Keywords: Cost estimation, Monte Carlo Simulation, Stochastic estimation

The accurate estimation of a road tunnel's construction cost is considered to be of major importance for the total construction cost of a road development project. This is even more important when financial resources available for development and construction are scarce. This paper suggests a suitable approach through which awarding authorities (such us owner or funder of the project) will be able to estimate the variation of the construction cost as early as in the design phase. By doing so, a probable upper limit of a road tunnel construction cost can also be calculated. Therefore "unpleasant surprises" during the construction phase are avoided, as potential excessive increase of the final as-completed cost is spotted and treated in the design phase.

The study provides an approach for the stochastic estimation of the construction cost of a road tunnel by determining parameters which contribute to it and are subject to variation due to the nature of the construction process. The proposed approach is illustrated through an indicative case focusing on civil works and specifically the geotechnical and structural works. It is important to be mentioned that civil works occupy approximately the 80% of a tunnel's total construction cost. The case study consists part of a real case of a Greek twin tube road tunnel. In total 89 cost variables have been taken into account.

All chosen parameters and data, regarding tunnel design were analysed on the basis of the Work Breakdown Structure (WBS), focusing mainly on stability and structural works. Based on the WBS, a detailed model for the calculation of all individual cost parameters was established and hence the deterministic cost of geotechnical and structural work was calculated, using the bottom up approach. Unit prices for each cost parameter were based on existing work tariffs as defined by the Greek Ministry of Public Works (YP.Y.ME.DI.) and published in the Government Gazette.

Following, a quantitative analysis of stochastic cost estimation was performed. In the analysis, cost parameters prone to uncertainty were determined and transformed to cost variables. The cost uncertainty in each one of these variables was quantified through a triangular distribution defined by the minimum, maximum and most probable values. The cost variables that were stochastically analysed range from application rates of typical cross sections of tunnel excavation, temporary support and final lining to main unit prices of work tariffs for earthworks, concrete and steel.

The values used for the triangular distribution were based on the experience in tunnels under similar geological conditions and on a reasonable consideration of unit price changes due to inflation and current financial state of the country. The analysis was performed by using Monte Carlo Simulation by applying 10.000 iterations. From this analysis, a cost distribution was determined, where the stochastically estimated cost with a 5% overrun probability was found to be increased by 3,25%, compared to the initial deterministically estimated cost. Based on the results of the simulation, the deterministically estimated cost corresponds to a 94% overrun probability. This final outcome indicates the importance of the proposed approach and the benefit that can be realised of its use by the awarding authorities. The proposed approach can also be useful if seen from the contractor's perspective as well, especially at the stage of tendering.

O54

An insider's approach to concurrent tunnel engineering with inadequate data and strict construction schedule

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Keywords: Fast Track Process, Design Management, Strict Time-Schedule, Geotechnical Risk

The current financial status of large construction projects internationally, often calls for fast track tunnel engineering procedures, with concurrent execution of design and construction within a very strict and demanding environment, both in terms of time schedule and client requirements, and in lack of any previous studies and adequate geotechnical investigation data. Finding the way to success in such tunnelling projects offers a great challenge to both the designer and the contractor. Tunnel design management problems, such as those concerning the geotechnical uncertainty and risks, the need for rapid and unconventional decision making, the interaction with other design disciplines and the execution of final designs within very short time periods with very limited or no available information from previous studies, as well as complex contractual and liability issues, are only some of the subjects that will arise in the frame of such demanding tunnelling projects. The interactive relationship between the designer and the contractor, the constant and dynamic presence of the designer on site, the immediate feedback from the construction site and the effective evaluation of relevant information, as well as the growing experience and added value from mistakes and setbacks in previous concurrent engineering tunnelling projects, are some of the keys to successful and beneficial completion for all the involved parties.
The present paper addresses the above mentioned tunnel design and construction model, emphasizing on and analyzing the crucial features that the designer must dispose in order to actively support such projects with a leading role, giving relevant examples from a hydraulic tunnel project in Albania, designed during construction with a demanding fast track procedure.
The water transfer tunnel of Rrapun 3 & 4 Hydro-electric projects in the area of Librazhd in Albania, is a 2400m long hydraulic tunnel, with an excavation diameter of ~5.5m, through molassic formations in the vicinity of a major thrust zone of an ophiolithic complex mass on them. The nature of the project, as well as the Client (Orthodox Autocephalous Church of Albania), created a context of limited budget and need for rapid construction, in order to profit from the project's operation as soon as possible. Therefore, the commencement of tunnel construction was of major importance and in fact from multiple excavation faces (construction of an access tunnel), in order to speed the excavation process. In addition, (a) the absence of previous (e.g. preliminary) designs or any relevant geotechnical data and (b) the serious difficulties and restrictions related to the execution of exploratory boreholes, due to the unfavourable area morphology and the timely process of licensing for the creation of access roads from the local forest service, called for important and immediate design decisions with limited of even no geotechnical data and thus with increased geotechnical risk.
Issues that were major for the specific Fast Track construction process, but would not suggest important factors during a conventional Design – Bid – Build project, had to be

taken into account and influence basic design aspects. Such issues were the availability of mechanical equipment on site (determination of the tunnel's geometry and dimensions not only based on hydraulic criteria), the duration and cost of procurement of materials from the local market of Albania or from Greece (cost and timely availability of materials were important aspects of the design), the period of tunnel construction in relation to the water levels in the adjacent Rrapuni river and the necessary protection against flooding of the construction site (determination of entrance and exit portal levels and of construction site's access roads geometry). The design of the portal cuts of the main and the access tunnel was performed based on a careful geological mapping and the experience of the designer from tunnelling in similar formations in Albania and Greece. The construction was executed based on detailed drawings issued before the compilation of any design report. The observational method and the fine-tuning during construction, with the constant and effective presence of the designer on site, guaranteed the beginning of the underground construction with only minor problems. The limited geotechnical data acquired from 2 executed boreholes, as well as the information from the excavation of the access tunnel were rapidly evaluated, in order to produce construction drawings for the underground tunnel stretch that included specific geometrical configurations, such as the cavern on the junction of the access tunnel to the main tunnel and the required widened sections and perpendicular galleries for the crossing of vehicles and the temporary deposition and managing of the excavated materials. The management of the balance between the considerable geotechnical risk and the limited budget of the project (need for rationally conservative design approach), necessitated the constant and true cooperation of the designer and the contractor, under common understanding of both the design and construction risks by both parties. The tunnel excavation was completed within 7 months in July 2014 without significant problems.

P1

Application of the Spatial Rock Mass Behaviour into 2DFEM Model

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Keywords: Numerical modelling, FEM, Tunnels, NATM

The construction of a tunnel is clearly a three-dimensional mechanical problem. Practical engineers instead of modelling the whole process in 3D tend to analyze typical cross sections in a 2D environment under the plane strain conditions. In the case of 3D numerical model the effect of 3D stress redistribution must be simulated. The convergence confinement method is widely spread for such simulation using a 2D approach. This approach can take into account a ground displacement occurring prior to tunnel excavation, a time delay in the lining installation behind the excavation face and the material change of the support (e.g. sprayed concrete) according to the construction period. This method models the development of deformations in a given cross-section by reducing the pressure using parameter *b* in the calculation steps (this method is also called *b*-method). In the first step the initial state is modelled so the internal pressure p_0 in the openings is equal to the external earth pressure. The next step simulates the state before lining construction (spatial effect such as longitudinal vault) the internal pressure is reduced with parameter *b*which can range between 0 and 1. The value 0 is equal to the external earth pressure and *b* 1 corresponds to full excavation (no internal pressure). The parameter *b* has a great influence to the internal forces, lining deformations and surface settlement. The value of parameter *b*cannot be impartially defined and rely on empirical relations or engineer's estimate. From the practical point of view the use of convergence confinement method requires convergence data for the parameter *b* calibration. In the initial design, it is therefore possible to exploit convergence data known for other underground structures constructed in a similar geology.

To examine the behaviour of the parameter *b* influence a parametric analysis of the Tomický railway tunnel and road tunnel Brusnice was performed. Excavation of the tunnels according to the principles of the NATM was modelled using the GEO FEM software. In the paper the results of the analysis are described: the influence of the parameter *b* on the internal forces in the primary lining, the stress in the rock mass and the subsidence. For the Tomický railway tunnel the biggest influence was on the internal forces in the primary lining. In the case of Brusnice tunnel a verification of calculated displacements of the overburden above excavation supported by primary lining was made utilising the results of geotechnical monitoring. The difference in the subsidence was small – in the matching points 5% at the most.

P2

Preliminary analysis of tunnel face stability for risk or back analysis

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Keywords: Face stability, limit equilibrium analysis, silo theory.

This article develops a fast judging mean of tunnel face stability in naturally complex cases. The result is a «safety factor» allowing design of the stabilizing pressure or back analysis of the site observation. In urban tunneling projects, this tool can be used in particular along the line as a mean of assessing the likelihood of occurrence of the instability of the face or of the excavation repercussion on the environment. The developed method is a limit equilibrium analysis in continuous medium consisting of the stability assessment of a tetrahedral shape volume ahead of the face. Besides its own weight G and the resisting forces along the lateral faces τ, the volume is subjected to a vertical load P_1, a pressure flow F_0 and a counter confining pressure P_0 if the latter two are present. This «dihedral» is then approximated by the quarter of ellipsoid in which it is included.

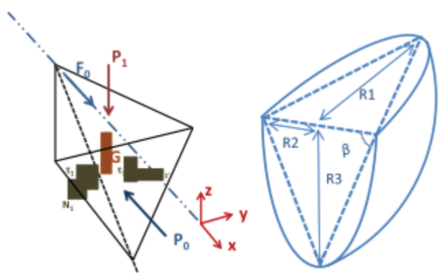

Figure 1. Forces acting on the dihedral and ellipsoidal approximation

The method is innovative in the failure mechanism considered ahead the face and in the calculation of the overload: according to the ground conditions, different types of loads, consistent with the observations made on site or models, are determined according to the « silo theory ». In the presence of water, undrained and drained conditions, under and above the water level are differentiated. Stratigraphy may also be taken into account with, for each layer, different load geometry and different hydraulic conditions.

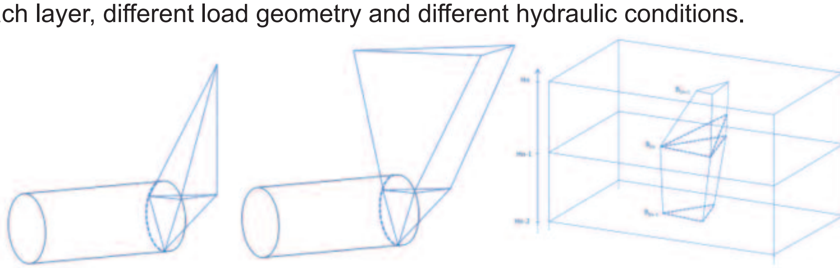

Figure 2. Overload for a cohesive-frictional soil, for a purely cohesive soil and for a layerd soil

P3

The Albanian Motorway – Rreshen Kalimash Section Thirra Tunnel

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Keywords: tunnel, field measurements, laboratory testing

The **Albania–Kosovo Highway** is a four-lane highway being constructed since 2007 by the American-Turkish consortium Bechtel-ENKA between **Albania** and **Kosovo**. The highway starts at **Thumanë**, Albania and ends at **Gjergjica**, Kosovo. Once the Kosovo part of the project is completed, the motorway will link the **Adriatic Sea** ports of **Durrës** and **Shëngjin** in Albania with the **Pan-European corridor X** in Serbia via **Pristina**.
Dubbed the "patriotic highway," the project links Albanians in **Kosovo** and **Albania**, helping to boost cultural and economic ties. It includes a six kilometer tunnel in Albania, making travel and trade easier for the hundreds of thousands of people vacationing in Albania during summer holidays and for business.
The highway passes through a 5.5 km-long double-bore tunnel. Construction works on the tunnel began in May 2007 and were completed with one tunnel tube inaugurated in June 2009. The south-bound tunnel was completed in July 2010. All four faces of the two tubes of the tunnel have been worked on simultaneously. Rrëshen - Kalimash segment's third section of road between **Thirrë** and **Kolshi**. Laying road on Mt. Runes proved to be a challenge for the engineers.
In this paper we are going to describe all the insitu measurements and laboratory test that were performed during the tunnel construction.

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