The 3rd Training course
TUNNELLING IN URBAN AREA
Prague, 4-5th May 2007

Conventional Tunnelling – General

TRAINING MATERIAL PREPARED BY

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Conventional Tunneling - General
Principles of Conventional Tunnelling

- View the ground as a load-bearing element of support.
- The ground reactions is measured, stability confirmed by monitoring.
- Requirement for rapid rigid support or slim deformable support is identified.
- Contract to allow most economical type of support installation.
- Conventional tunnelling based on rock classification system (stand-up time).
- Rock class agreed between Contractor and Engineer at the excavation face.
Conventional Station Design

- Specific advantages of Conventional Mining for Station Design near sensitive and valuable Historical Structures
- Mined Method allows limitation of number of stress shifts, as every stress shift reduces natural bearing capacity of ground.
- Investigation of Design Alternatives leads to decision for Station Configuration.
Mined Station Advantages

- Virtually unlimited space in the configuration of the underground station.
- Chances to minimize settlements and deformation of surrounding ground.
- Technology to monitor and to limit deformations within calculated prediction.
Tunnels / Stations

Evolution of Design 1974 - 1995

1974 - 1976 Subway Bochum, Germany
1975 - 1977 Subway Nuremberg, Germany
1977 - 1982 Subway Munich, Germany
1981 - 1982 Metro Mexico, Mexico
1991 - 1995 Subway Munich, Germany
1986 - 1991 Station Washington, USA
1992 - 1993 Subway Milano, Italy
1991 - 1992 Metro Los Angeles, USA
1993 - 1995 Subway Paris, France

Conventional Tunnelling - General

1992 - 1995  Metro Washington, USA
1994 - 1995  Metro Lille, France
1998 - 2000  Subway San Juan, Puerto Rico
2000 - 2000  Metro New Delhi, India
2000 - 2001  Sound Transit Seattle, USA
1998 - 2001  Subway Stuttgart, Germany
1999 - 2002  East Side Access New York, USA
1998 - 2004  Metro Budapest, Hungary
1976 Subway Bochum, Germany

Subway Station Berliner Platz
X - section and Construction Stage

Conventional Tunneling - General
1977 Subway Nuremberg, Germany

Subway Station Lorenz Church
X - Section and Final Structure

Conventional Tunneling - General
1982 Subway Munich, Germany

Subway Station Theresienwiese
X - Section and Final Structure

Conventional Tunnelling - General
1991 Station Washington, USA

“Fort Totten Station“ - Completed Structure

Conventional Tunneling - General
1991 Station Washington, USA

Fort Totten Station – X-Section

Conventional Tunneling - General
1992 Metro Los Angeles, USA

Conventional / TBM Interface

Conventional Tunneling - General
2000 Subway San Juan, Puerto Rico

Conventional / TBM Interface

Conventional Tunneling - General
2000 Metro New Delhi, India

Chawri Bazar Station – 3D View

Conventional Tunneling - General
2000 Metro New Delhi, India

Chawri Bazar Station – X - Section

Conventional Tunnelling - General
Pacific Station – 3D View

Conventional Tunnelllling - General
2004 Metro Budapest, Hungary

Fövam Ter Staion 3D - Perspective View

Conventional Tunnellling - General
Gellert Ter Station - Binocular Plan

Conventional Tunnelling - General

2004 Metro Budapest, Hungary
Gellert Ter Station - Binocular Section

Conventional Tunneling - General
2004 Metro Budapest, Hungary

Gellert Ter Station – Binocular Type

Conventional Tunneling - General
Improvement of Design

Design should consider following major aspects

- Excavation Aspects (e.g. Size, Shape, Drifts)
- Symmetrical Structure
- Computation
- Stress/Strain Relations
- Geotechnical Aspects (Presupport, Soil Improvement)
- Groundwater Control
• Design and construction method must satisfy the project conditions defined by geometry and site conditions.

• Construction activity on surface is restricted and minimum impact to the public is expected.

• Multiple Drift Station can be limited to construction shafts to be decked over for minimum traffic
Multiple Drift Stations II

- Shotcrete Lining has to take full loading in construction
- Final Lining is designed to take full loading while shotcrete properties are converted into soil properties
- Lining dimensioning is based on superposition of loads
Subway Vienna Numerical Model

Tunnel Cross-Section of Subway Vienna

Conventional Tunneling - General
Metro Washington - Numerical Model

Conventional Tunneling - General
Metro Washington - Fort Totten Station

Multiple Drift Construction Phases

Conventional Tunnelling - General
Metro Washington - Fort Totten Station

Multiple Drift Construction

Conventional Tunneling - General
2

Metro Budapest - Mined Station Sequence
Metro Budapest - Mined Station Sequence

Conventional Tunneling - General
Mined Station – Cross Section Projection

Conventional Tunneling - General
3 Construction Monitoring

• State of the Art Data Evaluation

• The problems experienced when tunnelling through poor ground are well known all over the world.

• Proper modelling during design, continuous and adequate monitoring of behaviour of ground and support structure forms basis for on site decisions.
Monitoring in Construction

Conventional Tunnelling - General
Laser Beam Deflection Monitoring
Displacement History Plots

Value of Information

- Assuming continuous face advance, displacement rate over time has to decrease.
- Displacement acceleration indicates destabilisation, unless there are ongoing construction activities in the monitored tunnel section (e.g. bench and invert excavation, or shaping activities).
- Stabilisation is reached after bench and invert excavation.
Typical displacement history diagram, showing expected behaviour and indication of destabilisation.
Final displacements extrapolated from few readings, using previous experience and including the actual geological situation.
Deflection curves

Value of Information

- When showing several deflection curves on the same plot, comparison of displacements along tunnel is possible
- Information on the longitudinal extent of tunnel deformation behaviour is provided
- Trends of relative decreasing or increasing ground behaviour can be verified
The extrapolation of deflection curves to the tunnel face and the addition of the resulting difference ("pre-displacements") to the measured values.
Typical plot of deflection curve when excavation approaches a "weak" zone (schematically)
Trend Lines

Value of Information

- Trend lines provide an overview of displacement development along tunnel axis, used for extrapolation beyond face.
- Trend lines used to determine appropriate support type and quantity for comparison of similar deformation behaviour.
- Trend lines with increasing displacement tendency can indicate critical situations and must be analysed.
- Trend line shows settlement behind face.
Trend line of settlement when tunnelling in homogeneous rock mass and when passing a fault zone (schematically)
4

Risk Categories

- Risks to be identified in the Risk Register
- Design and Construction Risks, e.g. inadequate design, unforeseen ground conditions
- Risks are to be prioritized and quantified
Risk Analysis Measures

- RA takes measures to avoid double risk counting
- RA takes account of correlation between risk types
- Quantification of potential cost overruns reflects possibility of increased staff costs
- Correlation between unforseen ground condition cost and risk of contractual claims should be estimated
Risk Management Methodology

Step 1 Establish objectives and risk appetite
Step 2 Risk identification
Step 3 Risk classification
Step 4 Risk allocation
Step 5 Risk assessment, impact & quantification
Step 6 Identification of mitigation procedures
Step 7 Preparation and update of risk register

Conventional Tunneling - General
Allocation of Risk

- Establish objectives and risk appetite
- Risk Identification, Classification and Allocation
- Assessment, Impact and Quantification
- Identify Mitigation Procedures
- Prepare or Update Risk Register
Standard Support

- Standard support measures are to be installed all along the length of the tunnel. Means and methods should be defined and documented.
- It should be demonstrated when and how additional support measures respectively contingency support measures will be installed.
Additional Support

- It has been proposed to cover regular expected ground conditions with standard support measures, not exceeding $1.0 \times d_{\text{crit}}$.

- It $d_{\text{crit}}$ represents a threshold value which is on the very safe side, for the purpose of defining the value requiring additional support measures.
Actual time and location related deformations to different tunnel support measure categories

**Conventional Tunnelling - General**
### Conventional Tunneling - General

#### Decision Matrix

<table>
<thead>
<tr>
<th>CROSS SECTION</th>
<th>SUPPORT TYPE</th>
<th>0.7</th>
<th>0.8</th>
<th>0.9</th>
<th>d&lt;sub&gt;cm&lt;/sub&gt;</th>
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</thead>
<tbody>
<tr>
<td>STANDARD SUPPORT MEASURES</td>
<td>0 ADVANCE LENGTH (AL) 4'</td>
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<td>1 SOIL NAILING 21 (Standard)</td>
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<td>3 DEWATERING / PROBE HOLES: 5 WELL POINTS IN TOP HEADING, VACUUM LANCES IN INVERT</td>
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<tr>
<td>ADDITIONAL SUPPORT MEASURES</td>
<td>0 REDUCED ADVANCE LENGTH (AL) 3'</td>
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<td>1b ADDITIONAL SOIL NAILS: for AL + 30%</td>
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<td>3a LATTICE GIRDER: on 3' spacing, Type PS 95/20/30</td>
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<td>3b SPLINT: Bar size 5, (1.0 sqin)</td>
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<td>4a FACE SEALING: 2&quot; (Total) fibre shotcrete</td>
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<td>4b FACE BOLTING: 9 pcs, fibre glass, L=28', in top heading</td>
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<td>CONTINGENCY SUPPORT MEASURES</td>
<td>0 DIVIDED FACE EXCAVATION</td>
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**NOTES:**
- TUNNEL WALKER HAS AUTHORITY TO ADDITIONAL MEASURES AT ANY TIME AS REQUIRED BY FACE CONDITIONS.
- MEASURES CANNOT BE REDUCED WITHOUT CONSENSUS.
Conventional Tunnelling Conclusions

- Ground is viewed as integrated element of support
- Ground reactions are measured to confirm stability
- Ground should be kept undisturbed
- Type of support to allow most economical design
- Tunnelling on ground behaviour