ITA - AITES WORLD TUNNEL CONGRESS 2007 PRAGUE

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

Conventional Tunnelling – General

TRAINING MATERIAL PREPARED BY

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ASSOCIATION INTERNATIONALE DES TRAVAUX EN SOUTERRAIN
AITES

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INTERNATIONAL TUNNELLING ASSOCIATION

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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

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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 Configration.

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.

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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

Tunnels / Stations

Evolution of Design 1992 - 2006

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

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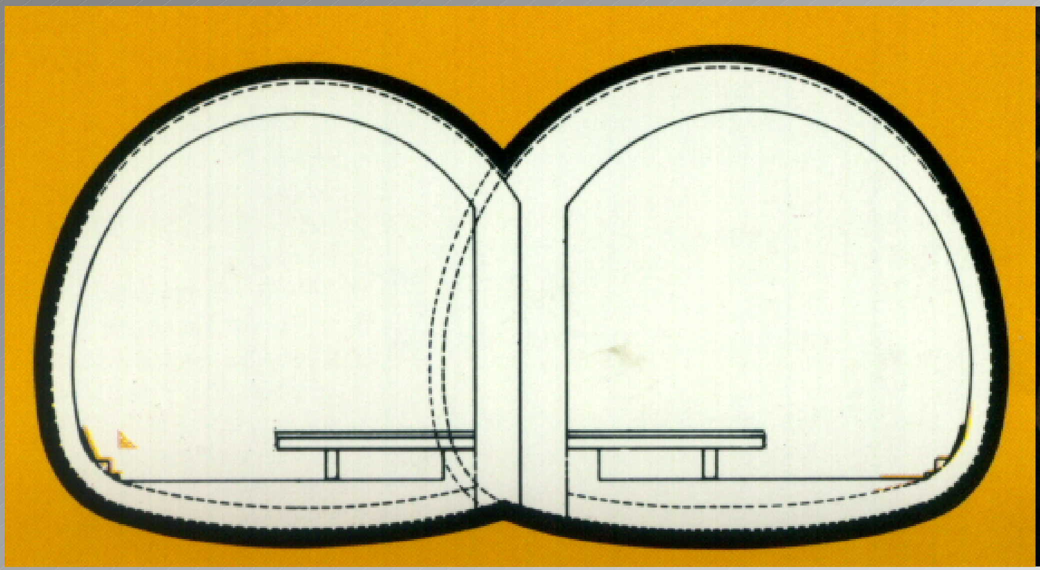
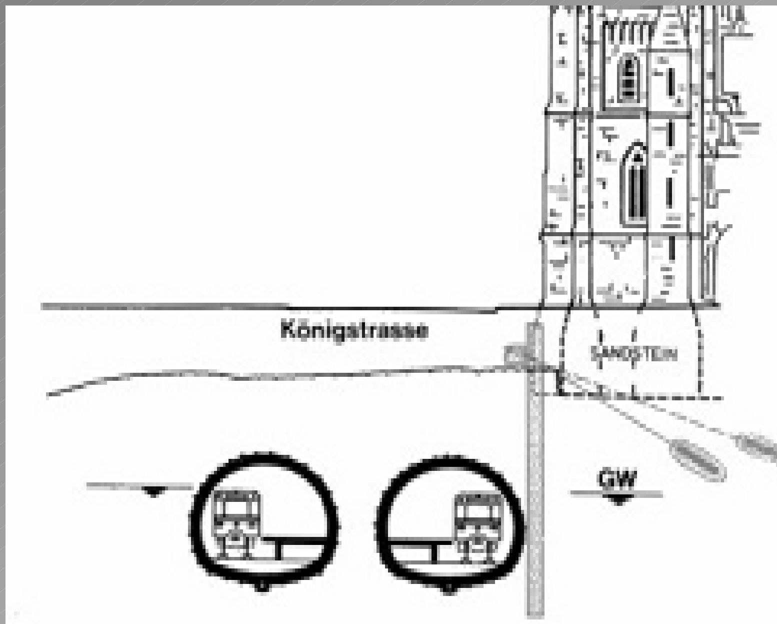
1976 Subway Bochum, Germany



Subway Station Berliner Platz

X - section and Construction Stage

1977 Subway Nuremberg, Germany



Subway Station Lorenz Church

X - Section and Final Structure

1982 Subway Munich, Germany

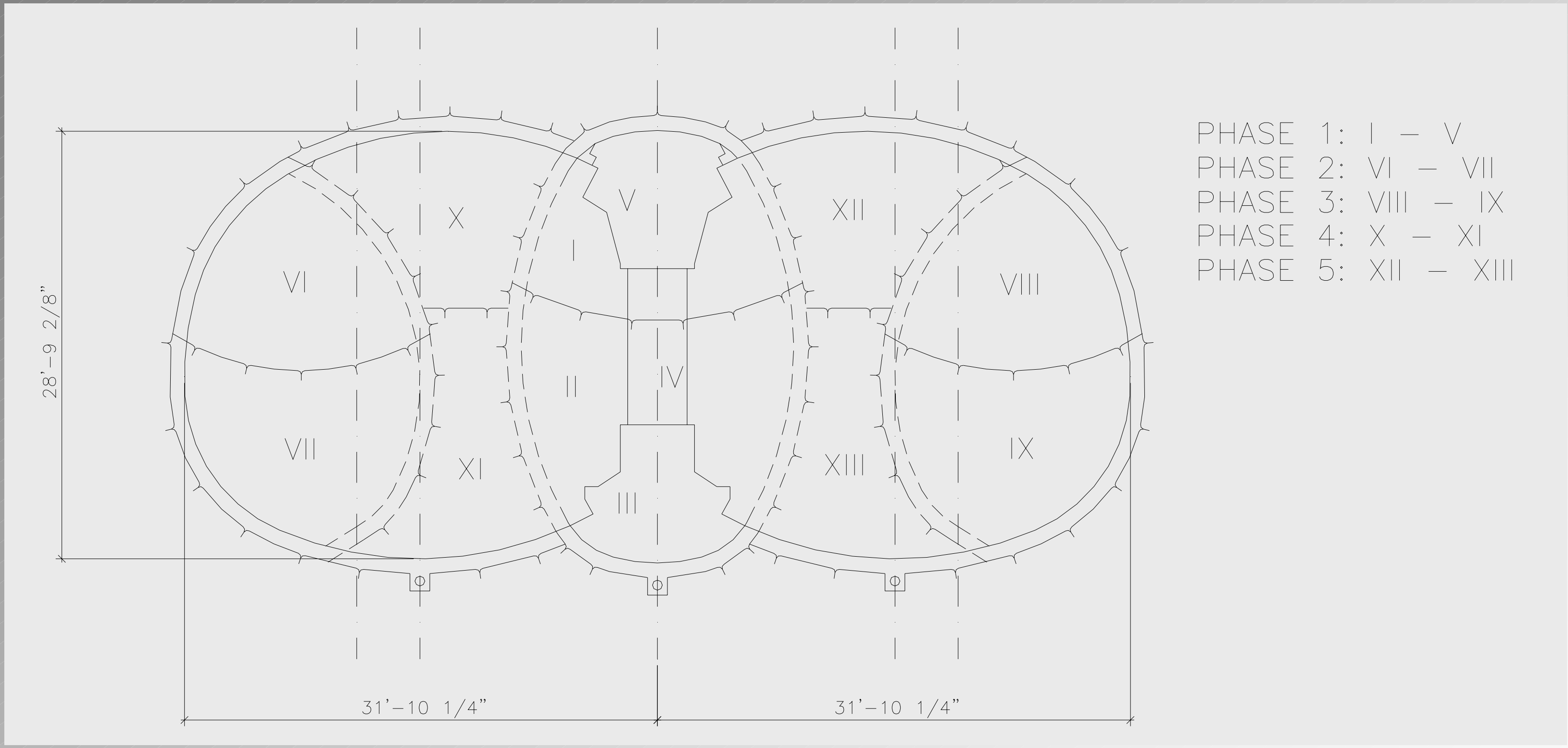
Subway Station Theresienwiese

X - Section and Final Structure

1991 Station Washington, USA

“Fort Totten Station“ - Completed Structure

1991 Station Washington, USA



Fort Totten Station – X-Section

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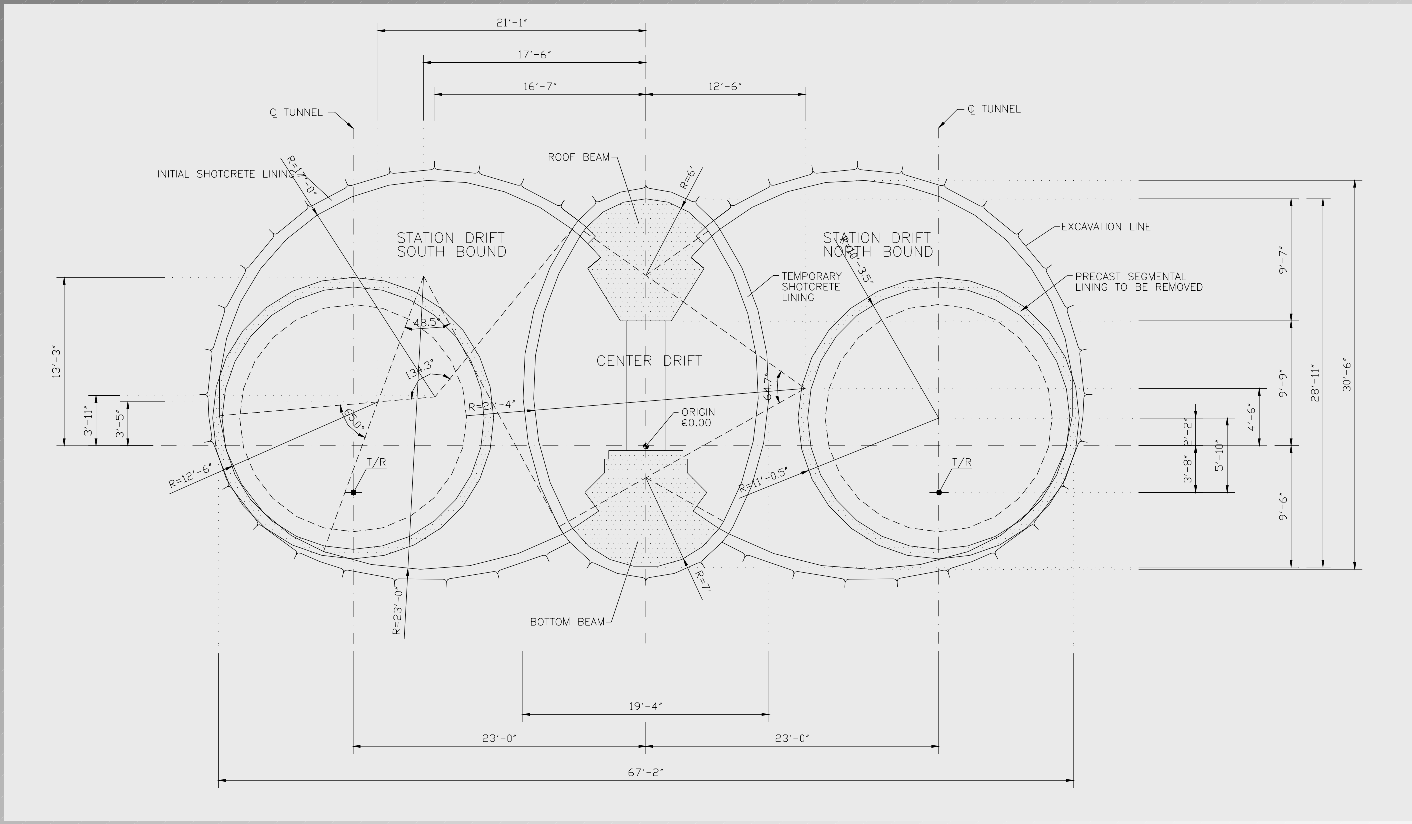
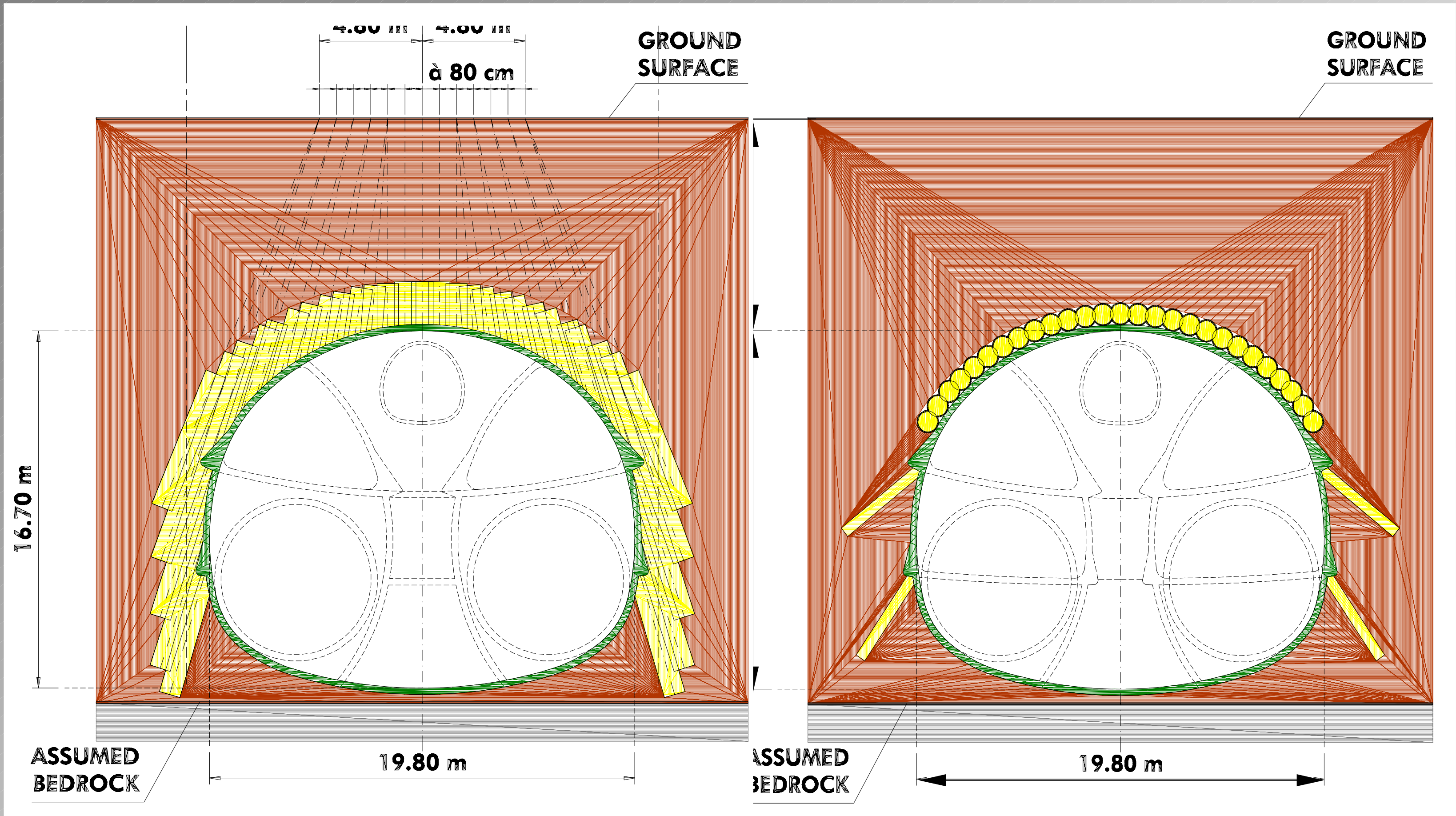
1992 Metro Los Angeles, USA



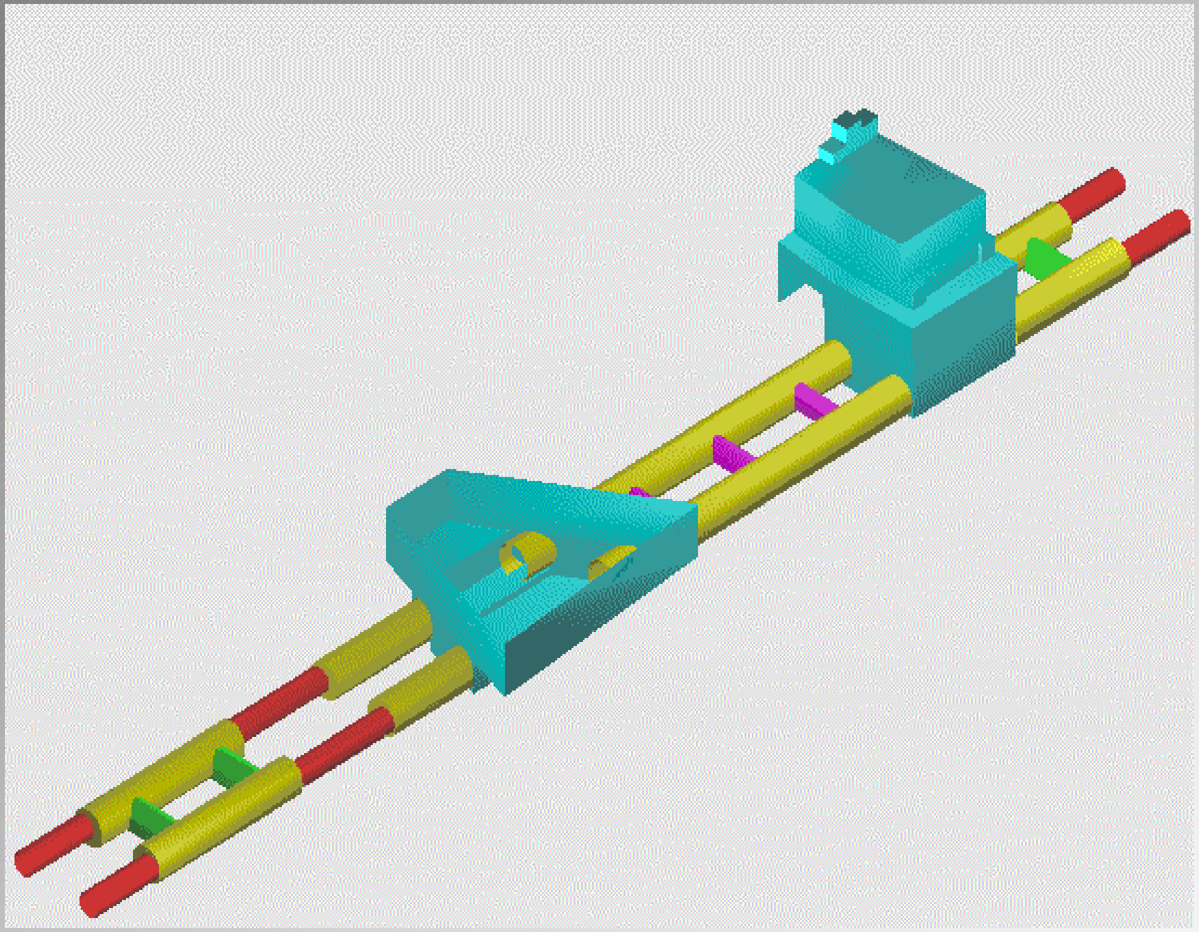
Conventional / TBM Interface

2000 Subway San Juan, Puerto Rico



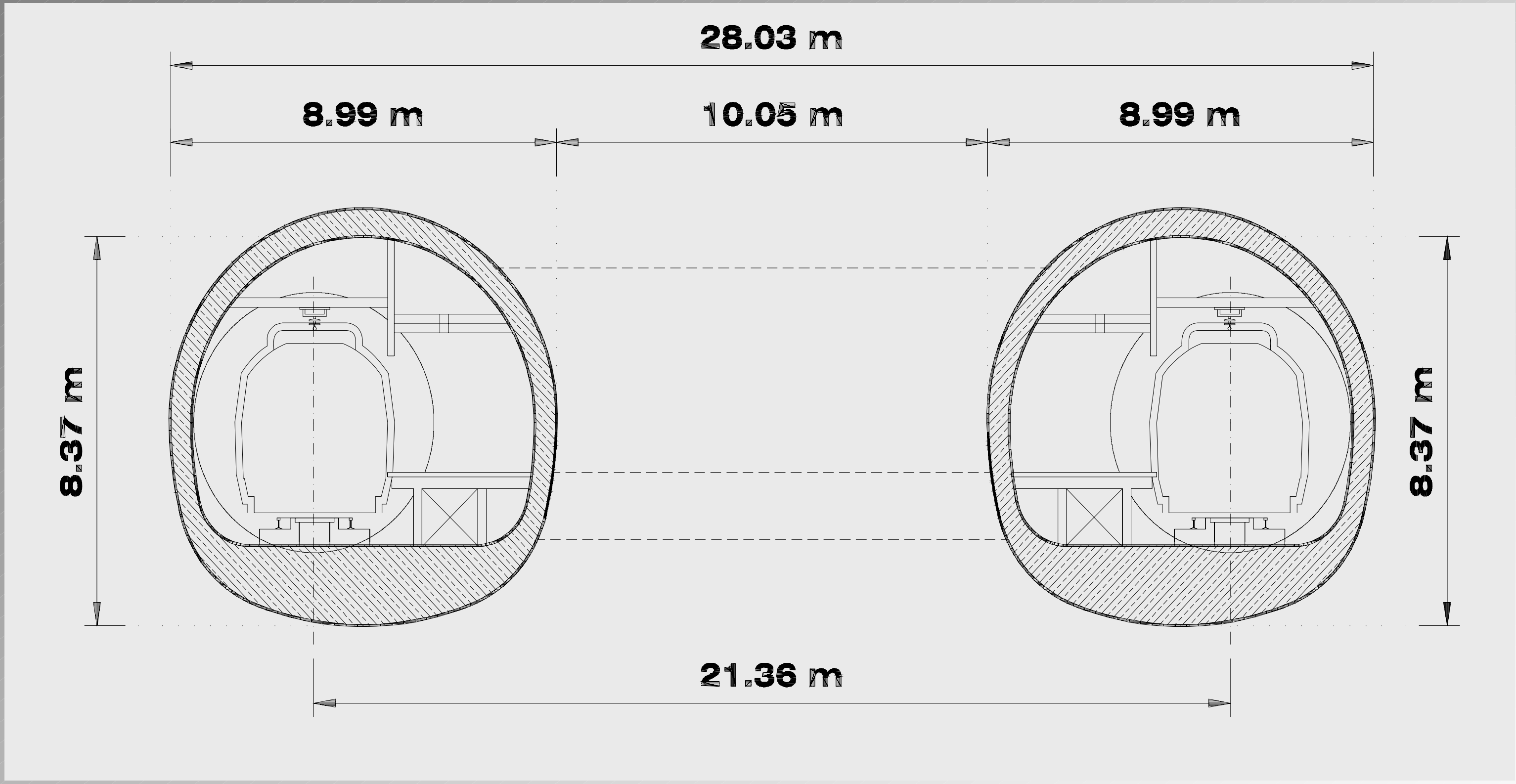
Conventional / TBM Interface

2000 Metro New Delhi, India



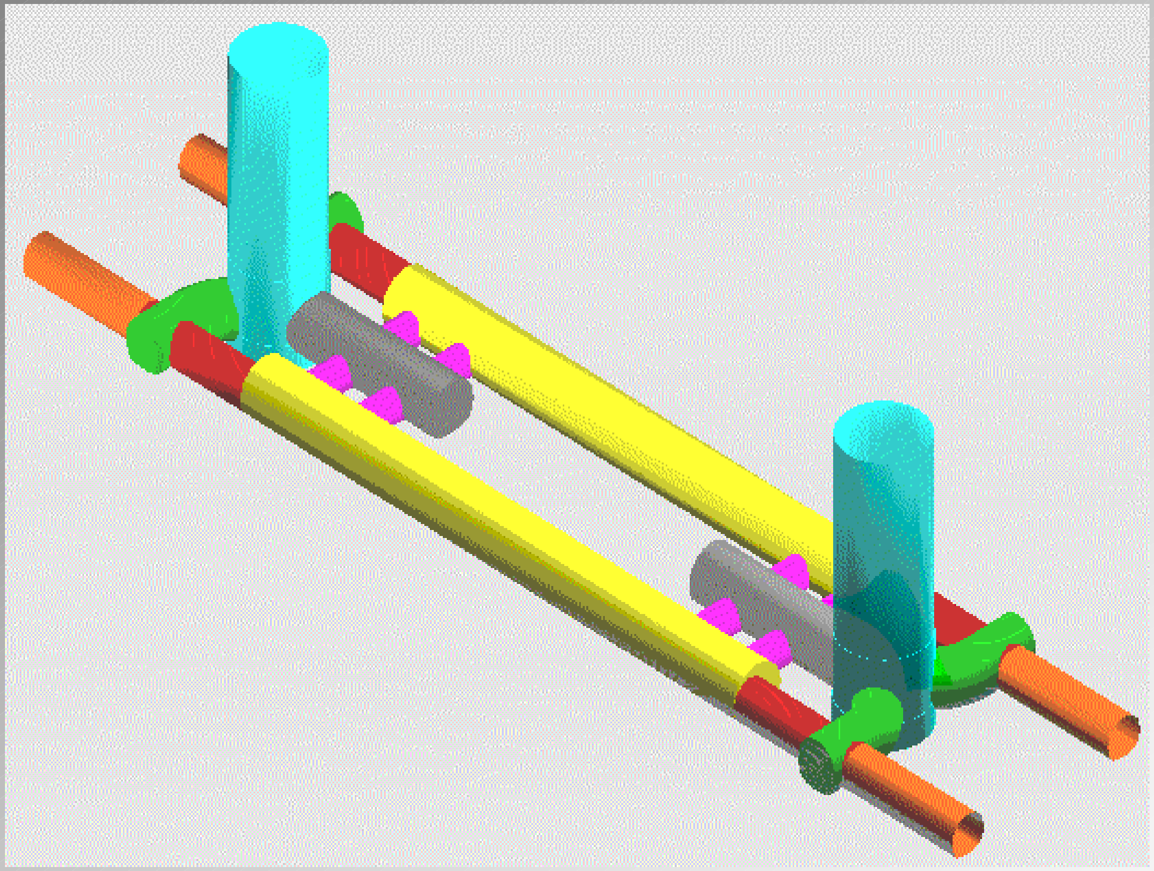
Chawri Bazar Station – 3D View

2000 Metro New Delhi, India



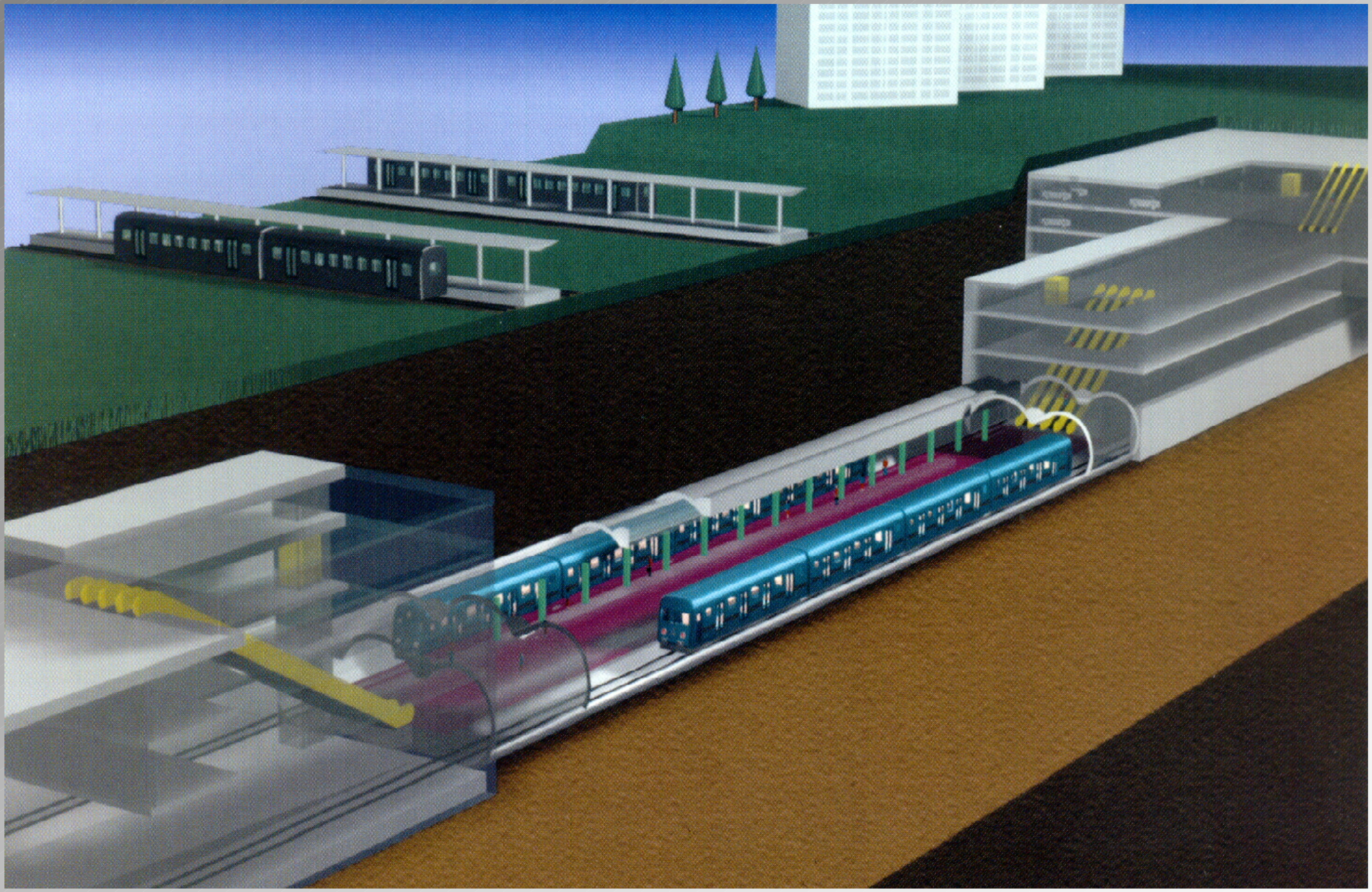
Chawri Bazar Station – X - Section

2001 Sound Transit Seattle, USA



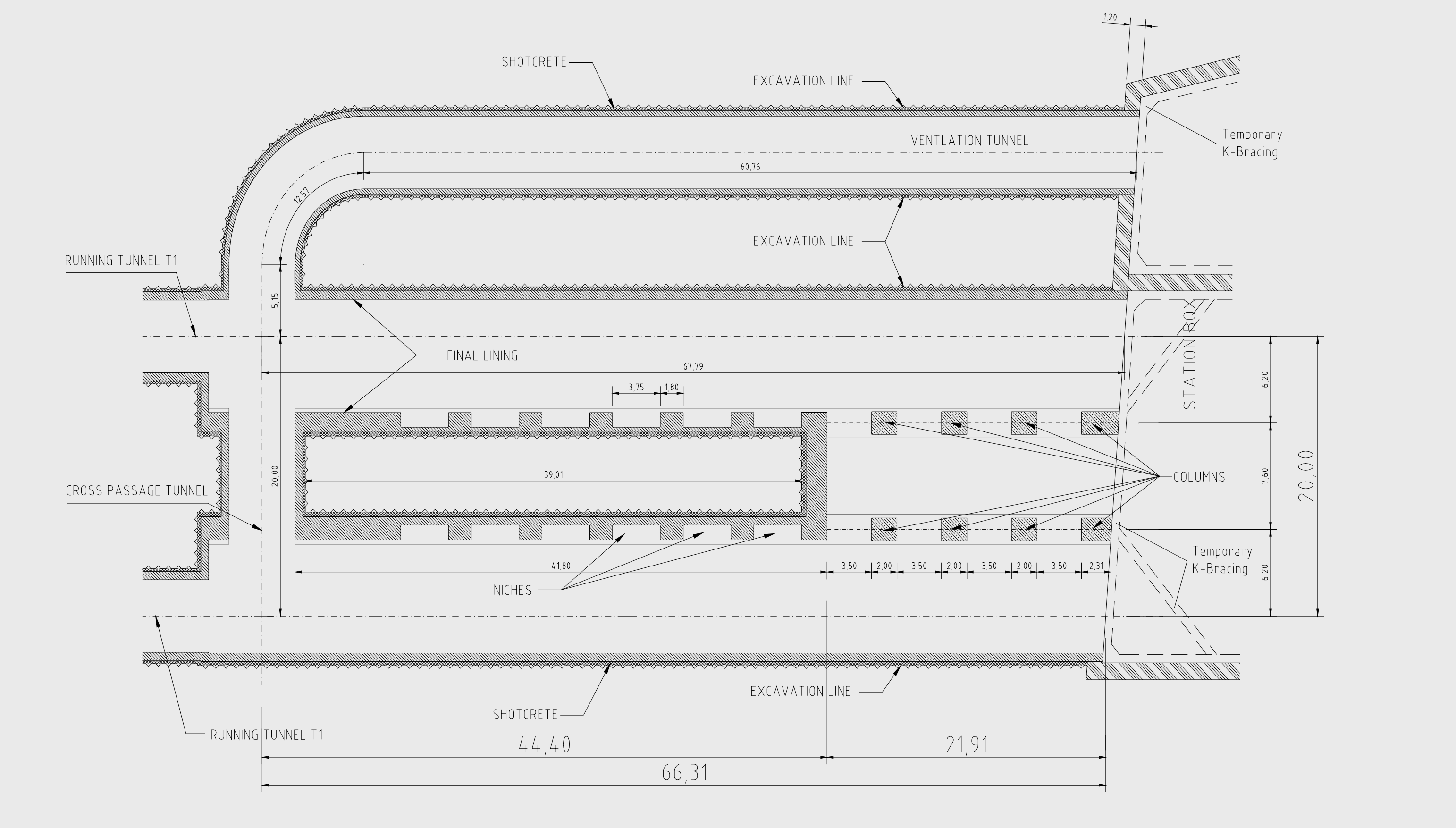
Pacific Station – 3D View

2004 Metro Budapest, Hungary



Fövam Ter Staion 3D - Perspective View

2004 Metro Budapest, Hungary



Gellert Ter Station - Binocular Plan

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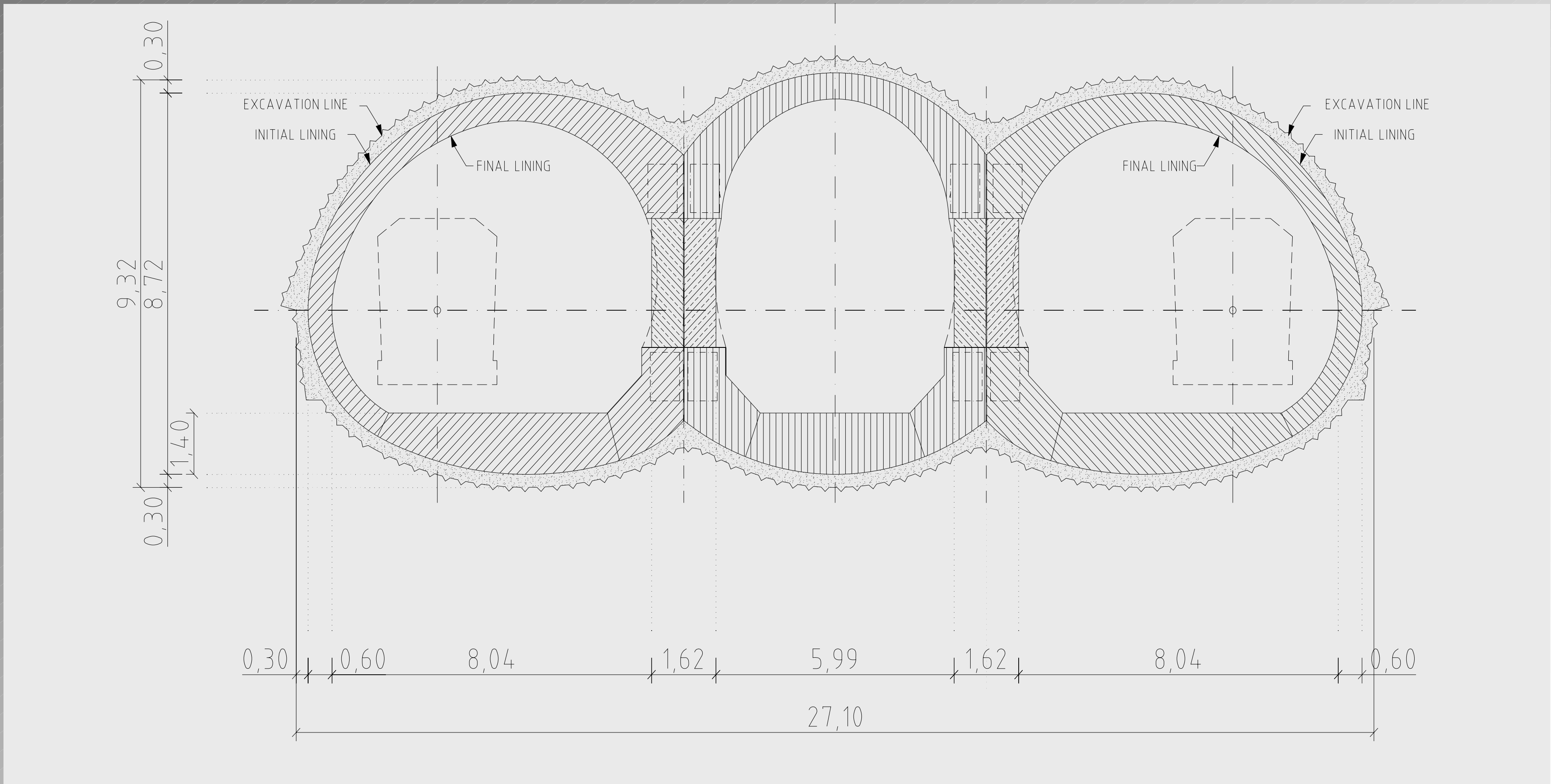
2004 Metro Budapest, Hungary



Gellert Ter Station - Binocular Section

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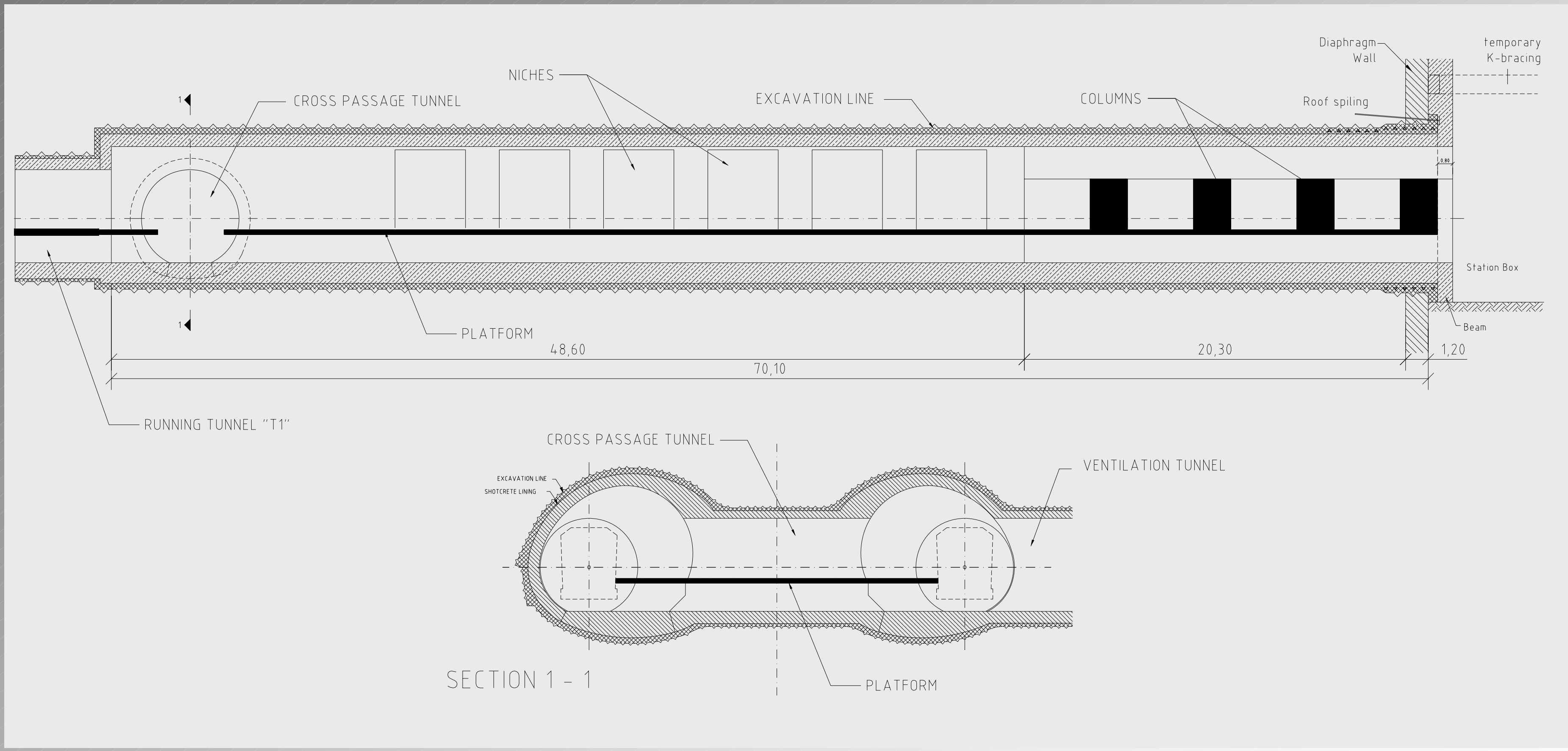
2004 Metro Budapest, Hungary



Gellert Ter Station – Binocular Type

Conventional Tunnellling - 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

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Mined Multiple Drift Stations I

- 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

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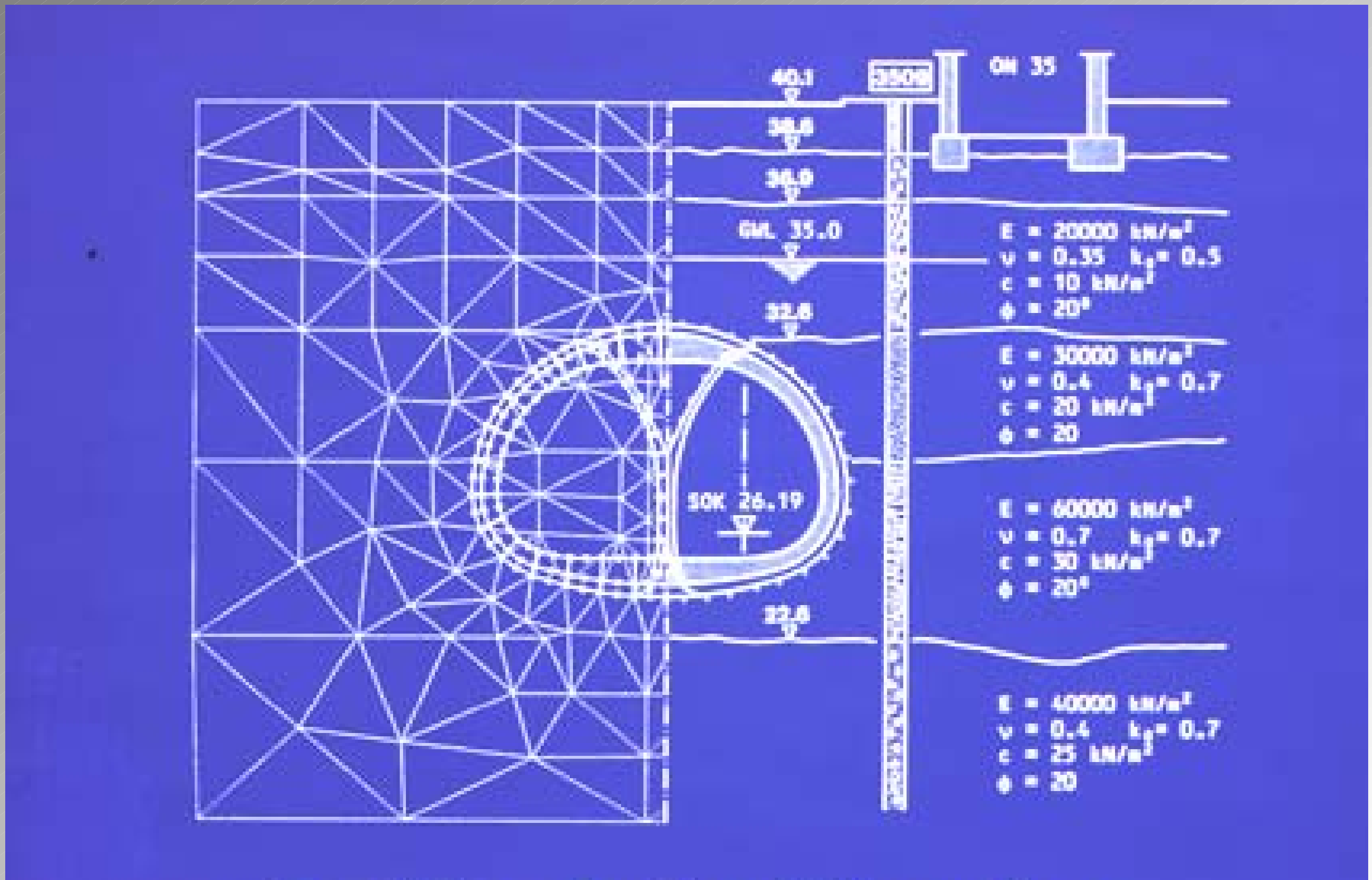
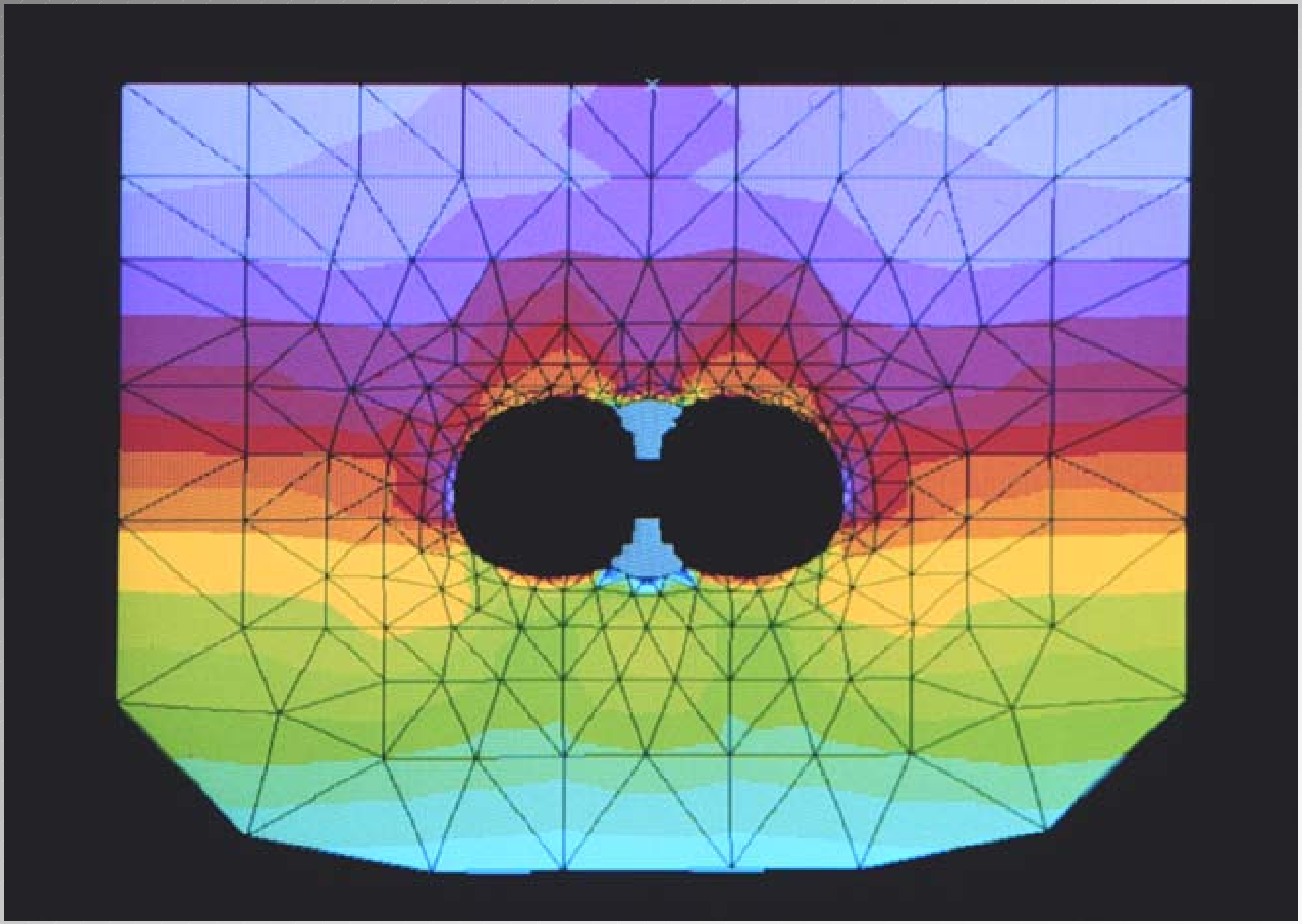


Tunnel Cross-Section of Subway Vienna

Metro Washington - Numerical Model



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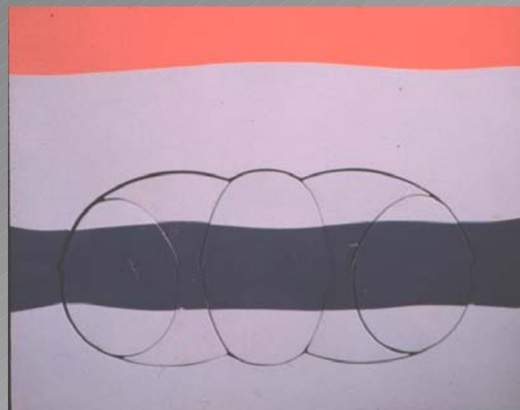
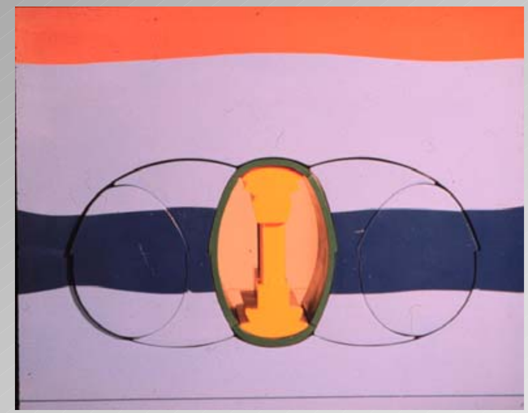
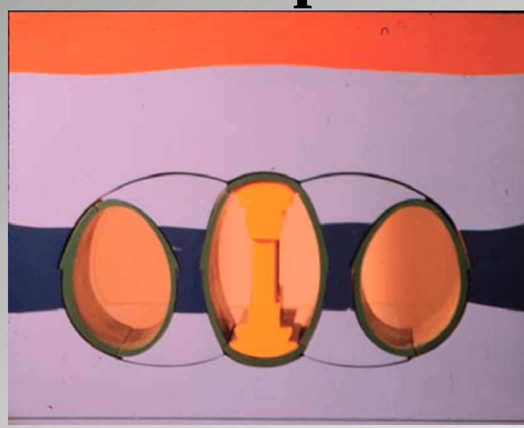
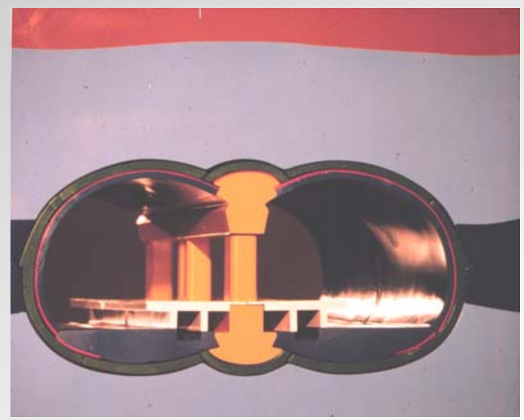
Metro Washington - Fort Totten Station





Multiple Drift Construction Phases

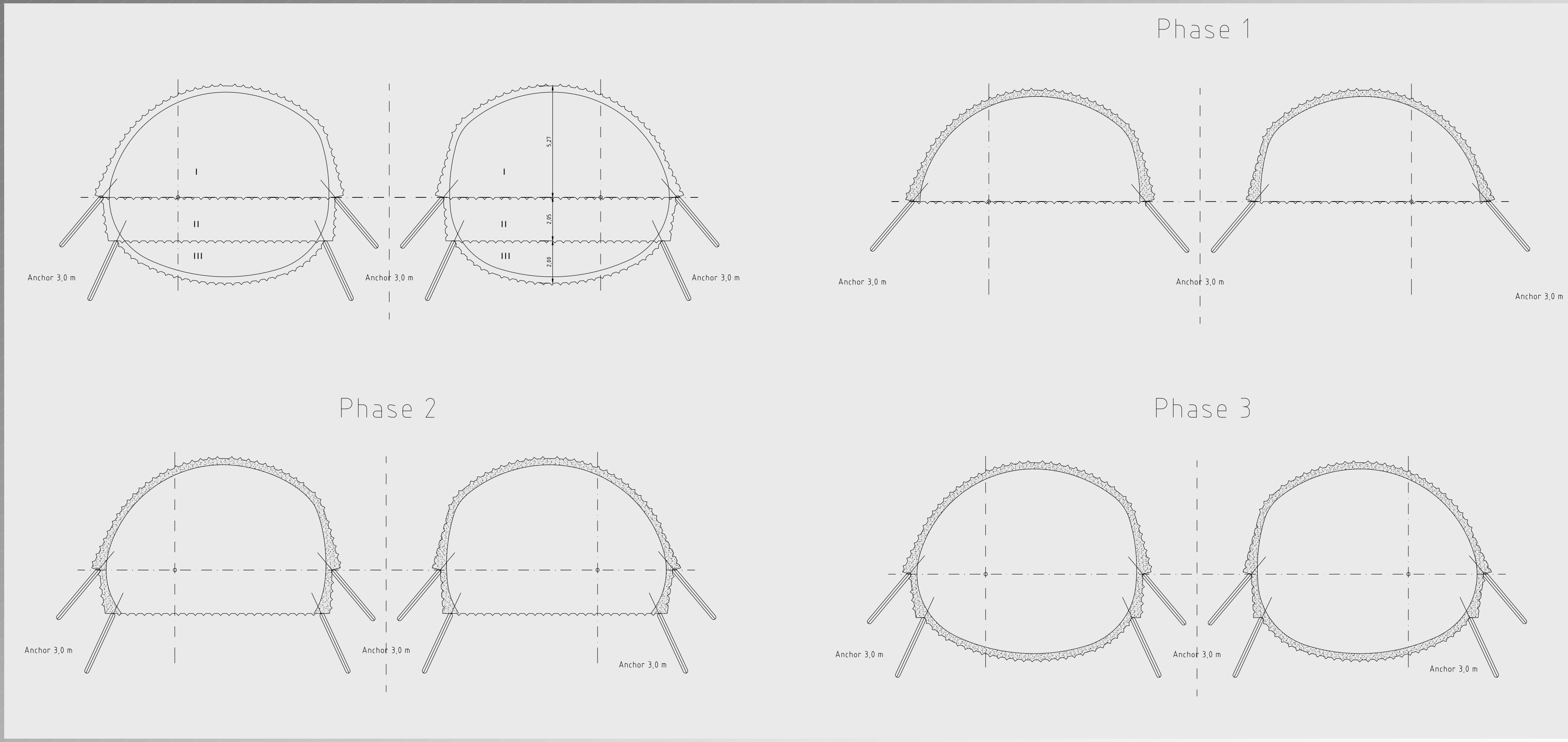




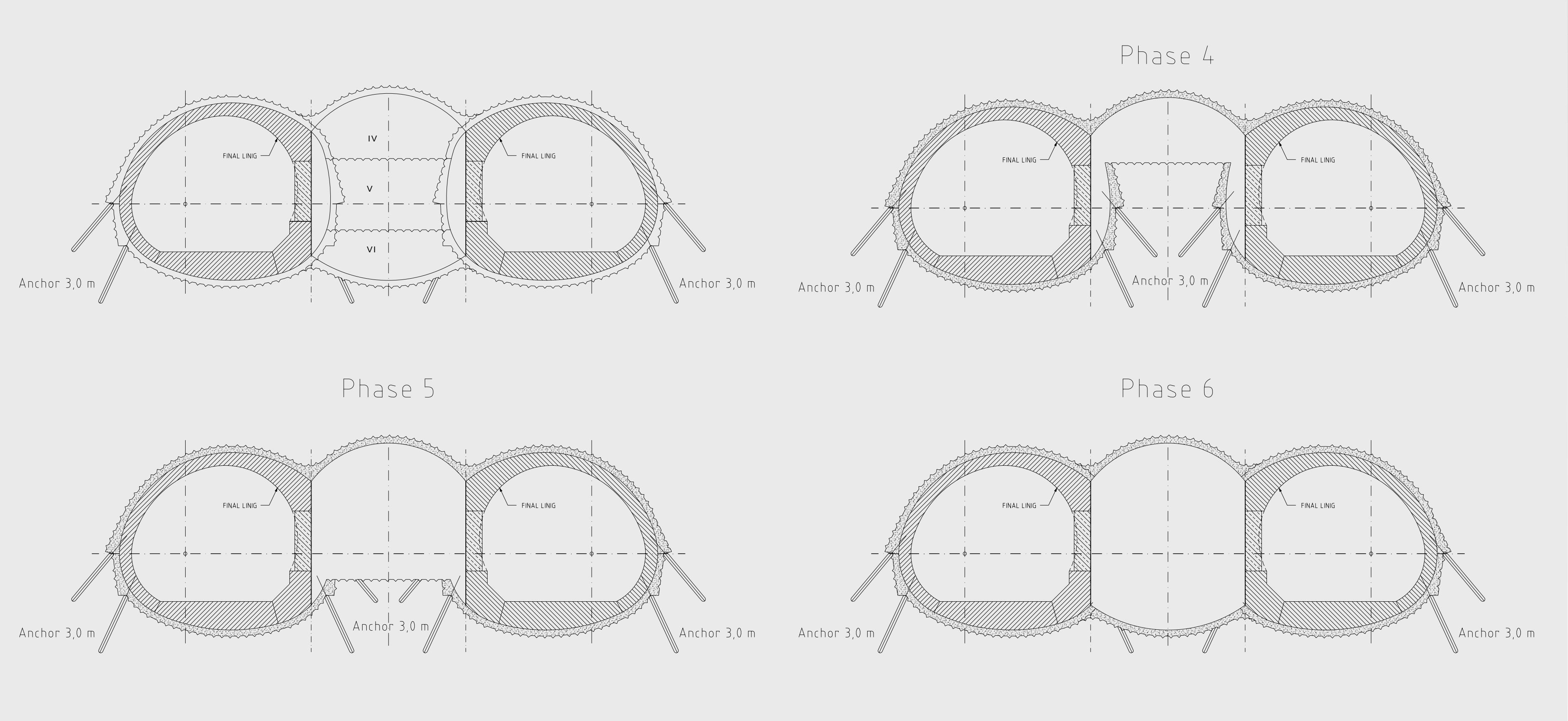
Metro Washington - Fort Totten Station

Multiple Drift Construction

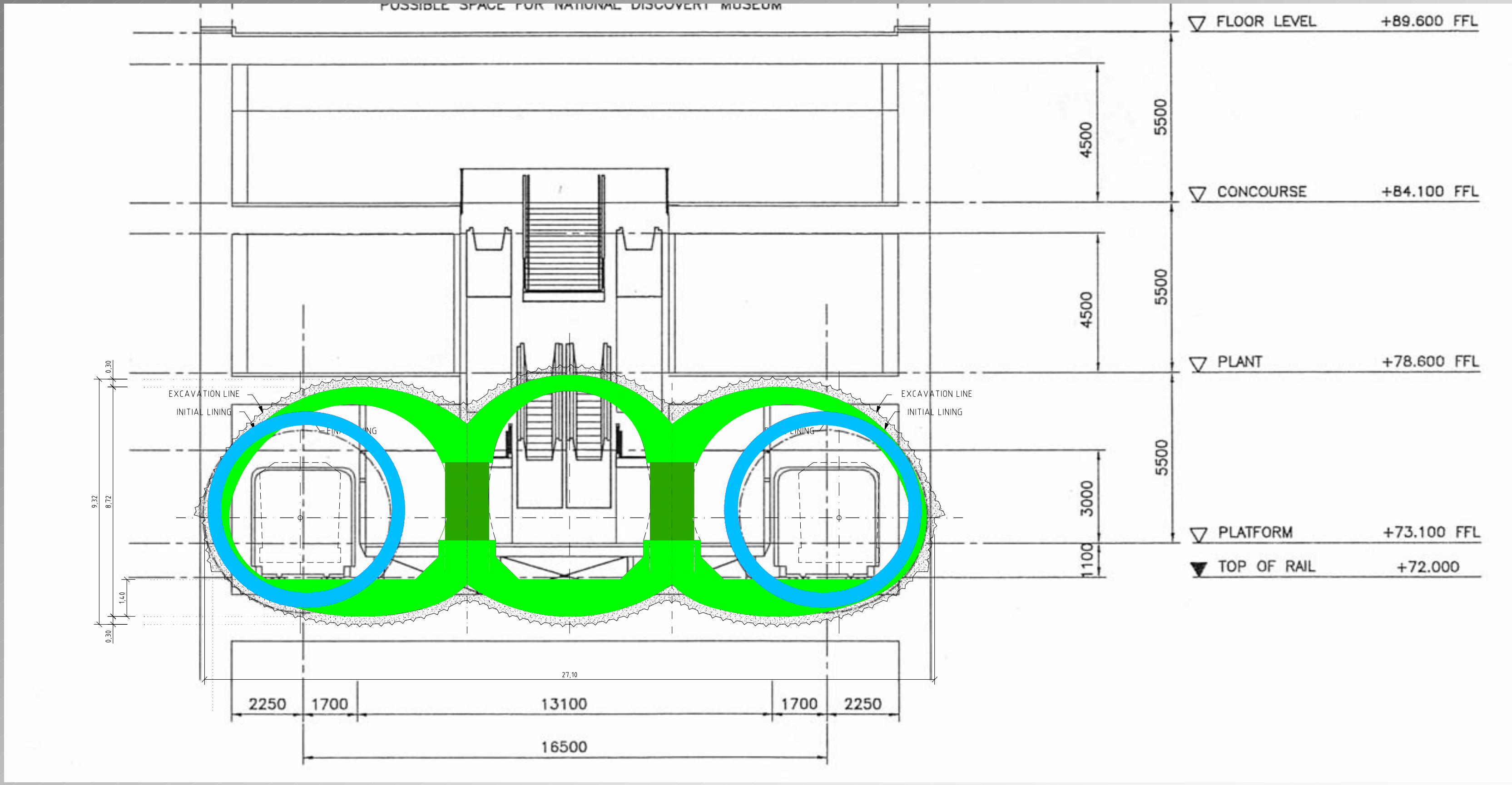
Metro Budapest - Mined Station Sequence



Metro Budapest - Mined Station Sequence



Mined Station – Cross Section Projection



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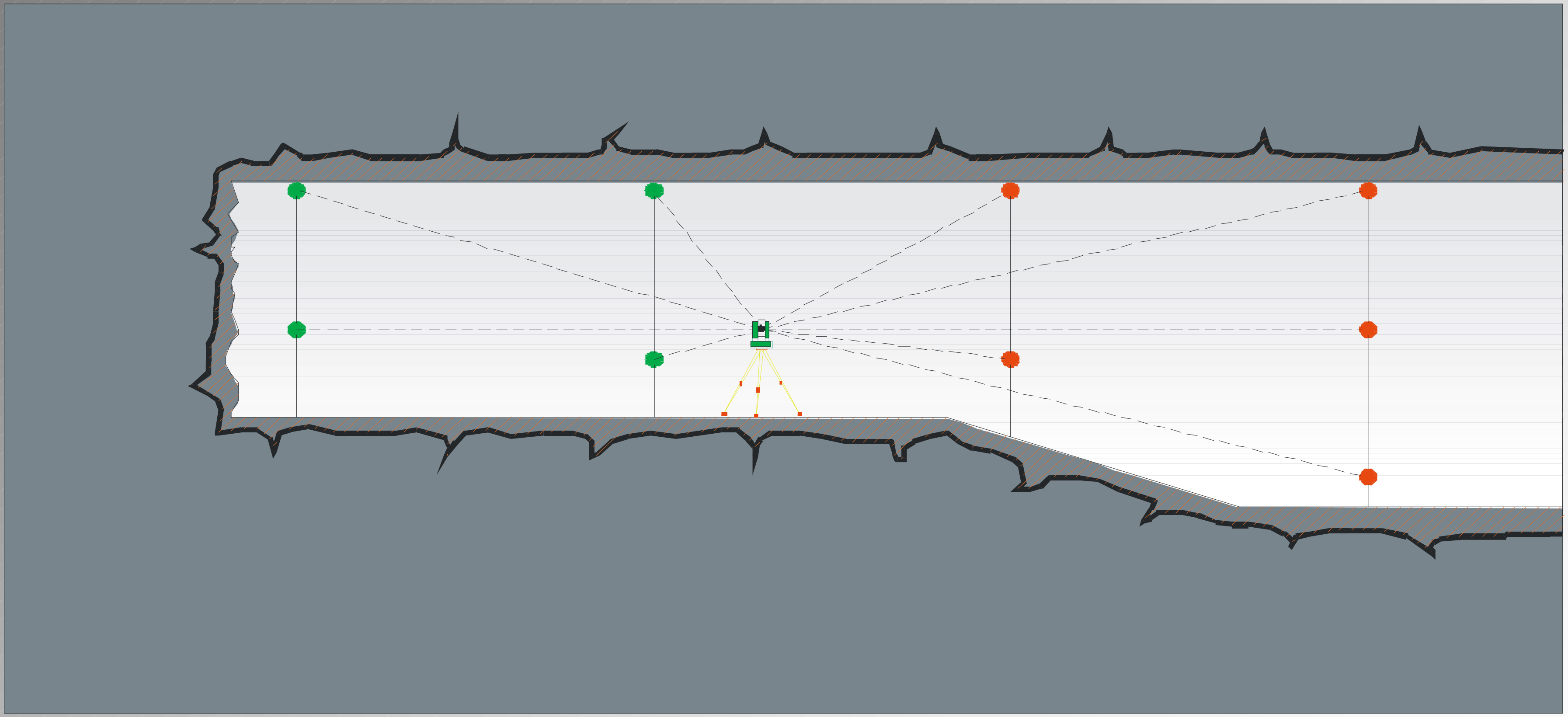
Construction Monitoring

- 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

Laser Beam Deflection Monitoring

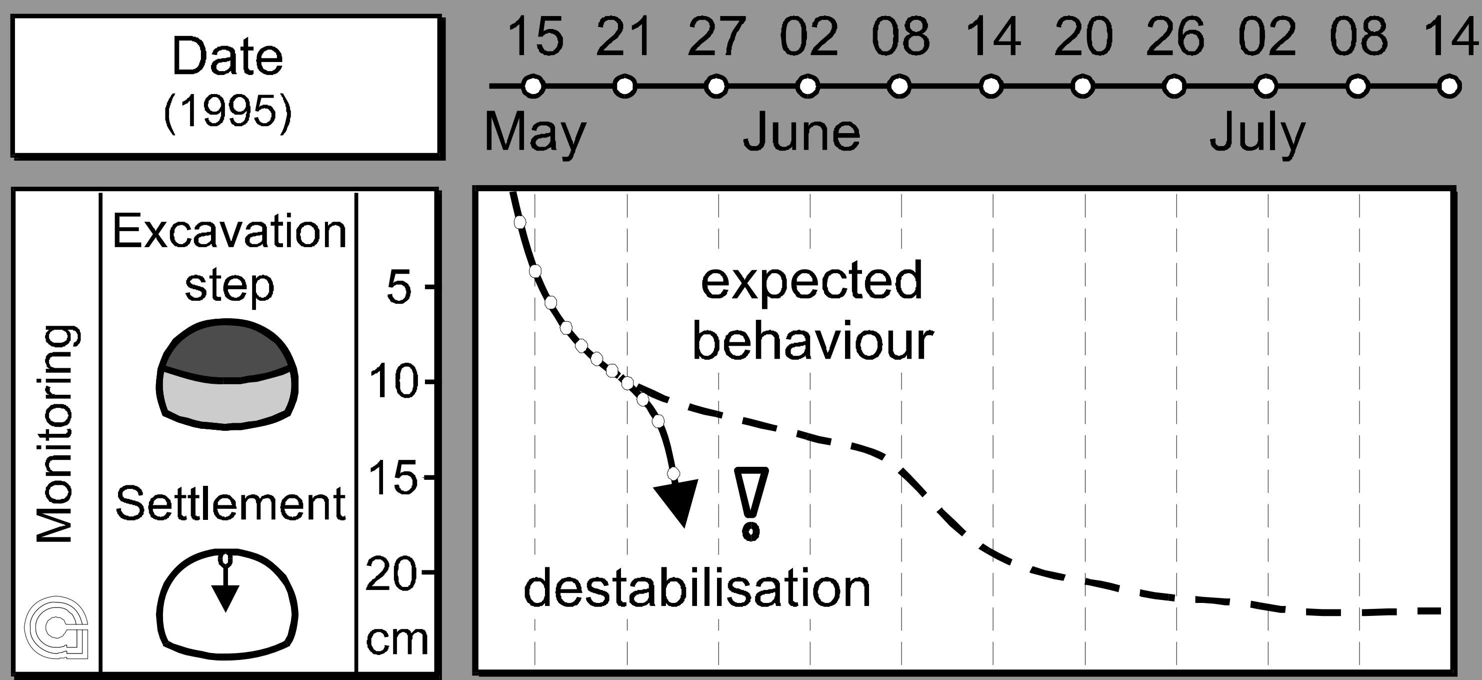


Displacement History Plots

Value of Information

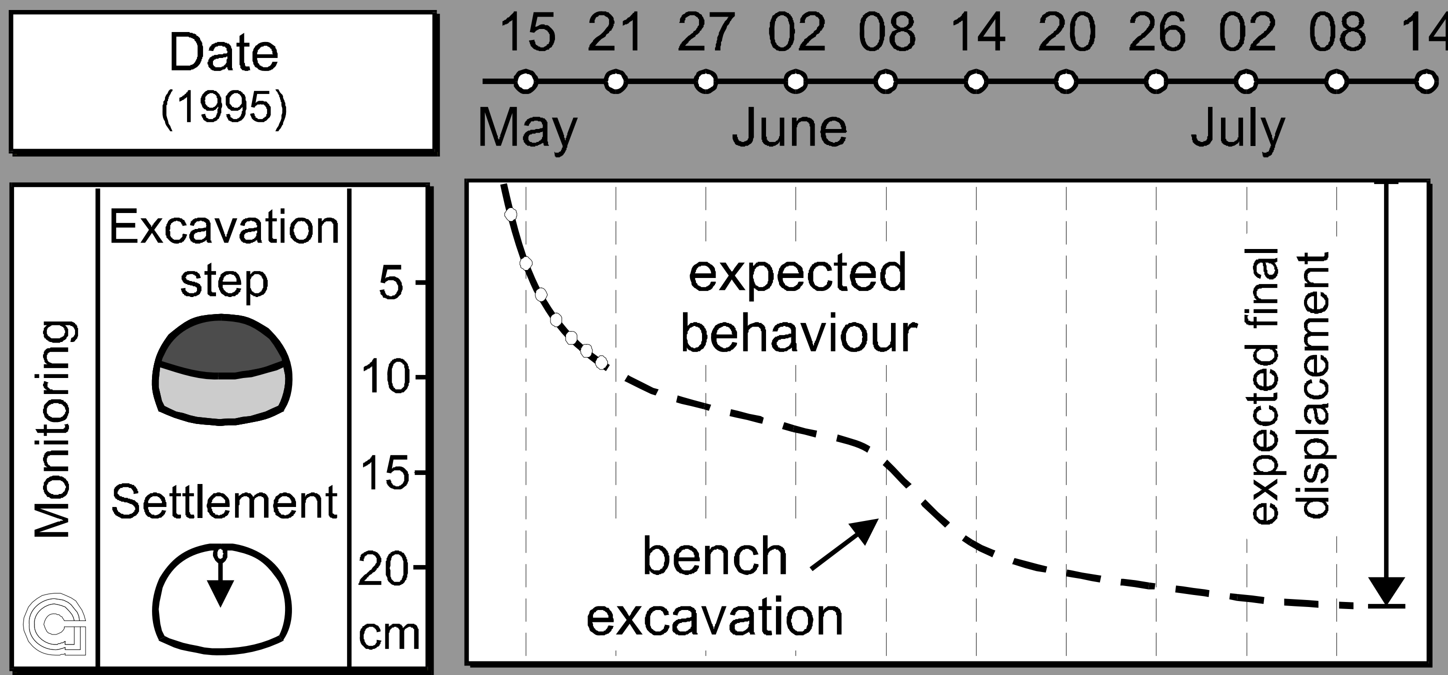
- Assuming continuous face advance, displacement rate over time has to decrease
- Displacement acceleration indicates destabilisation, unless there are ongoing construction activities in the monitored tunnel section (e.g. bench and invert excavation, or shaping activities)
- Stabilisation is reached after bench and invert excavation

Typical Displacement History Diagram



Typical displacement history diagram, showing expected behaviour and indication of destabilisation

3 Final Displacements



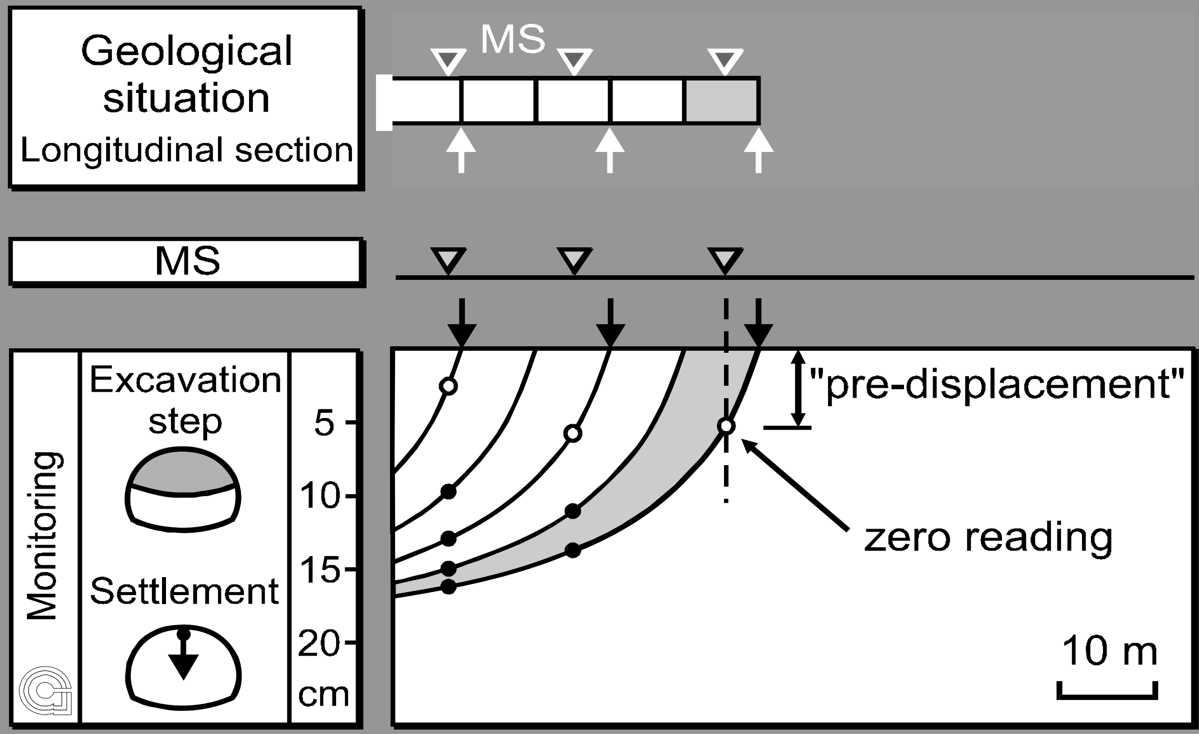
Final displacements extrapolated from few readings, using previous experience and including the actual geological situation

Deflection curves

Value of Information

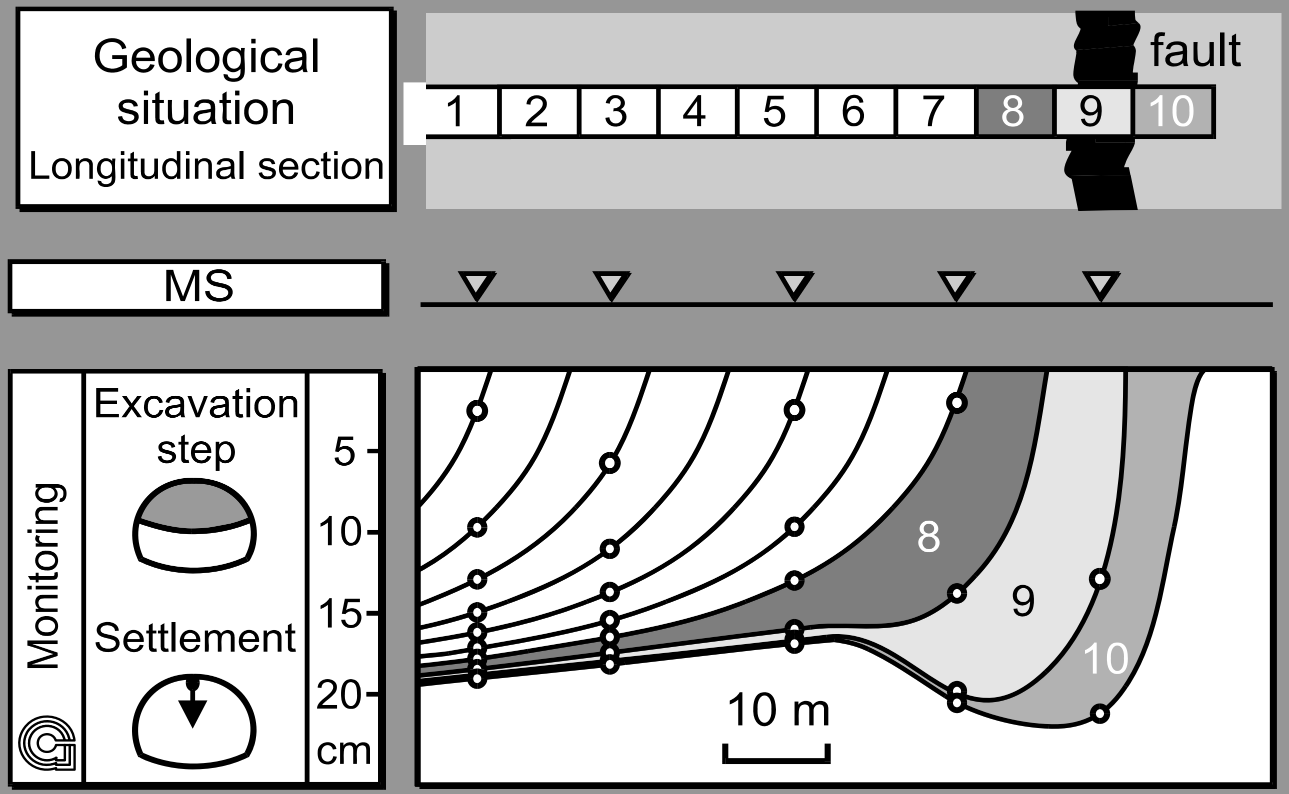
- When showing several deflection curves on the same plot,
  comparison of displacements along tunnel is possible
- Information on the longitudinal extent of tunnel deformation behaviour is provided
- Trends of relative decreasing or increasing ground behaviour can be verified

Extrapolation of Deflection Curves



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



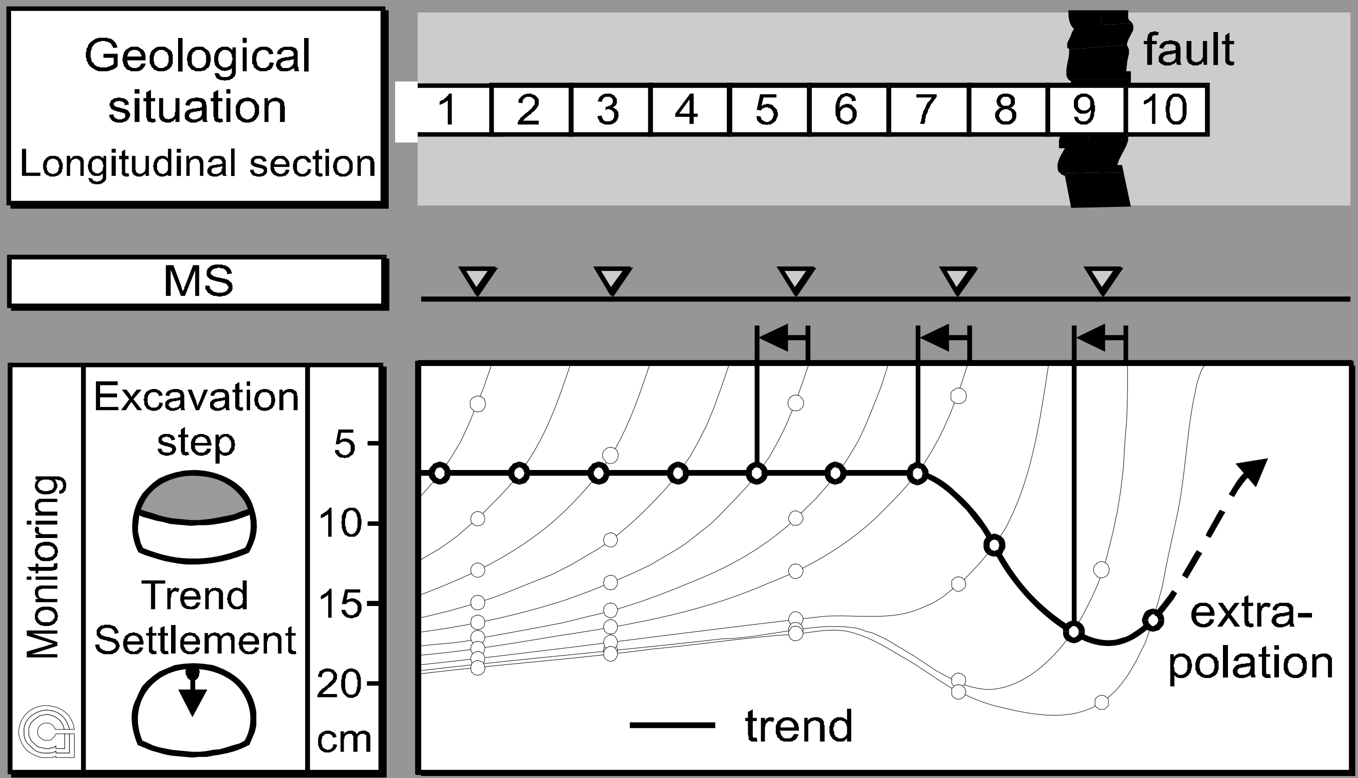
Typical plot of deflection curves when excavation approaches a "weak" zone (schematically)

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



Trend line of settlement when tunnelling in homogeneous rock mass and when passing a fault zone (schematically)

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Risk Categories

- Risks to be identified in the Risk Register
- Design and Construction Risks, e.g. inadequate design, unforseen ground conditions
- Risks are to be prioritized and quantifie

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

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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.

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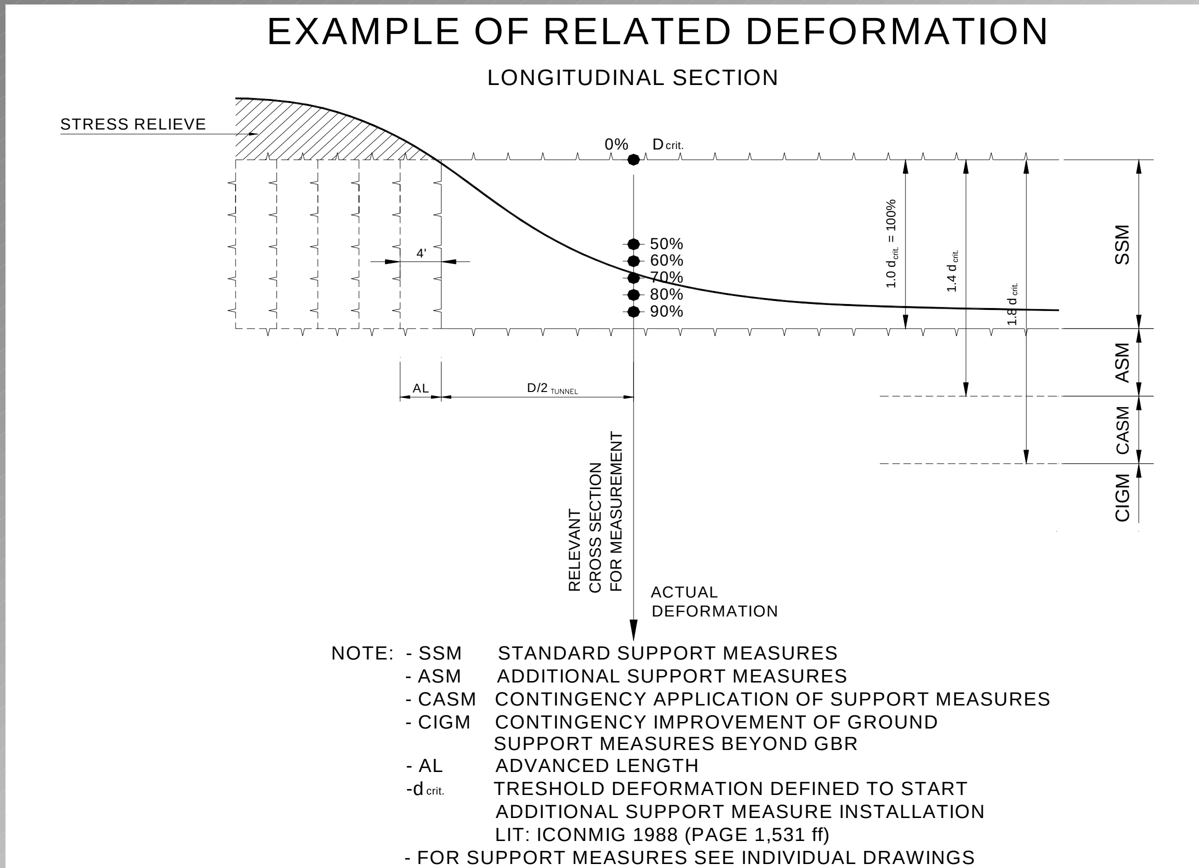
Additional Support

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

- It d_{crit} represents a threshold value which is on the very safe side, for the purpose of defining the value reuiring additional support measures.

4 Related Deformation



Actual time and location related deformations to different tunnel support measure categories

Decision Matrix

CROSS SECTION

	No.	SUPPORT TYPE	0.7	0.8	0.9	d_{crit}	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8
STANDARD SUPPORT MEASURES	0	ADVANCE LENGTH (AL) 4'												
	1	SOIL NAILING 21 (Standard)												
	2	SHOTCRETE: (10 cm) 4"												
	3	DEWATERING / PROBE HOLES: 5 WELL POINTS IN TOP HEADING,												
		VACUUM LANCES IN INVERT												

	No.	SUPPORT TYPE	0.7	0.8	0.9	d_{crit}	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8
ADDITIONAL SUPPORT MEASURES	0	REDUCED ADVANCE LENGTH (AL) 3'												
	1a	ADDITIONAL SOIL NAILS: 21 (Add.) /3' for 100 % AL												
	1b	ADDITIONAL SOIL NAILS: for AL + 30%												
	2	ADDITIONAL SHOTCRETE												
	3a	LATTICE GIRDERS: on 3' spacing, Type PS 95/20/30												
	3b	SPILING: Bar size 9, (1.0 sqin)												
	4a	FACE SEALING: 2" (Total) fibre shotcrete												
	4b	FACE BOLTING: 9 pcs, fibre glass, L=28', in top heading												
	5	PIPE ROOF: 29 pcs, L=50' e=10'												

	No.	SUPPORT TYPE	0.7	0.8	0.9	d_{crit}	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8
CONTINGENCY SUPPORT MEASURES	0	DIVIDED FACE EXCAVATION												
	1a	ADDITIONAL SOIL NAILS: For 100 % AL as required												
	1b	ADDITIONAL SOIL NAILS: for AL + 50% as required												
	2	ADDITIONAL SHOTCRETE												
	3	PIPE ROOFING												
	4a	FACE SEALING: 2" (Total) fibre shotcrete												
	4b	FACE BOLTING: Fibre glass, L=28', in top heading												
	5	GROUTING												
	6	JET GROUTING: improvement of Qpnl												

NOTES: - TUNNEL WALKER HAS AUTHORITY TO ADDITIONAL MEASURES AT ANY TIME AS REQUIRED BY FACE CONDITIONS.
- MEASURES CANNOT BE REDUCED WITHOUT CONSENSUS.

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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