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SEMINAR

EXPERIENCES IN ROCK

BANGKOK , July 24, 2013, 1:00 – 3:00 pm

CHOICE OF TUNNELLING METHODS

Viewing at Tailands Future Infrastructure

SYNOPSIS

Harald Wagner, Consulting Engineer & ITA EXCO Expert

The choice of Tunnelling Method and the evaluation of Tunnel Behaviour means estimating the interaction between equipment and ground. For the designer it means production of drawings to visualize a structure which shall become a tunnel. The tunnel designer becomes the manager of tunnel construction including its risks, as his choice of design is a management tool in construction.

This lecture on the principle choice of tunnel methods for Thailands future Infrastructure and for construction management by design summarizes the state of the art for both conventional (NATM) and mechanized (TBM) tunnelling. A detailed brief description will be given in regard to Future Urban Infrastructure and the Choice of Tunnelling Methods, Principles of CTM Tunnelling, Principles of TBM Tunnelling, Monitoring for CTM and TBM Tunnelling, CTM Tunnelling in Soft Ground & Hard Rock, Urban Infrastructure, Transport on Water, High Speed Train, Floodwater Control Tunnels, Underground Nuclear Power Stations, design stages, contractual applications, and construction organization.

Fundamental requirements for a tunnel are

- ground investigations with evaluation and classification of ground conditions with respect to particular project requirements
- design with subdivisions in stages, following the project and construction development, which provides the framework for a range of potential applications
- construction methods suitable for standard plant, equipment and material
- back checking of predictions by geotechnical monitoring and adjustment to the conditions encountered
- flexible contractual models for fair remuneration.
- Demand for proper designed Underground Works has been continuously growing since decades.

Conventional Tunnelling Method is well suited for tunnelling in difficult, complex and changing geological and geotechnical conditions. The main purpose is to minimise construction cost by selecting optimum driving cross section, driving methods and lining during the design and construction phases. During tunnel excavation simultaneous and joint decision by the contract partners must be realized within predetermined limits to manage flexible response to changing ground and ground behaviour conditions.

Tunnelling needs trained, qualified and experienced owners, designers and contractors, it needs qualified and experienced engineers on site, and qualified and experienced workforce. It needs a suitable design as well as a suitable contract model. This goes hand in hand with a contract system which had to be developed for being able to cope with changes in ground behaviour together with the character and scope of the works in a fair and objective way.

Water tunnels have been excavated using open hard rock TBM's, where in urban areas recently small EPBM- and Slurry-Shield Machines have been used for pipe jacking. A lot of experience has been gained with medium diameter TBM's for subways, whereas large diameter TBM's have been used for long railway tunnels.

Where extensive ground recognition is performed, advanced technologies in ground recognition are involved in large Conventional and TBM Tunnelling Projects, such as the tunnels for Bangkok Metro, High Speed Train Tunnels, Double Track Railway Tyunnels, and Flood Water Control Tunnels. Examples for comprehensive Ground Recognition are given in other parts of the woeld, e.g. in Switzerland with Lötschberg and Gotthard Tunnels, and in Austria the Brenner-, Semmering- and Koralm-Tunnels.

Technological development and Engineering practice in tunnelling paved the way for new theoretical explanations to substantiate an economical beneficial approach. A flexible contractual network has been developed to allow for fair remuneration of all activities, which are difficult to quantify before excavation works are finished. The theoretical basis of tunnelling is to view the ground around and on top of the tunnel not only as a load but also as a load bearing element of support. In combination with the timely development of ground reactions as a result of tunnel excavation, the type and quantity of required support elements is systematically adjusted.

The ground reactions in form of lining deformations and lining pressure are measured and the stability of the excavated cavity confirmed by frequent monitoring. Depending on the project conditions (e.g. shallow soft ground tunnel, deep hard rock tunnel), and the results of geotechnical measurements, the requirement for rapid rigid support or slim deformable support is identified. Adjustable contractual arrangements have to allow the most economical type and amount of support installation in the tunnel.

Typical support elements for Conventional, Mechanized and Hybrid Tunnelling are the systematic application of shotcrete and excavation steps to allow for controllable deformations of the ground. Steel ribs or lattice girders provide limited early support before the shotcrete strength development ensuring at the same time correctness of the profile geometry. Face bolting, sealing shotcrete, spiling or roof piping canopy are installed, if ground conditions require support at or in front of the excavation face.

When applying conventional methods for hard rock, design could be carried out by the clients engineering team, by the consultants design offices, or by the construction contractors design team, where the consultant together with the Independent Checking Engineer is representing the client being usually responsible for design in all phases of a conventional tunnel project. The project development stages of a tunnel project usually is subdivided into four different stages,

- the conceptual design stage,
- the preliminary design stage,
- the tender design stage, also called the detailed design phase 1, and
- the construction design stage, also called the detailed design phase 2.

The tunnel designer needs to rely on the following basics for the conceptual design, which has to be provided by the client. At the beginning of the project following has to be prepared.

- proposed alignment in plan and section,
- number and size of required underground structures (standard cross section, structure gauge, dynamic envelopes, etc.)
- topographical survey,
- geological and hydrological investigation and description,
- environmental investigation including noise, vibration, air pollution, etc. .

Following general project activities have to be carried out before starting the design.

- site visits,
- literature search,
- searching for public data and documentation
- searching for relevant standard and guidelines.

The majority of aspects related to the design and construction of tunnels should be covered by national standards and guidelines.

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Choice of Tunnelling Methods for
THAILANDS FUTURE INFRASTRUCTURE

HARALD WAGNER, PhD, PE

July 24, 2013, 1:00 – 3.00 pm

CONTENT

1. Preambel
2. Urban Infrastructure
3. Choice of Tunnelling Methods
4. Choice for Conventional Tunnelling
5. Choice for TBM Tunnelling
6. Design Guidance
7. Monitoring Guidance
8. Construction Concept in Soft Rock & Hard Rock
9. Urban Infrastructure
10. Trains in Thailand
11. Floodwater Control
12. Underground Nuclear Power
13. Conclusions

1. PREAMBLE

Asia is the growth engine of the 21st century. A major problem of the region is how to handle ist rapid growth. Asia faces global mega trends such as urbanisation, energy shortages, and climate change.

For **Thailands Transportation Infrastructure**, times are rapidly changing. High Speed & Double Track Rails are planned. KMITL is now starting new classes to train Railway Engineers such offering career chances.

Beyond education, Thailand is in need for new **Alignments with Tunnels** and enormous amounts of railway equipment. Advice on techno / scientific cooperation is the order of the hour to provide implementation of latest state-of-the-art technology and investment cost savings.

TECHNO / SCIENTIFIC COOPERATION

PROJECT 1
RAILWAY RESEARCH INSTITUTE

INTERUNIVERSITY BILATERAL COMMITTEE

KMITL WORKING GROUP

EDUCATION GOALS

UNIVERSITY COURSES IN RAILWAY ENGINEERING

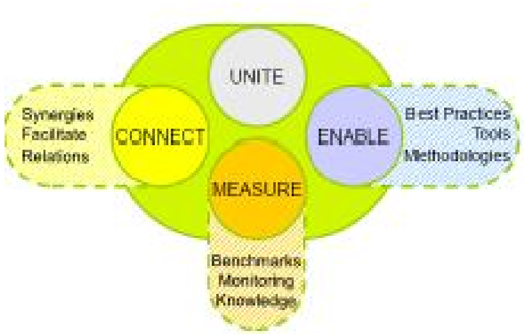
PROJECT 2
IT TECHNOLOGY TRANSFER

BILATERAL FINANCED FOUNDATION

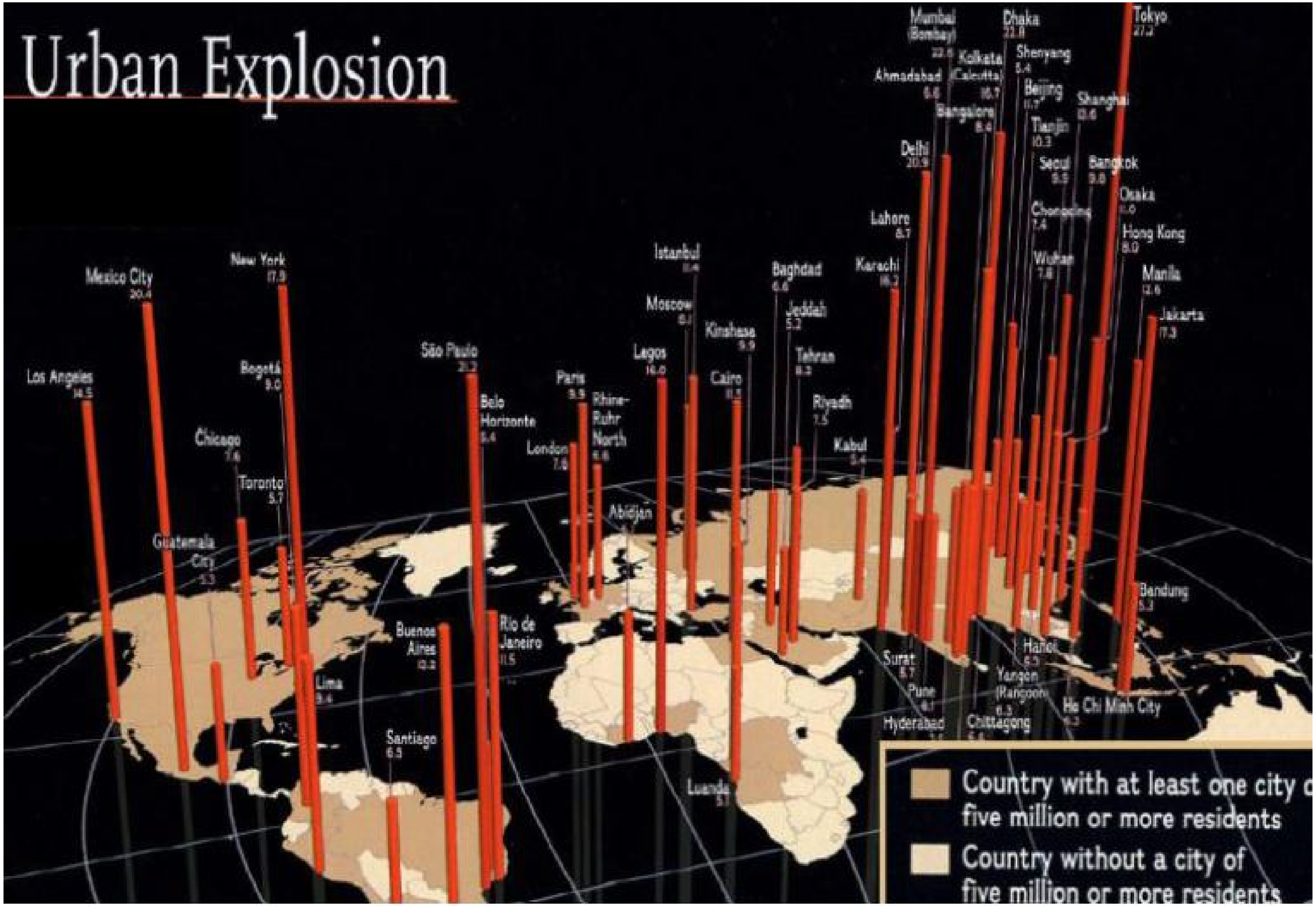
INTERUNIVERSITY COMMITTEE LADKRABANG

KMITL WORKING GROUP	SWP LADKRABANG
EDUCATION GOALS	START UP CORPORATIONS
MASTER COURSES	COMPANY A TBD
PHD TUITION	COMPANY B TBD
COURSES IN MANAGEMENT	COMPANY C TBD

2. URBAN INFRASTRUCTURE
PLANNING BETTER CITIES



- Half the world's population live in cities. By 2030 this figure will rise to 70% .
- Most cities will find it difficult to adapt to this pace of urban growth.
- Some 2 billion people are likely to reside in substandard housing and slums. Many will lack access to clean water, sanitation, education, health & decent productive work
- Cities already consume 70% of total energy output, generate 80% of all waste and contribute 60% of GHG. At the same time they are the primary victims of climate change.
- How we plan, build and manage our cities now , will determine the outcome of our efforts to achieve more sustainable and harmonious development tomorrow.



Urban Explosion
Country with at least one city of five million or more residents
Country without a city of five million or more residents

3. CHOICE of TUNNELLING METHODS

3 Challenges of the Urbanizing World are

- Population Growth,
- Environmental Risk Control
- Land Resource Limitations.

Limited land resources did become a growing challenge implying the need to be more efficient through **Urban Underground Space Use**. Influenced by short term considerations, little Technological Knowledge of how to chose **Underground Space Technology** can lead to wrong decisions.

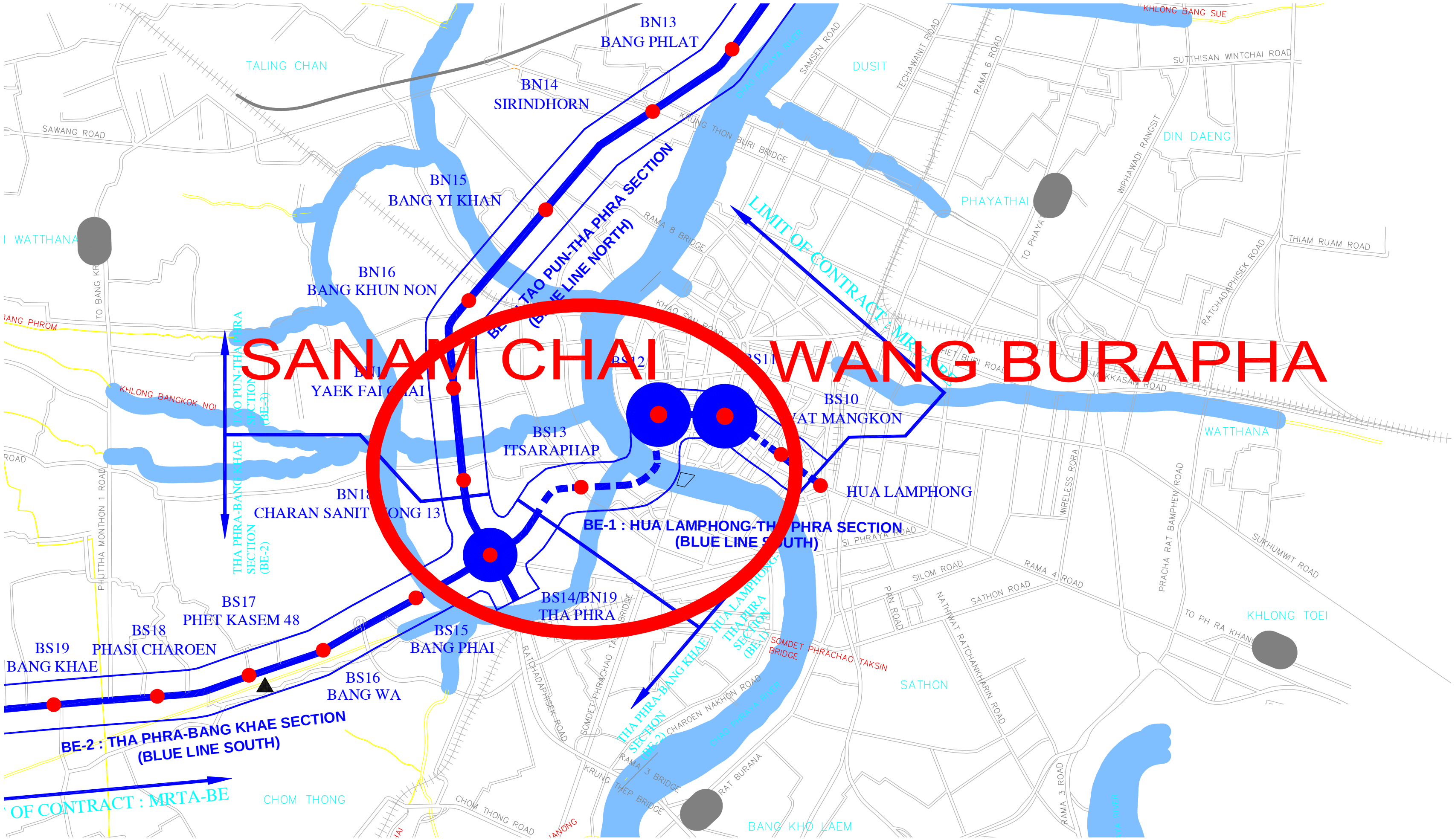
3.1 INCREASING MOBILITY OF PASSENGERS & FREIGHT

The need to add capacity in the area of both public and private transportation results from an **Increase of Mobility** of passengers and a higher volume of freight. It favors better use of urban underground space through innovations in

- Safe Energy Supply,
- Natural Disaster Prevention,
- Multiple Purpose Underground Structures,
- Intelligent Transport Solutions.

3.2 CHOICE OF TECHNOLOGIES

BANGKOK METRO BLUE LINE EXTENSION



3.3 CHOICE OF TECHNOLOGY

- **Chose** best suitable Tunnelling Method based on actual project conditions
- **Look** at Tunnel Design in the context of availability of best technological experience
- **Accept** modifications with significant contractual consequences only upon clear responsibility definitions (e.g. Value Engineering Proposals)
- **Cover** Geologic Risk in the contract and keep control above agreed client/contractor responsibilities.

4. CHOICE FOR CONVENTIONAL (NATM) TUNNELLING

- **In Theory, Conventional Tunnelling is viewing the ground around and on top of the tunnel not only as a load, but also as a load-bearing Element of Support.**
- **In Practice, Ground Reactions in form of Lining Deformations and Lining Pressures are measured to confirm stability of the excavation by frequent Monitoring.**
- **Depending on tunnels in either shallow soft ground or deep in the rock, monitoring results confirm the designed requirement for Rapid Rigid Support or Slim Deformable Support .**

4.1 GEOTECHNICAL QUESTIONS

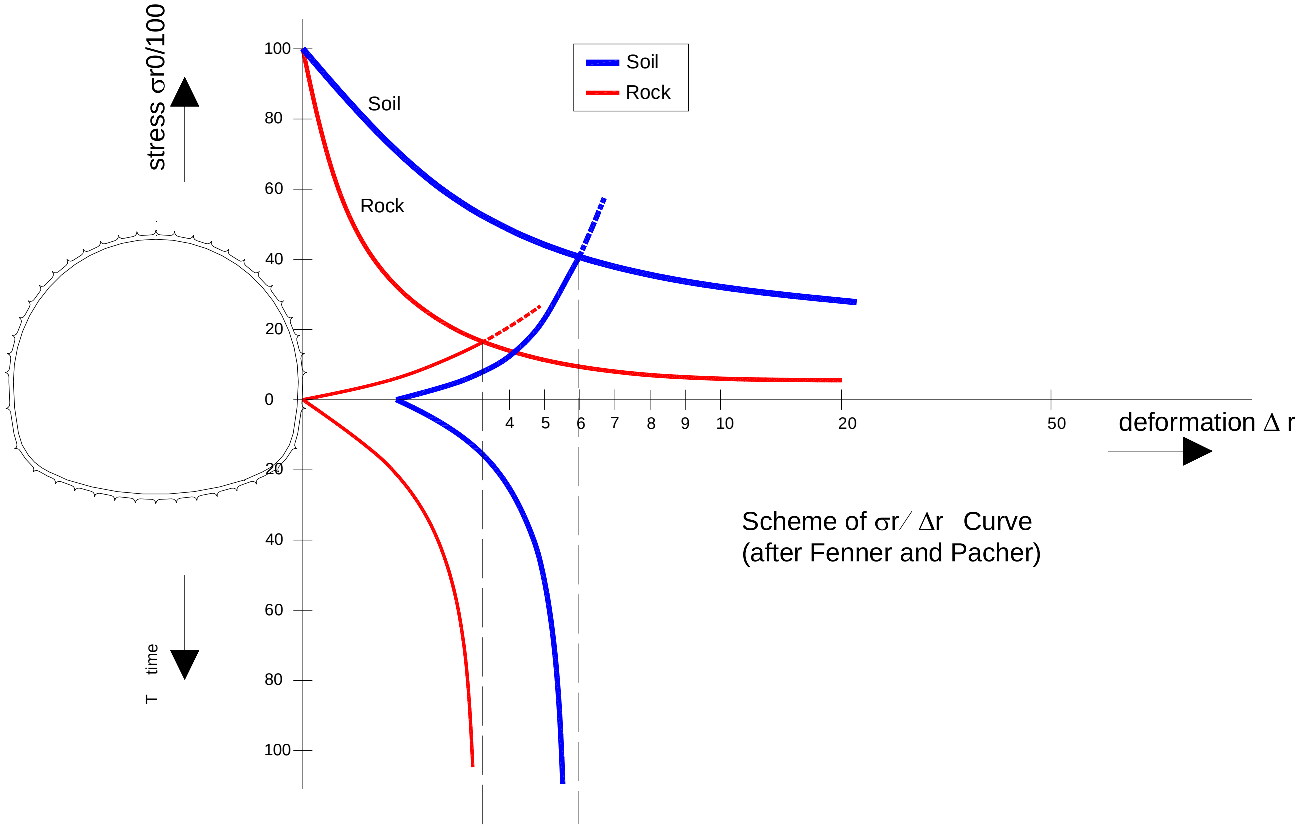
Question 1

How to achieve new ground equilibrium after excavation ?

Question 2

How to define safety of tunnel lining during and after construction?

4.2 GEOMECHANIC MODEL



Radial deformation governing size of excavation section

4.3 CTM CONTRACT CONCEPT

- Contract Arrangement shall allow for the Most Economical Design and installation of tunnel support .
- Conventional Tunnelling is originally based on a Rock Classification System related to ”stand-up time” of an unsupported section of the tunnel.
- Applicable Rock Class shall be agreed between Contractor & Engineer at the excavation face based on contractual frame-work provided by the designer and experience.

EXCAVATION SEQUENCE

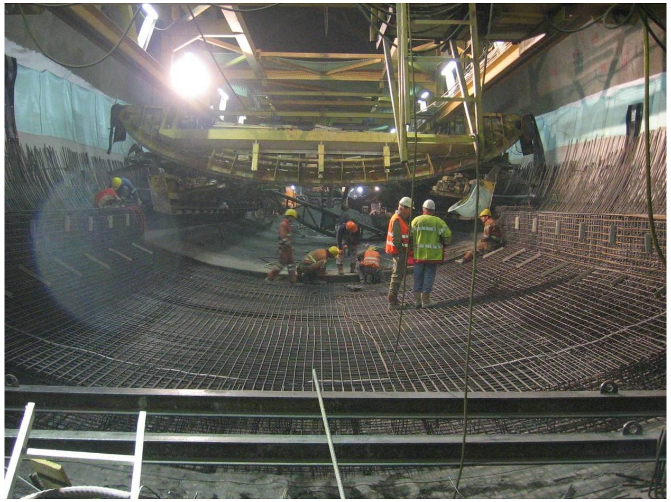
Backhoe and Shotcrete

Top Heading - Face Support

Bench Excavation

Full Cross Section

INSTALLATION SEQUENCE



Invert Reinforcement

Waterproofing Membrane

Final Lining Reinforcement

Structural Completed Tunnel

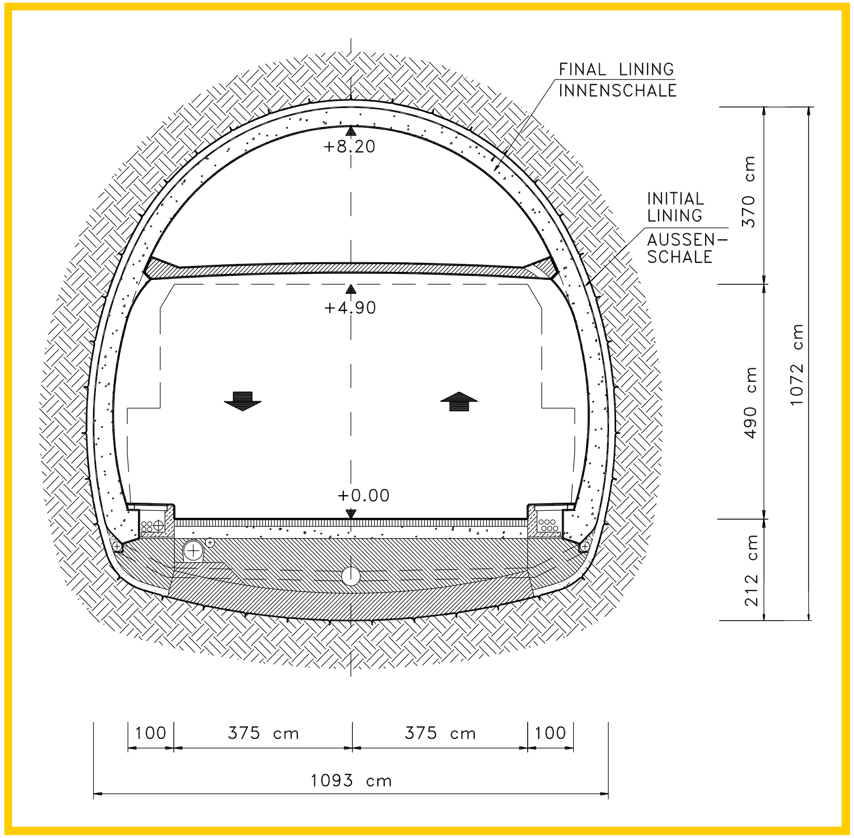
4.4 Transportation Tunnel - Design Issues

- Tunnels → Interactive Structures
- Ground Forces → Deformations
- Traffic Load → Ventilation
- Structural Components → Soil and/or Rock

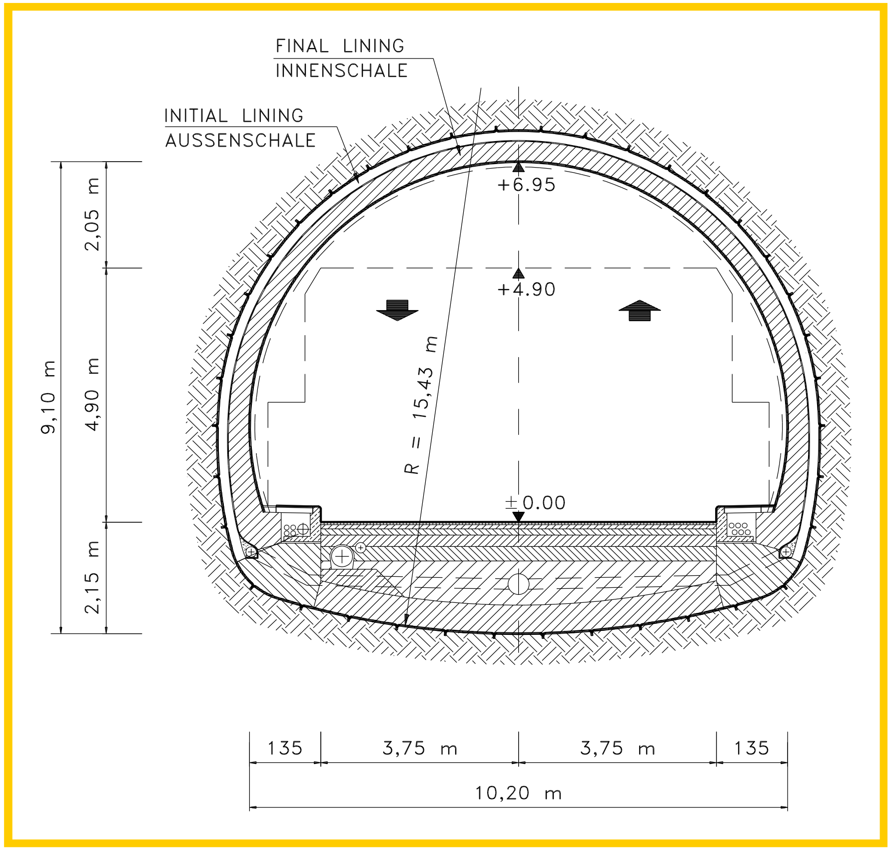
4.5 Transportation Tunnel - Operation Issues

- **Rock Pressure** → can crack tunnel lining
- **Water** → can damage tunnel drainage
- **Operation** → creates constraints
- **Repair** → structural constraints
- **Safety** → risk of increasing traffic

VENTILATION – Shaping Tunnel Roof

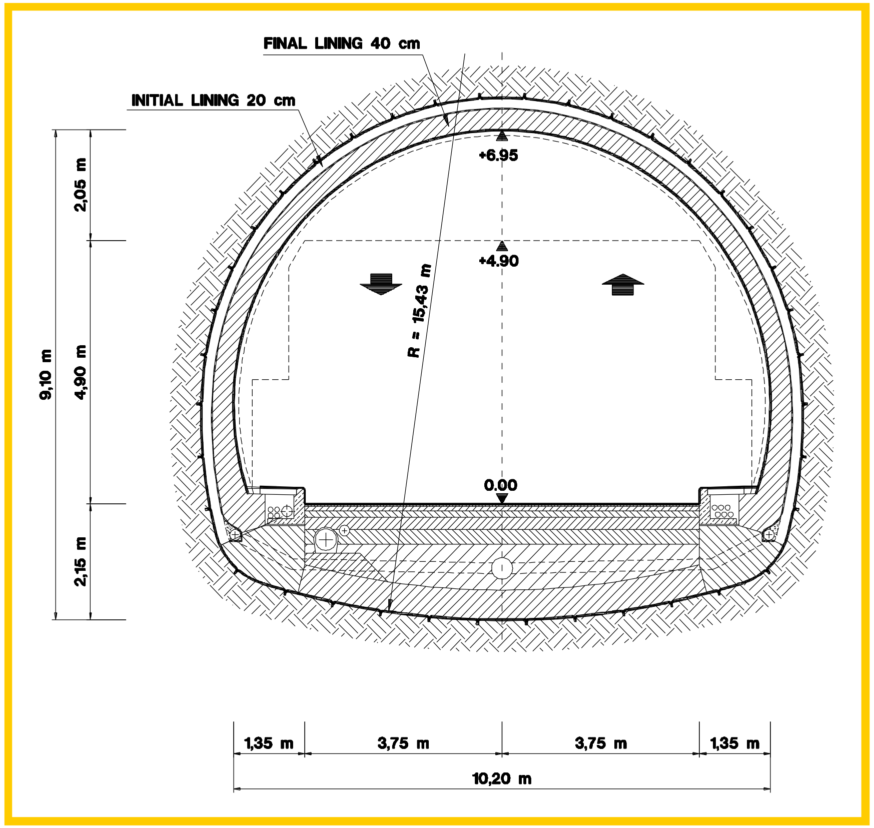


Transversal Ventilation

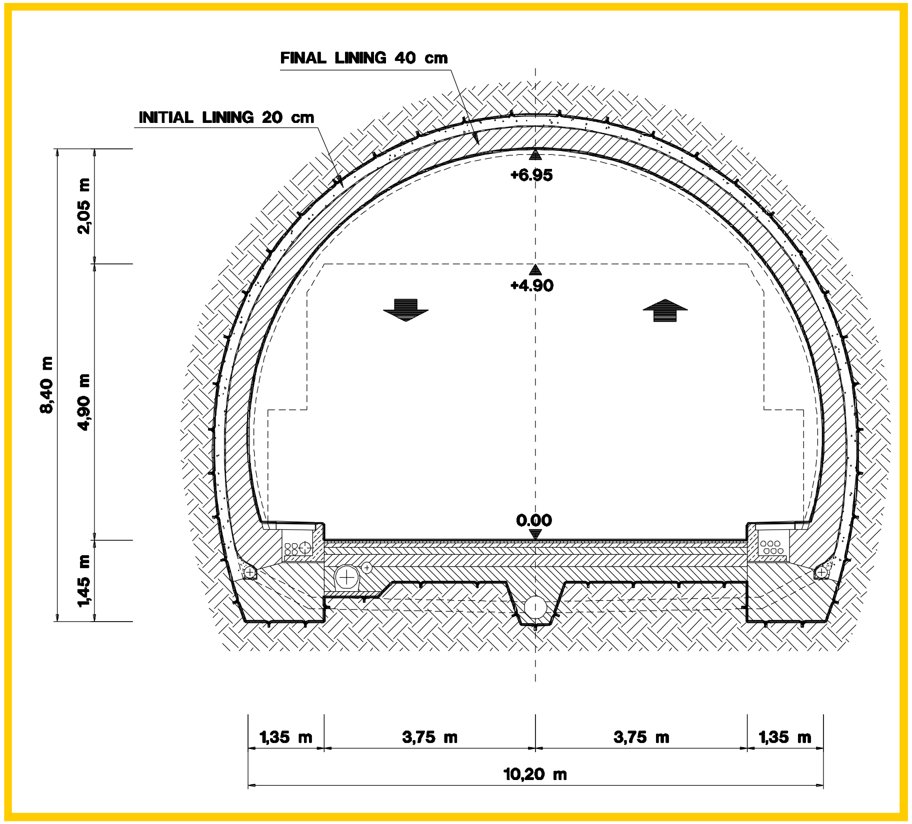


Longitudinal Ventilation

GEOLOGY - Shaping Cross Section



Soft Ground – Arched Invert



Hard Ground – Flat Invert

X - SECTION DESIGN

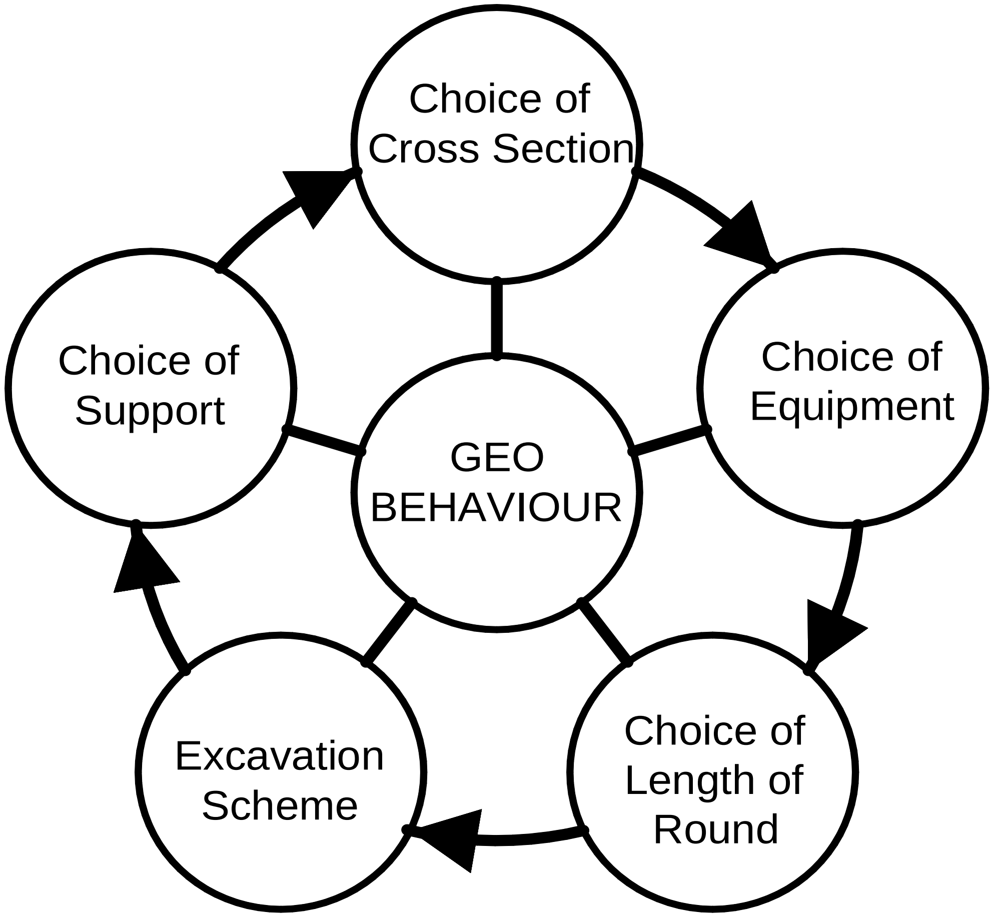
- **Approach**
  Geometry through Evaluation of Soil and Rock Parameters
- **Combine**
  - Structural Arches made of concrete with
  - Natural Arches made of ground
- **Create Sensitivity for Deformations through**
  - Prediction in Design
  - Control in Construction
  - Evaluation of Safety

PROJECT PREREQUISITS

- Geotechnical Baseline Report (GBR)
- Ground Behaviour Report
- Ground Support
  - Initial Shotcrete Lining
  - Final Lining
  - CIP Concrete or
  - Shotcrete of Final Durability

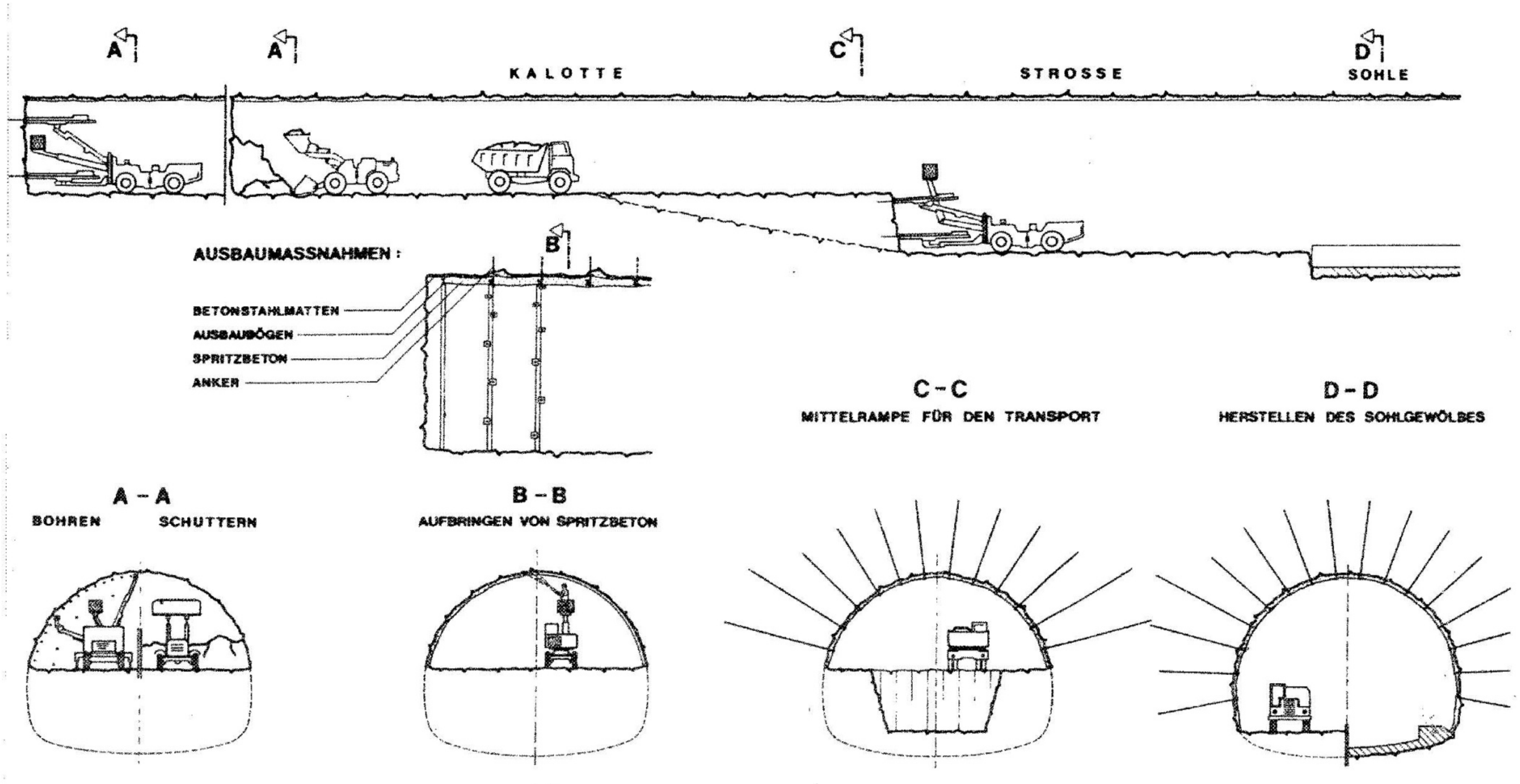
Lainzer Tunnel - Cross Passage

4.6 INTERDEPENDENT CHOICES IN CONSTRUCTION

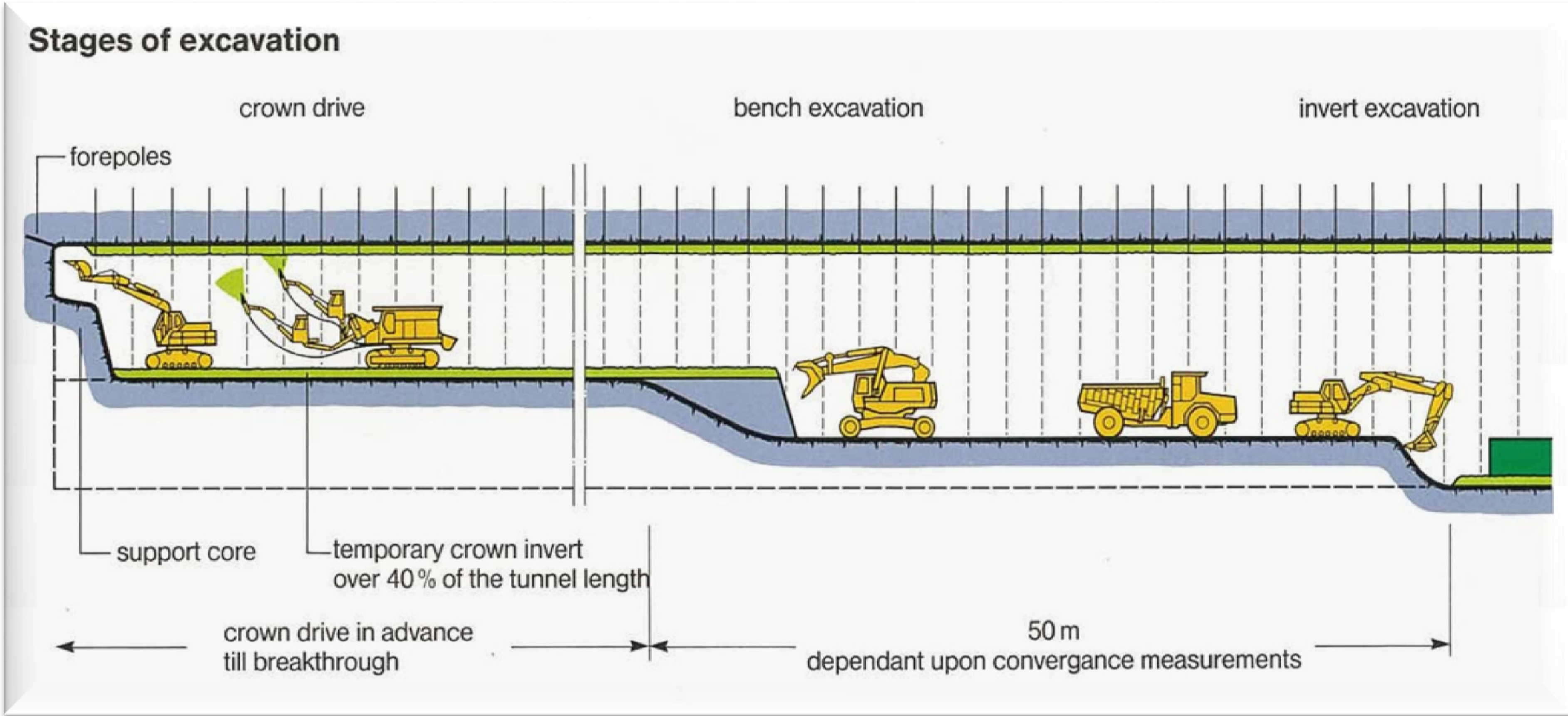


Ground Behaviour determines need for Ground Support

EXCAVATION SECTION SEQUENCE

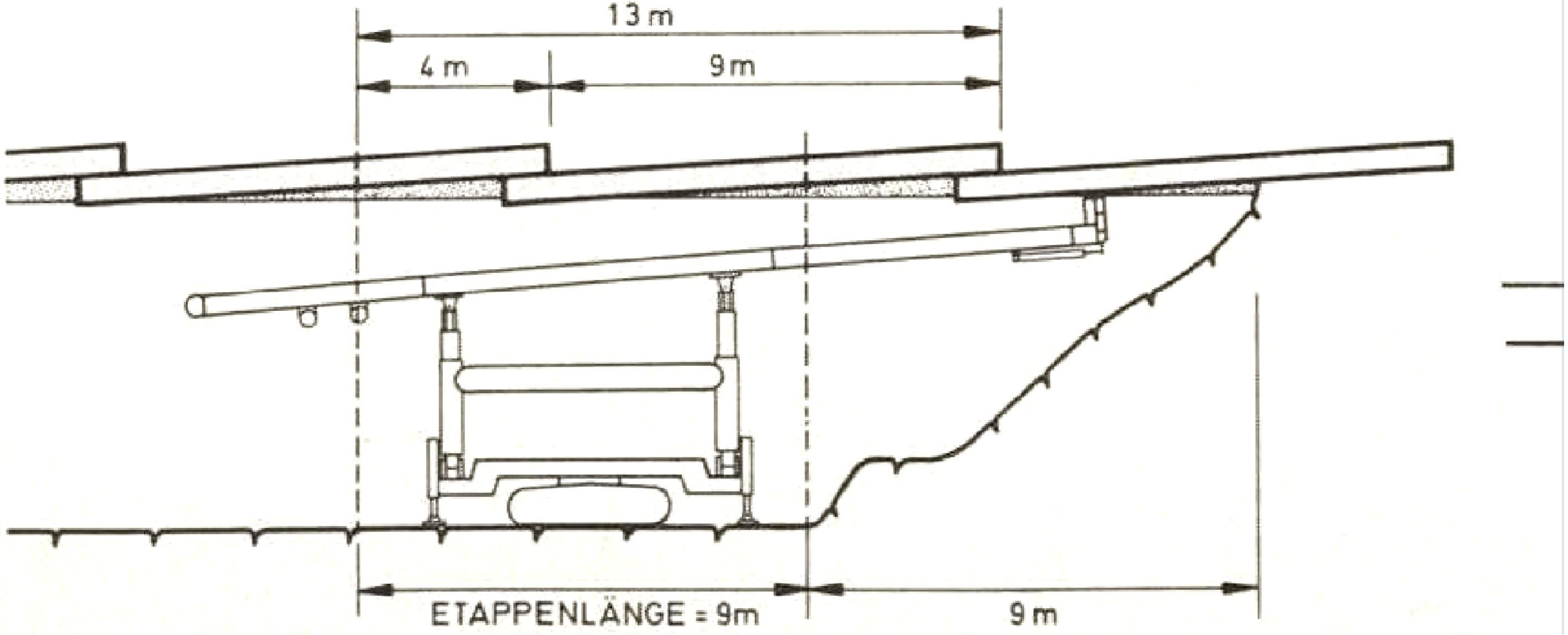


INSTALLATION OF SUPPORT SEQUENCE



FACE PROTECTION UMBRELLA

PRERUNNING & OVERLAPPING MEANS



MEANS & MEASURES of SUPPORT

Horizontal Jet Grouting

Roof Pipe Installation

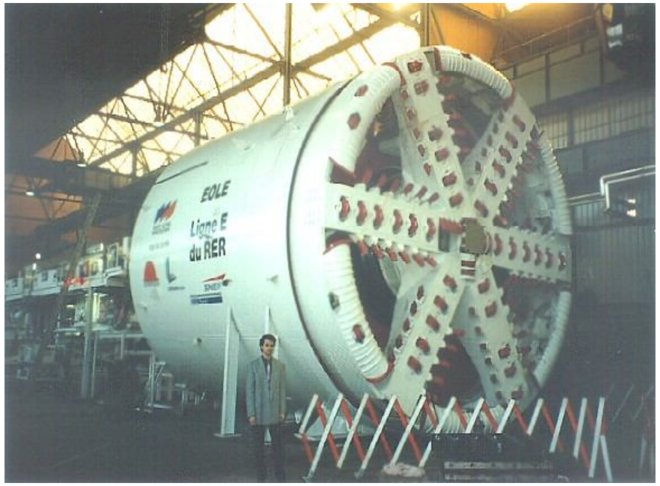
Excavation beneath Pipe Roof

Multiple Drift Excavation

4.7 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**

5. CHOICE FOR TBM TUNNELLING



Polyshield TBM EOLE Paris

Groene Hart TBM

Boston Harbour Outfall Tunnel

Testing Segment & Ring Geometry

5.1 VIEWING at TBM TUNNELLING

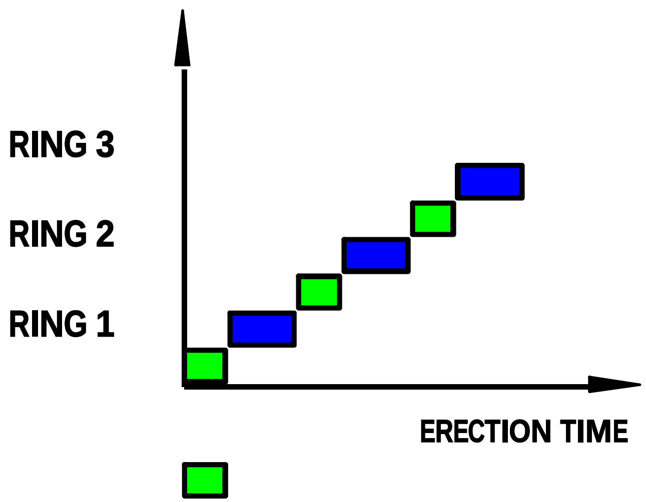
- **Geology** - **Less adaptable**
- **Progress** - **Better Rates**
- **Operating Mode** - **Continuous**
- **Tunnel Length** - **Extended**
- **Tunnel Diameter** - **Fixed**
- **TBM Equipment** - **Shielded**

TBM APPLICATIONS

- Single/Double Track Railway Tunnel
- Multiple Lane Highway Tunnel
- Double Deck Tunnel
- Water Tunnel
- Utility Tunnel

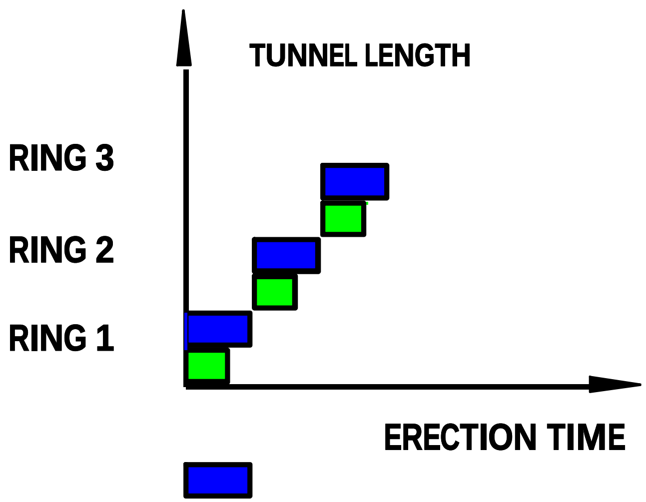
5.2 TBM OPERATION MODES

"SERIAL" TUNNELLING



EXCAVATION TIME PER RING

CONTINUOUS TUNNELLING



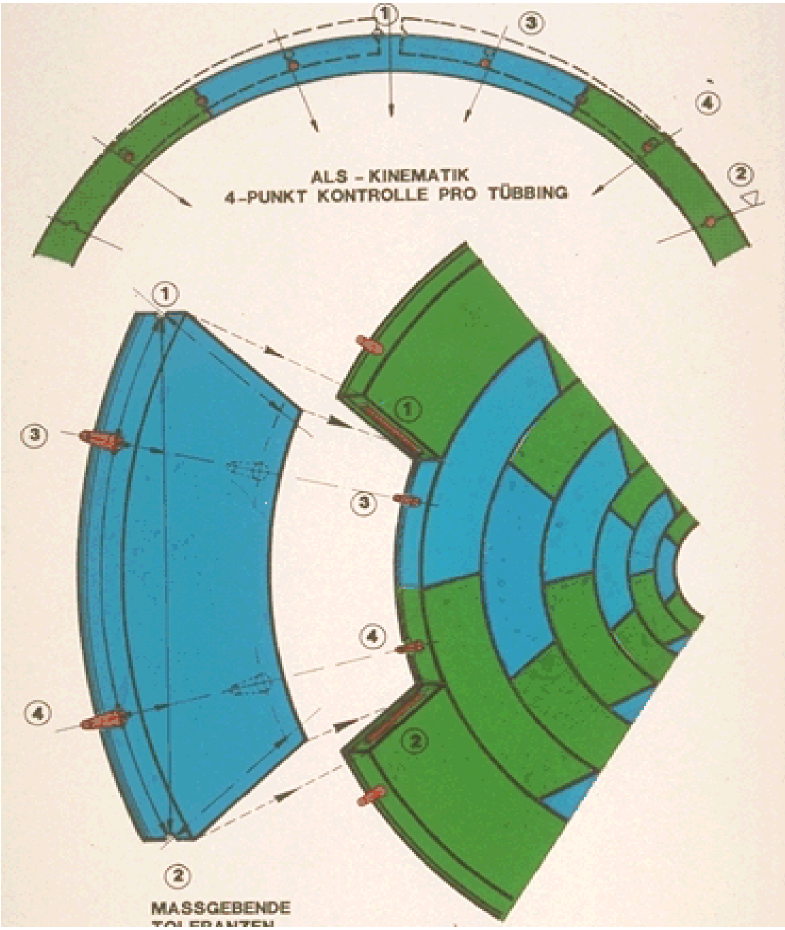
INSTALLATION TIME PER RING

$$T_{E,C} = 0,5 \, . \, T_{E,S}$$

CONTINUOUS TUNNELLING MODE

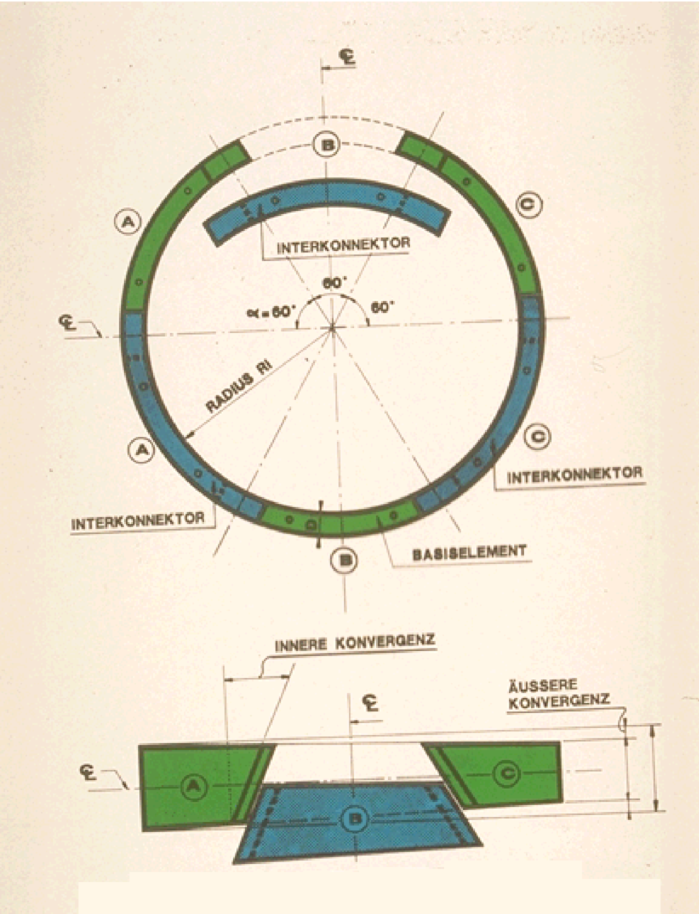
- **Excavation & Ring Erection – Simoultaneous**
- **Thrust Length – approx. 2 x Ring Width**
- **Key Stone Installation – in circumference at any location**

CONTROLLED KINEMATIC



- **Offsets** - minimized
- **Ovalization** - minimized
- **Assembly** - symmetric
- **Ring Rotation** - any
- **Tolerance** - no cumulation

KEY-STONE PARAMETERS
for continuous tunnelling



- Ring **Width**
- Ring **Partition**
- Segment **Thickness**
- Inner **Convergency**
- Thruster **Stroke Length**
- Thruster **Shoe Size**
- Joint **Design**

5.3 UNIVERSAL SEGMENT DESIGN FEATURED BY

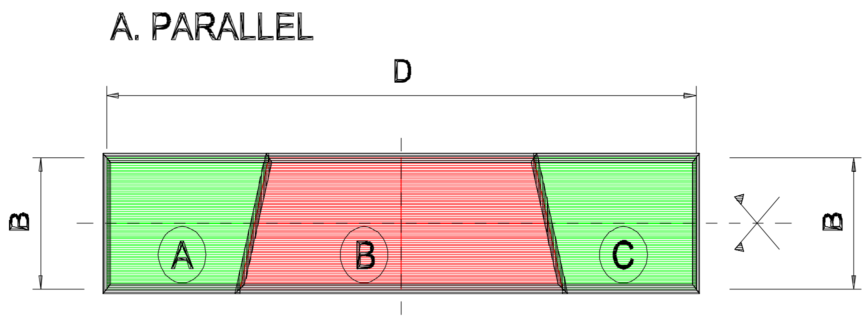
- Ring Partition
- Ring Width
- Outer Convergency
- Inner Convergency
- Chamfer configuration
- Radial joint
- Circumferential joint
- Key Stone condition

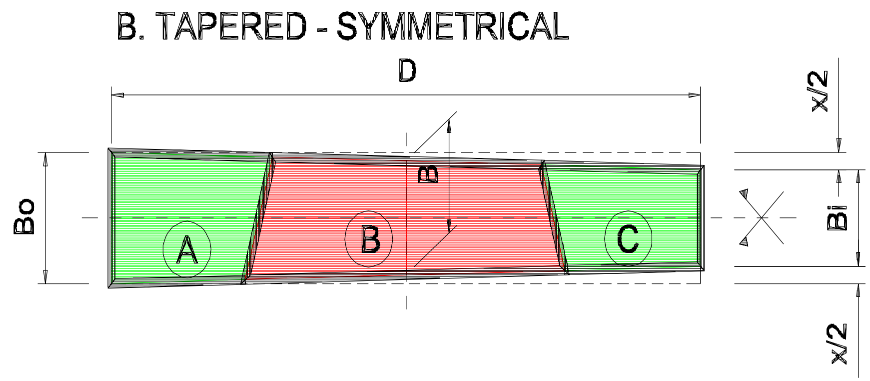
UNIVERSAL RING ADVANTAGES

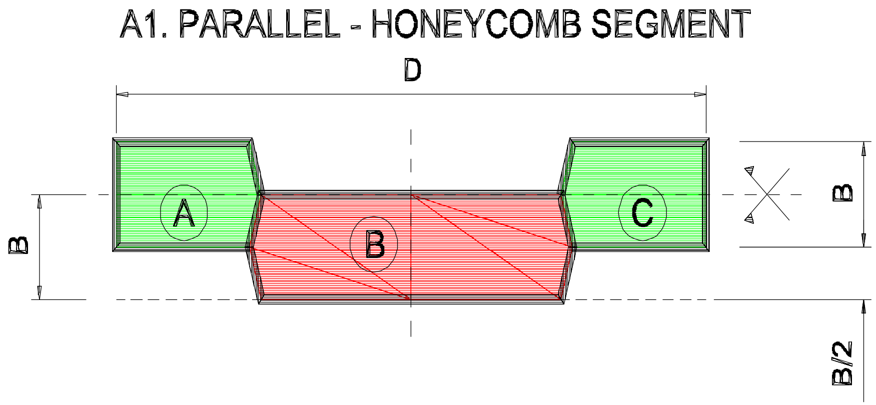
- Construction Time Reduction
- Personnel Reduction
- Repair Cost Reduction
- TBM Stop Reduction
- Equipment Depriciation
- Organization Simplification

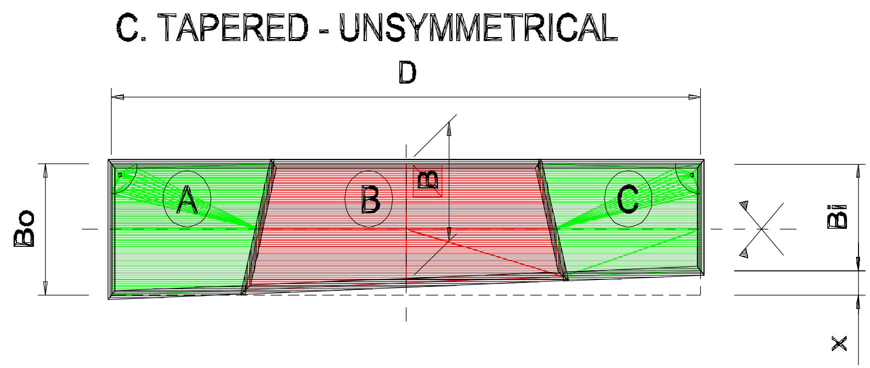
- Production Simplification
- Assembling Precision
- Construction Simultanity
- Assembling Time Reduction
- Finishing Reduction
- Mould Cost Reduction

UNIVERSAL RING TYPES





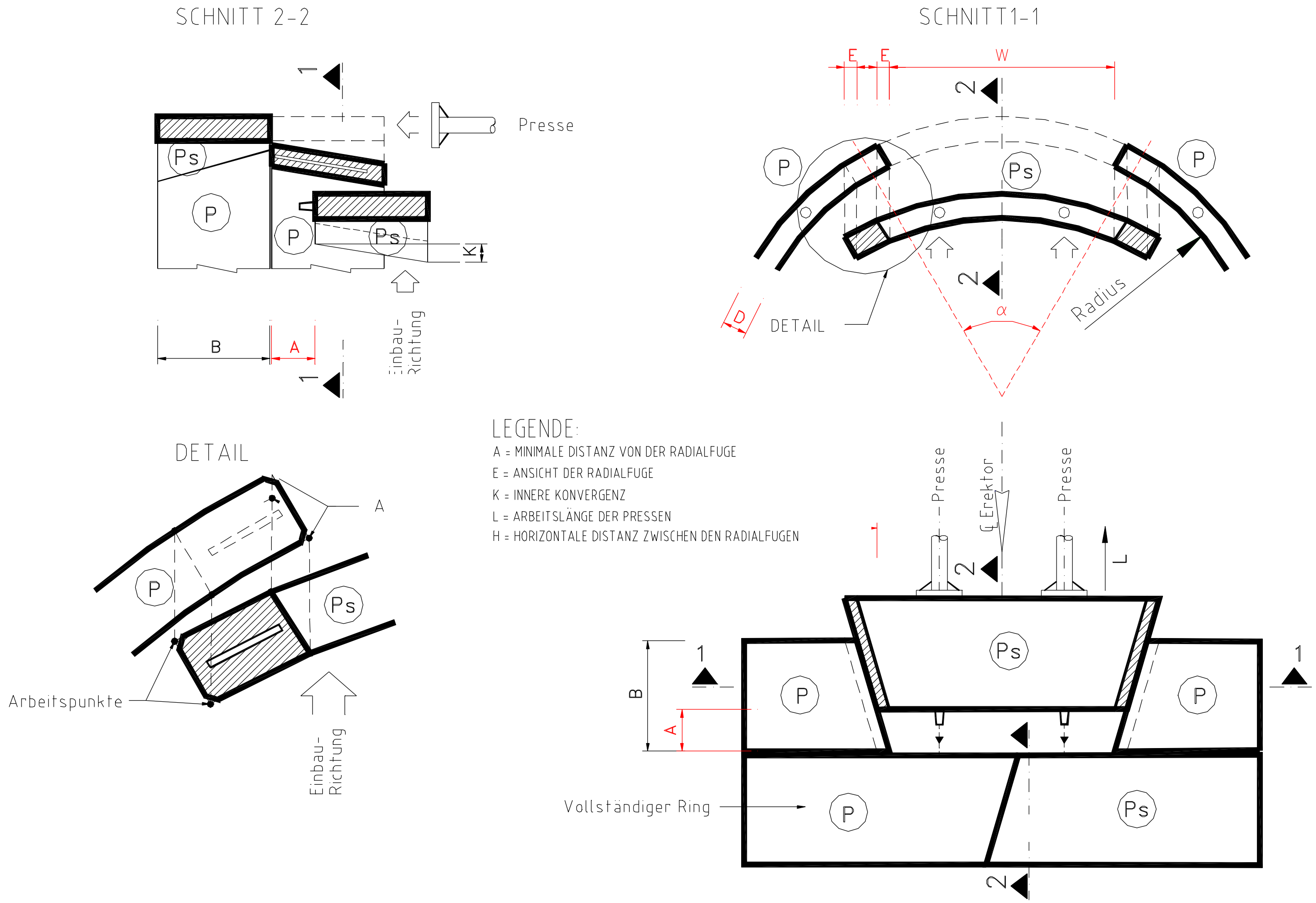




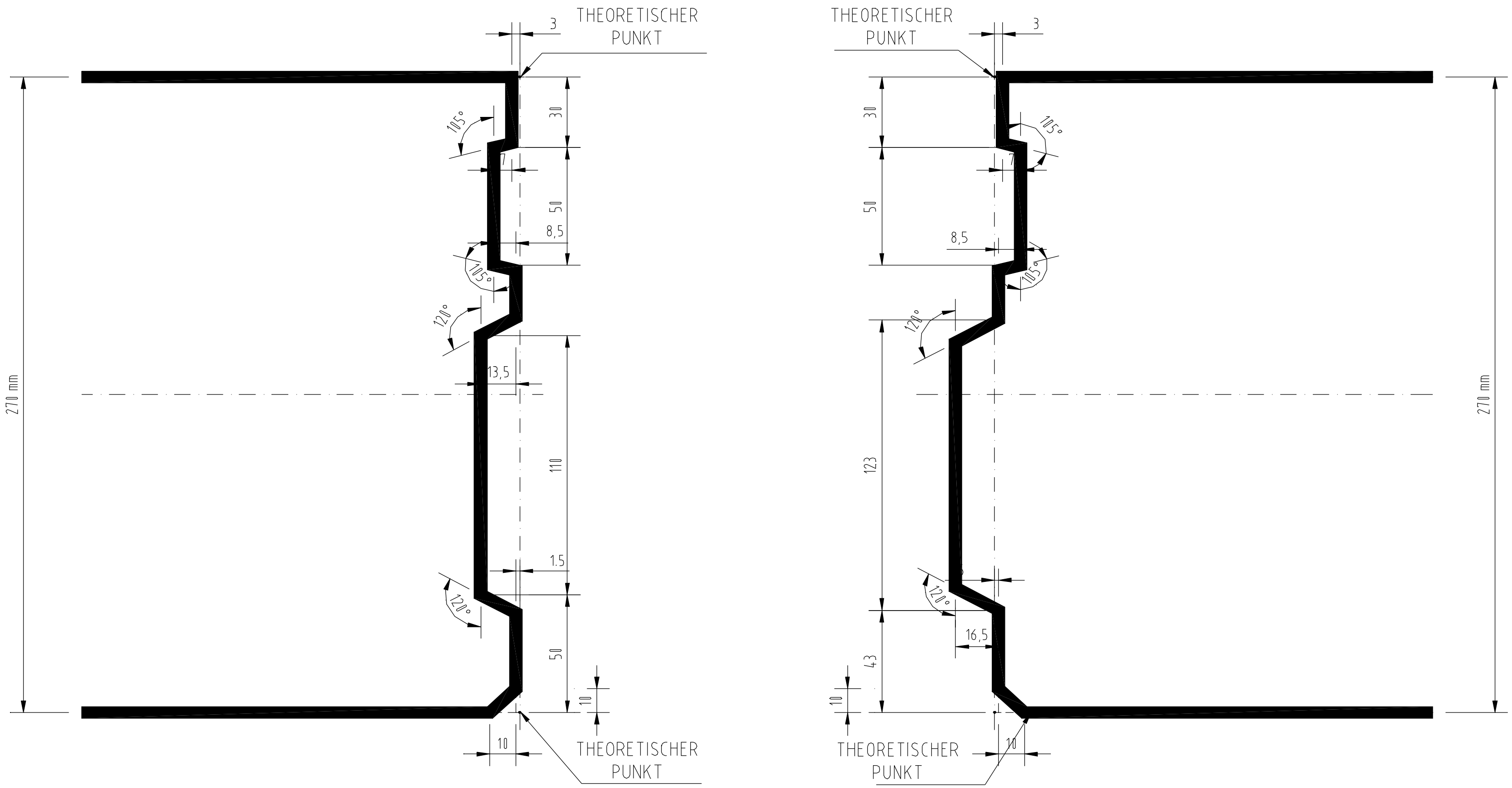
5.4 SEGMENT DESIGN DEFINED BY

- **Thickness due to structural needs**
- **Width due to space in rear of TBM**
- **Partition due to thruster jacks**
- **Shape due to designer‘s experience**
- **Weight due to ring erector**

KEY STONE CONDITIONS

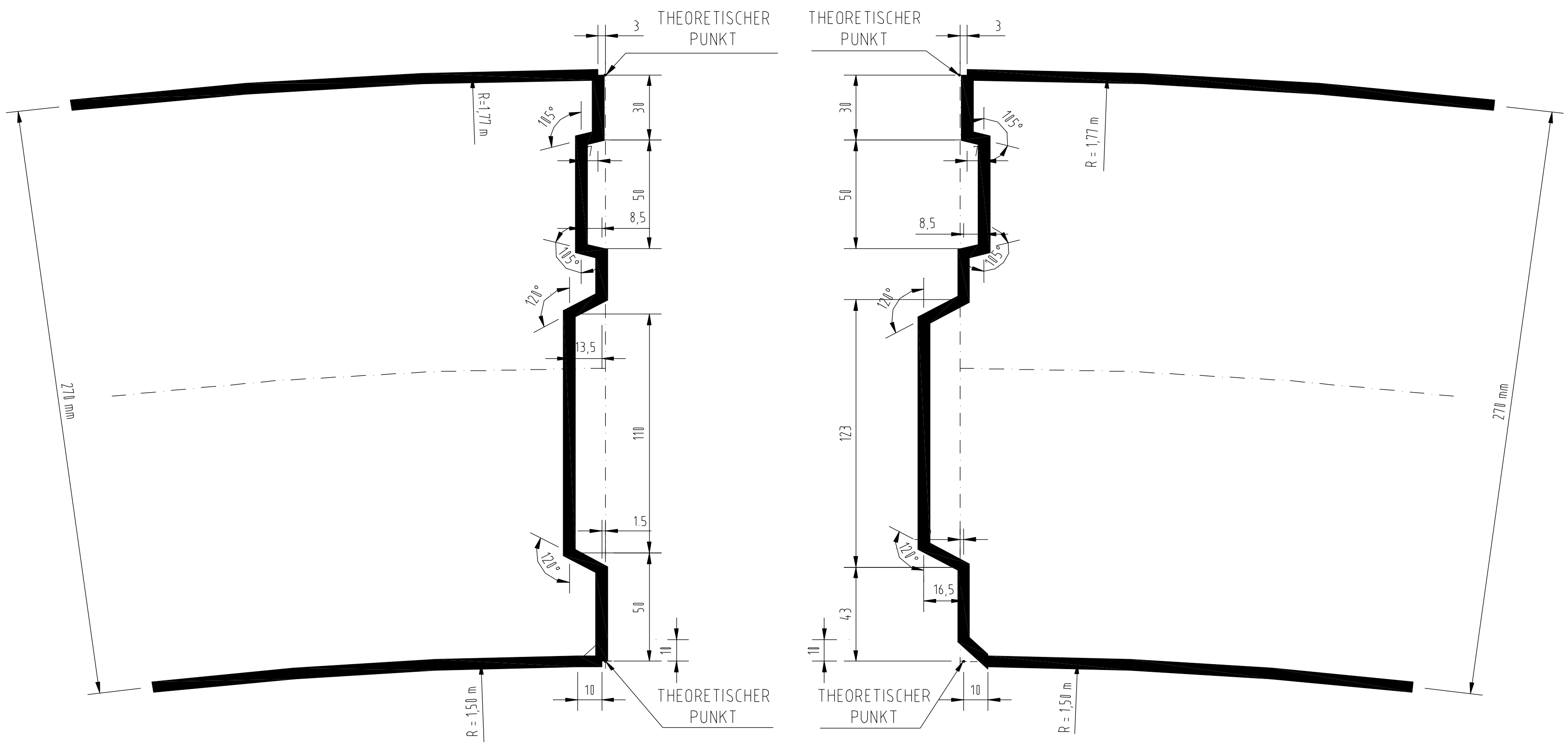


CONSERVATIVE T&G JOINT DESIGN



Circumferential Joint for water tunnel in soil

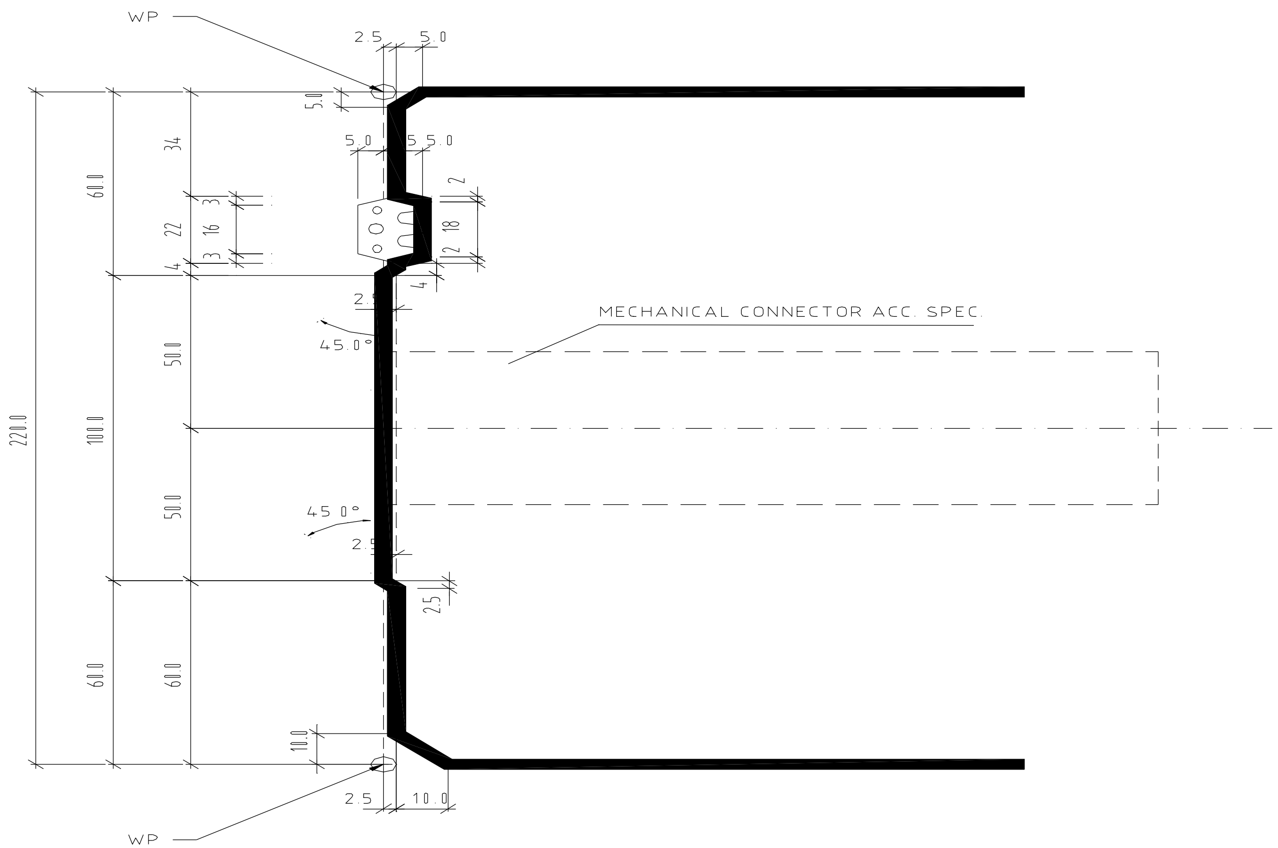
CONSERVATIVE T&G JOINT DESIGN



Longitudinal Joint for water tunnel in soil

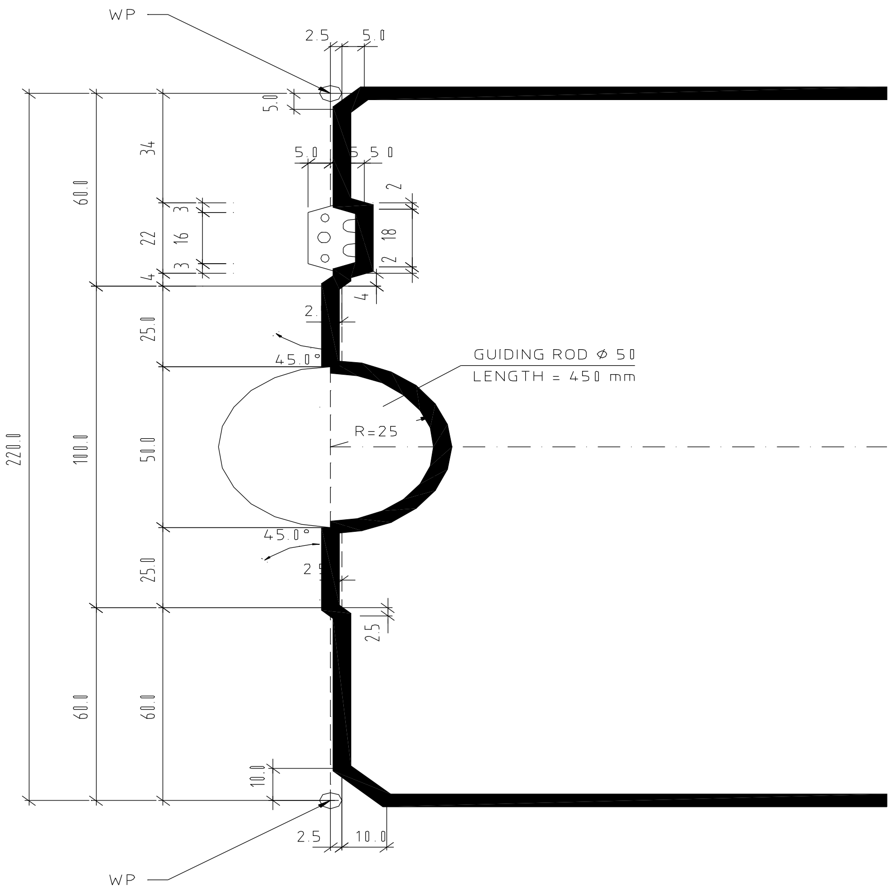
CIRCUMFERENTIAL FLAT JOINT DESIGN

ADVANCED JOINT DESIGN



Circumferential Joint for water tunnel in rock (WYRDPC)

LONGITUDINAL FLAT JOINT DESIGN



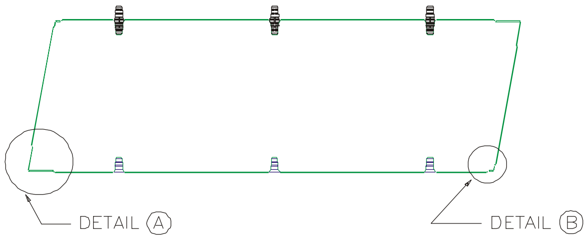
Longitudinal Joint for water tunnel in rock (WYRDPC)

ADVANCED FLAT JOINT DESIGN

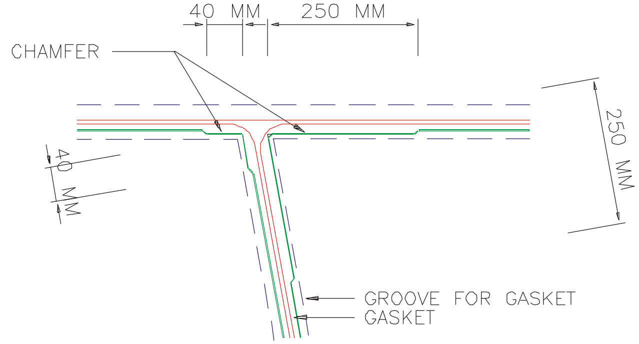
View of finished tunnel with flat joint design (WYRDPC)

CHAMFERED CORNER DESIGN

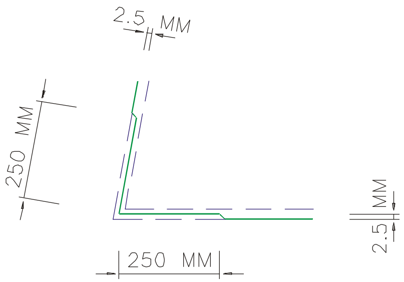
TYPICAL CHAMFER GEOMETRY



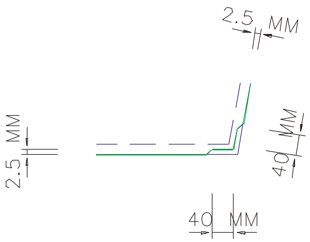
GASKET AT CHAMFER CORNER



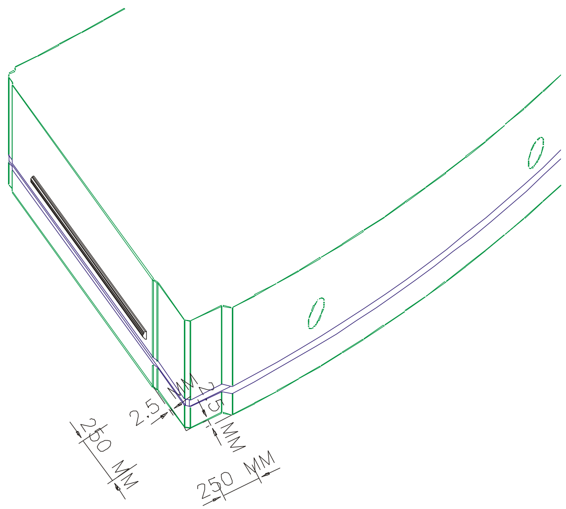
DETAIL (A)



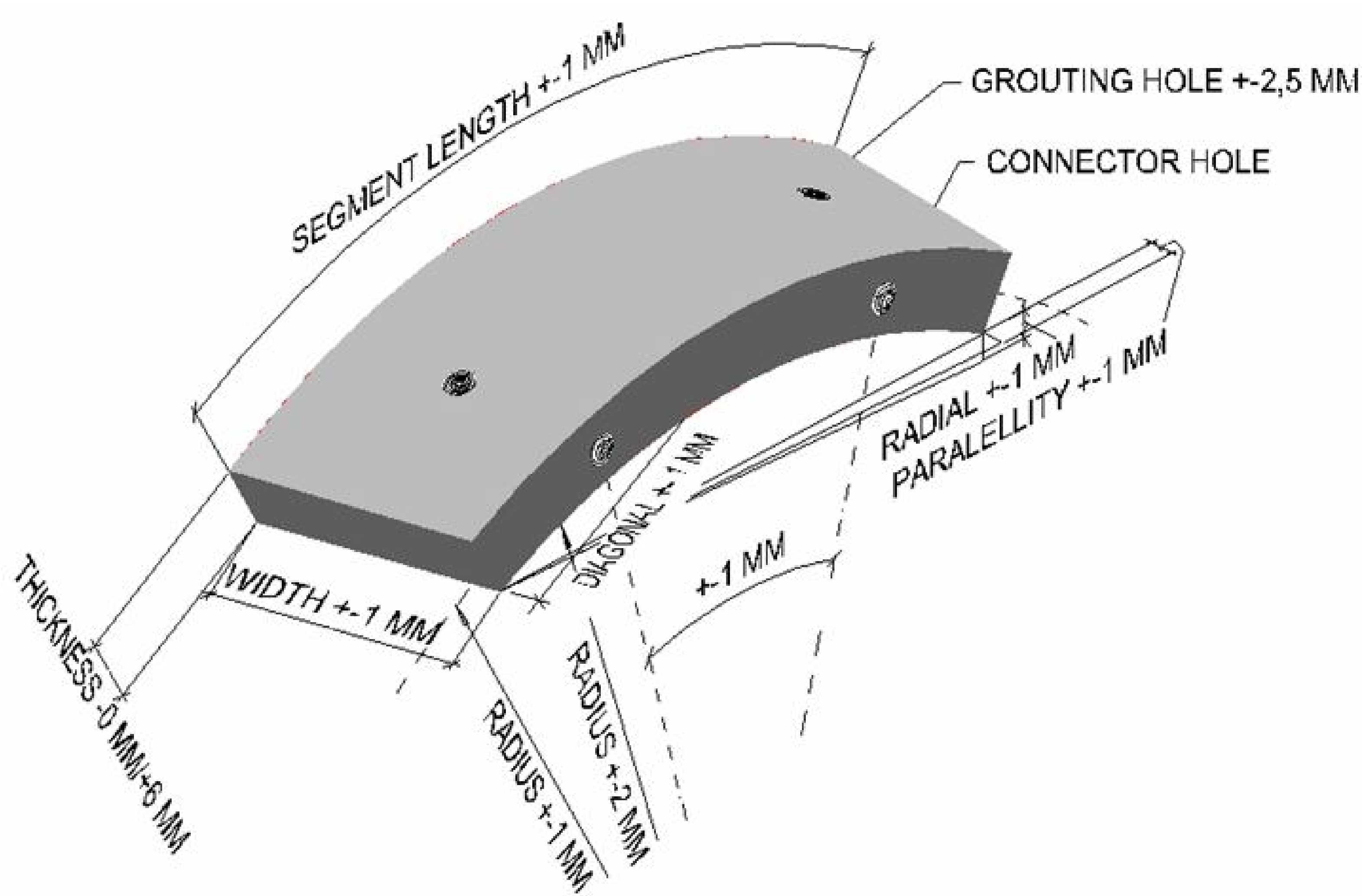
DETAIL (B)



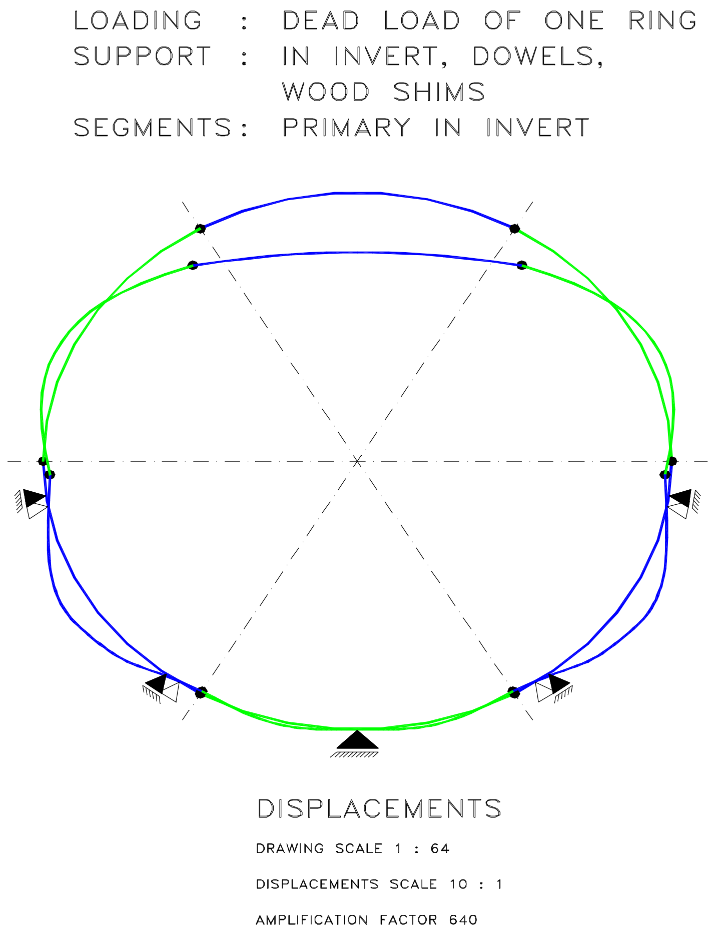
SEGMENT WITH IMPROVED CORNER



SEGMENT PRODUCTION TOLERANCES

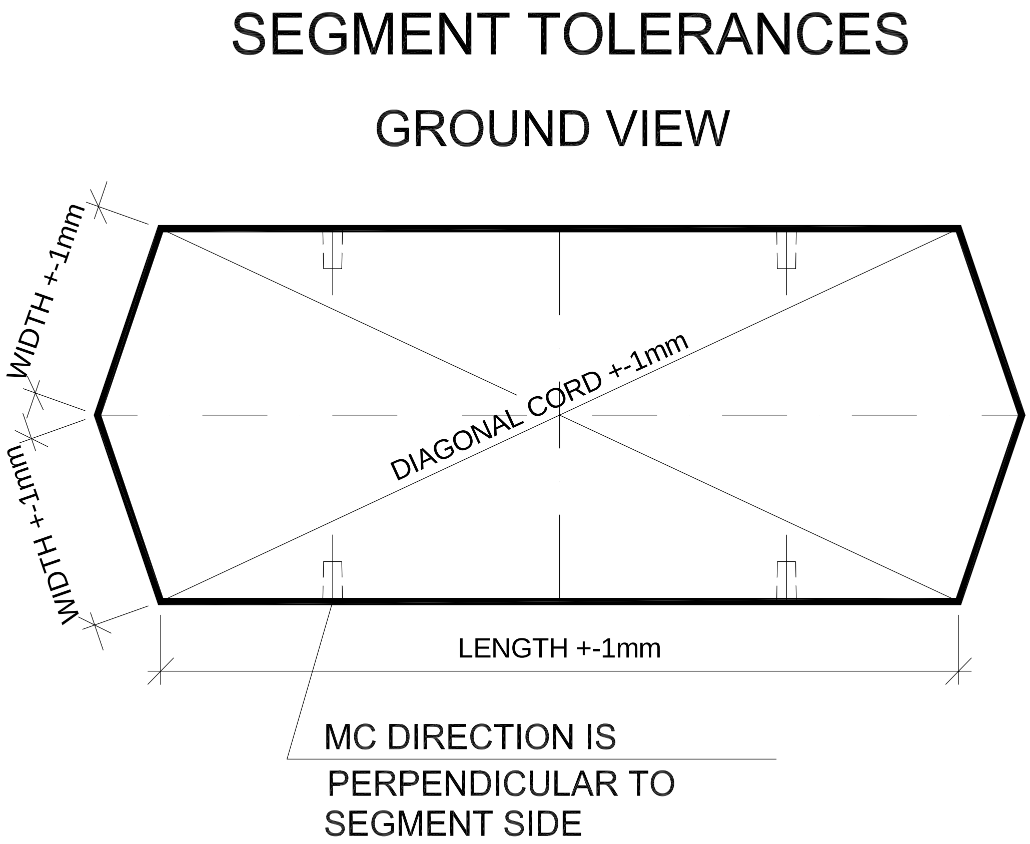


RING DISPLACEMENTS (OVALIZATION)



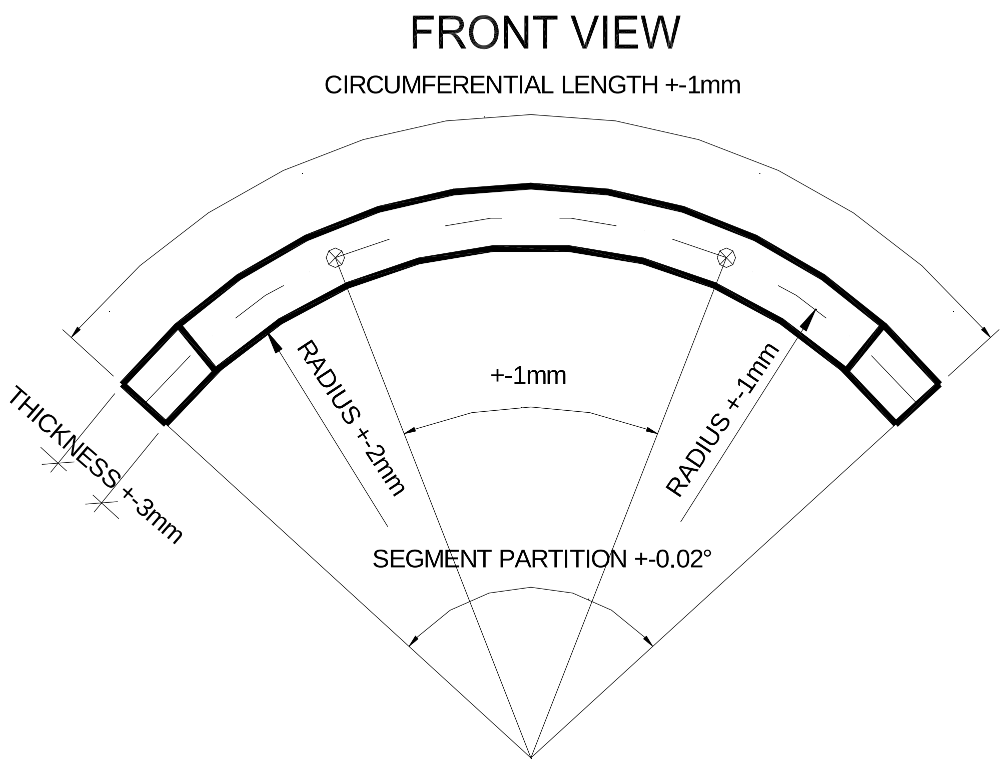
Schematic view of Ovalisation

LINING DIMENSION TOLERANCE



Segment Tolerances - allowable tolerance in production

LINING CURVATURE TOLERANCE



Allowable segment tolerances in production

5.5 TBM / LINING - INTERFACE

- **Tunnel** of justifyable length for use of TBM
- **Designers** of TBM & Lining to fix concept prior to start of works
- **Experience** of Designers to show minimum 10 years
- **Generic Design** by Client to specify TBM and lining
- **Responsibilities** to be specified at interface of TBM & Lining

5.6 RECOMMENDATION TO FOCUS ON

- **Joint Details**, Reinforcement and Joint Connectors in Segment Design

- **QA/QC measures**, e.g. on precasting and installation,

  Mould & Lining Tolerances
- **Erector Capabilities**

  - Learning-curve phase

  - Sensitivity and installation precision

5.7 GROENE HART

Railway Tunnel Netherlands (2000 – 2004)

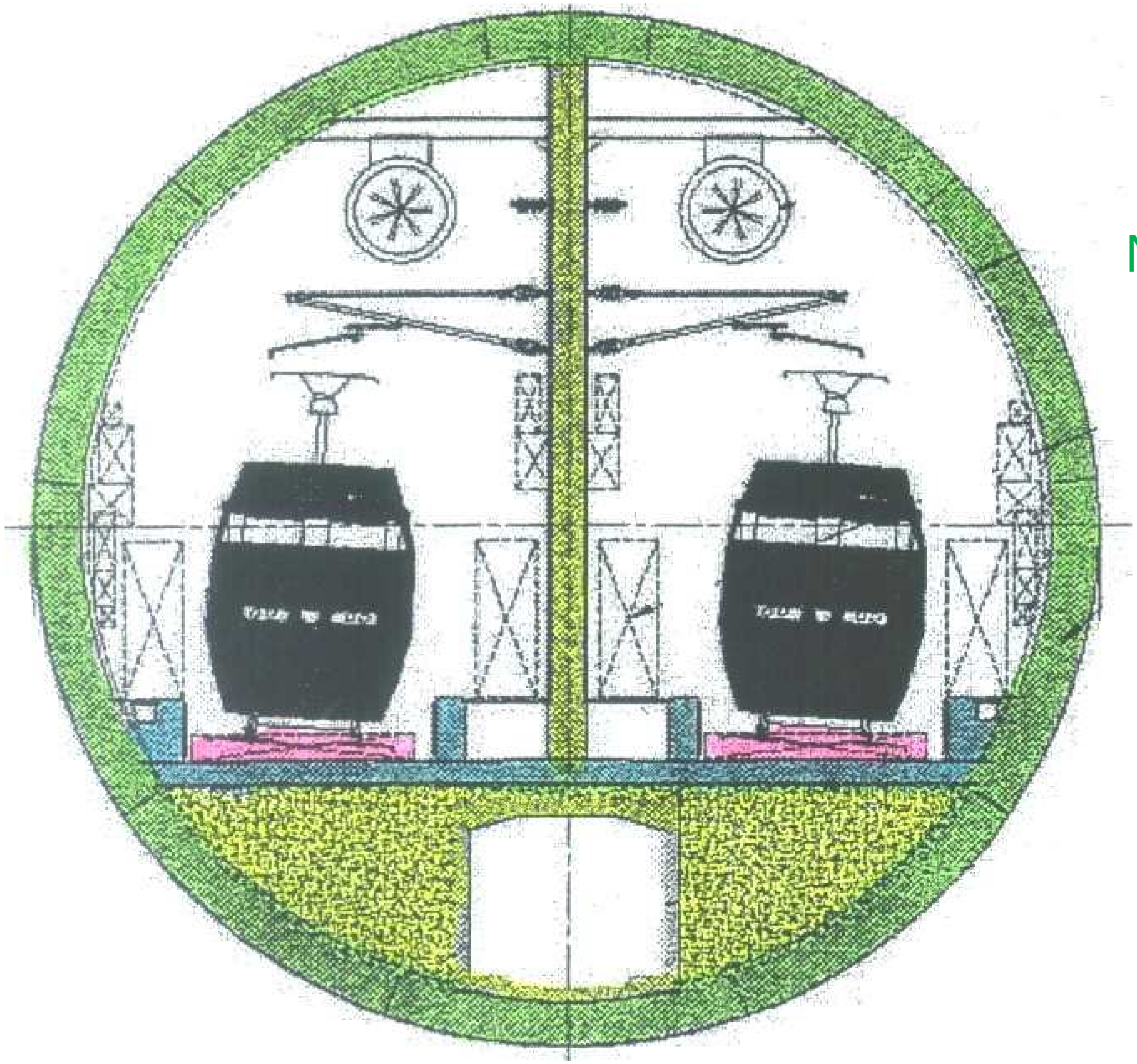
Project length	8608 m
Bored part	7160 m
Geology	10 - 15 m layer of soft clay and peath, very low strength
Machine	slurry shield with hydraulic mucking out technique

GROENE HART

Railway Tunnel Netherlands (2000 – 2004)

Mono Tube or Double Tube

- **Cost, Schedule & Risk Advantages**
- **Cross Passage Elimination**
- **Access Works Reduction**
- **Inter-tunnel Communication Improvement**
- **Environmental Advantages**



GROENE HART Railway Tunnel

Netherlands (2000 – 2004)

Cross section of monotube tunnel with partition wall

6. TUNNEL DESIGN GUIDANCE

Tunnel Design has 4 stages

- **Conceptual** Design
- **Preliminary** Design
- **Tender** Design (detail design phase 1)
- **Construction** Design (detail design phase 2).

Conceptual Design Frame

- **Select** alignment of tunnel
- **Confirm** alignment of tunnel
- **Provide** client with information for budgeting
- **Combine** with Preliminary Design

6.1 Conceptual Design

- **Verify** the scope of conceptual design
- **Select** preferred alignment from alignment studies
- **Develop** geotechnical characteristics from geological and hydrological information
- **Validate** anticipated construction including environmental aspects
- **Estimate** conceptual cost
- **Produce** construction schedule
- **Develop** ventilation scheme (if necessary)

Preliminary Design Frame

- **Priority** of Preliminary Design stage is focused on the legal aspects of water resources, forestry and nature protection.

- **Target** is to receive approval for construction of the project by the authorities.

- **Combination** with Conceptual Design possible.

6.2 Preliminary Design

- **Evaluation** of site investigation and lab test results
- **Identification** of portal locations, design of portal structures and slope design for portal cut
- **Development** of typical cross sections
- **Decision** on tunnel advance methods
- **Tunnel waterproofing** and drainage concepts
- **Construction concepts**, water and power supply, location of construction roads and muck depots
- **Detailed** construction programme
- **Revised** cost estimate

6.3 Tender Design

- **Scope of Tender** design is to detail the works in such a way that exact pricing of each work item is feasible.
- **Detail design** of all structures and incorporation of latest project developments, results of additional site investigations and requirements by the authority.
- **Update of geotechnical prognosis**, support measures drawings, distribution of support classes, detailing of auxiliary construction methods and provision of information as required by the national standards and guidelines

6.4 Final Design

- **The scope** of the construction design is the detailing of the work described in the tender stages in such a way, that they can be constructed.
- **Adaptation** of detailed design of excavation and support methods to the geological / geotechnical conditions encountered in-situ is target of of conventional tunnelling.
- **Production** of design drawings for construction
- **Consideration** of geological / geotechnical conditions encountered in-situ are targets of conventional tunnelling contracts

6.5 Geotechnical Design

- **Rock Mass Types** (RMT)
- **Rock Mass Behaviour Types** (BT)
- **Excavation Classes** based on behaviour types and excavation and support methods
- **Baseline construction plan** describing the expected rock mass conditions, assumptions, and the boundary conditions of the design
- **Results** of all phases of the geotechnical design have to be summarized in the geotechnical report.

Geological-Geotechnical Design – Design Phase

- Step 1: Determination of Rock Mass Types
- Step 2: Determination of Rock Mass Behavior Types
- Step 3: Determination of the excavation and support
- Step 4: Geotechnical report-baseline construction plan
- Step 5: Determination of excavation classes

Geological-Geotechnical Design - Construction Phase

- Step 1 – Determination of the encountered
  Rock Mass Type
- Step 2 – Determination of the actual
  Rock Mass Behavior Type
- Step 3 – Determination of excavation and
  support
- Step 4 – Verification of System Behavior

6.6 Geotechnical Construction

- **Rock Mass Parameters** have to be collected on site, recorded, and evaluated to determine the rock mass type
- **Monitoring Data** together with the rock mass type allows the behaviour type to be determined
- **Excavation and support measures** have to be chosen based on the criteria laid out in the baseline construction plan and the safety management plan

6.6.1 Geotechnical Baseline Report

- **Summary** of the results of geological and geotechnical investigations, and the interpretation of the results
- **Description of the Rock Mass Types** and the associated key parameters
- **Description of the Rock Mass Behavior Types**, the relevant influencing factors, the analyses performed, and the geotechnical model on which the BT is based
- **Determination of Excavation & Support**, relevant scenarios considered, analyses applied, and results
- **Baseline Construction Plan** with etailed specifications to the Baseline construction plan (system behavior, measures to be determined on site, warning criteria and limits, etc.)
- **Determination of excavation classes**, e.g. distribution along the alignment

6.6.2 Baseline Construction Plan

Baseline Construction Plan summarizes the geotechnical design and should contain

- **Geological Model** with distribution of Rock Mass Types and Behavior Types in a longitudinal section
- **Sections**, where specific requirements for construction have to be observed
- **Fixed excavation and support types** (round length, excavation sequence, overexcavation, invert distance, support quality and quantity, ground improvements, etc.)
- **List of measures** to be determined on site (support ahead of the face, face support, ground improvement, drainage, etc.)
- **Description of System Behavior** (behavior during excavation, deformation characteristics, utilization of supports, etc.)
- **Warning criteria** and levels, as well as remedial measures according to the safety management plan

6.6.3 Safety Management Plan

Safety Management has to cover

- **Design Concept** for the determination of excavation and support
- **Criteria** for the assessment of the stability based on the knowledge of the ground conditions during design
- **Monitoring Concept** with all technical and organizational provisions to allow a continuous comparison between the expected and actual conditions

7. MONITORING GUIDANCE

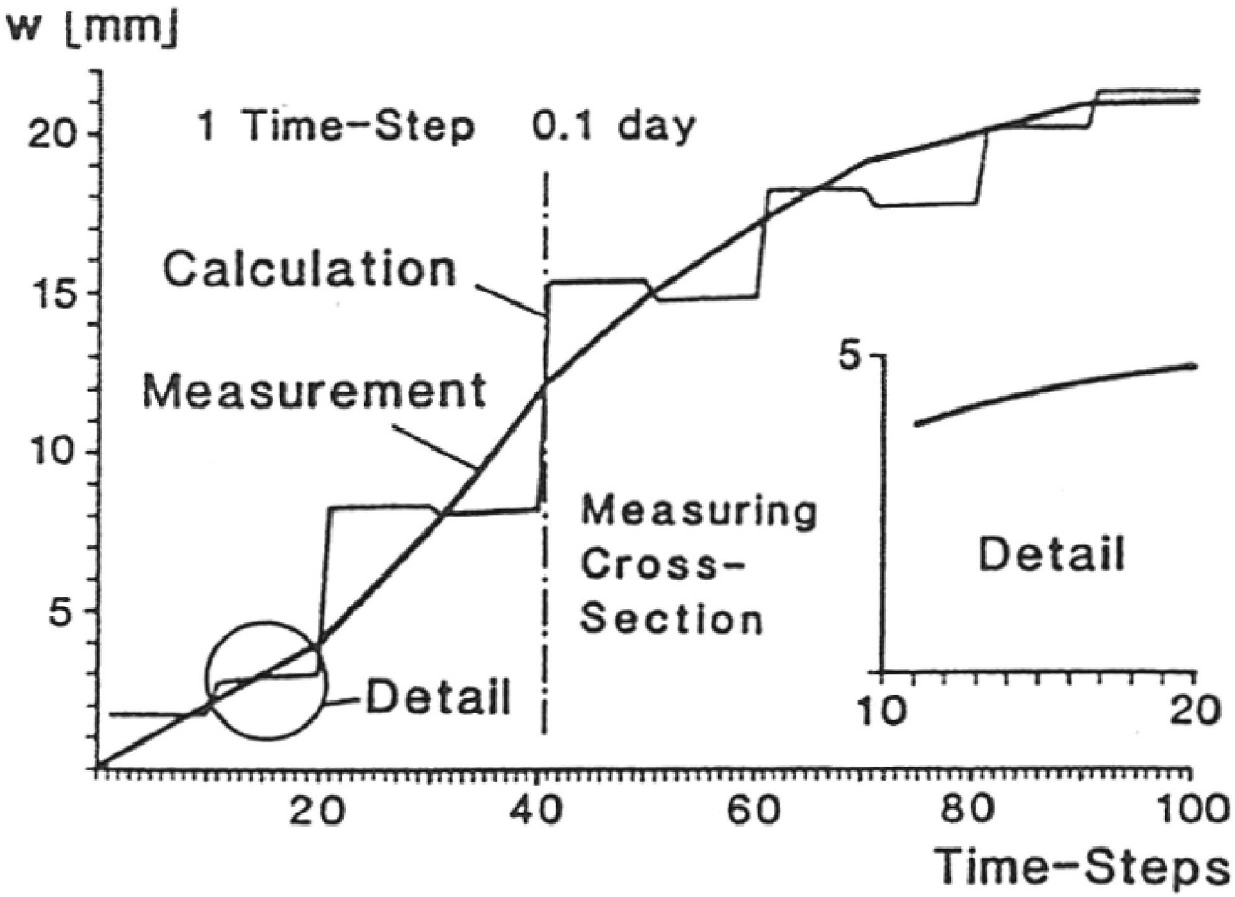
Geomechanical Data Evaluation is State-of-the-Art when

- **Tunnelling** through poor rock and fault zones which may cause problems in construction , with
- **Continuous Monitoring** of the behaviour of the rock mass and support structure such to
- **Base on-site Support Decisions**, beyond and above, proper modelling during the design.

7.1 Safety Monitoring Concept

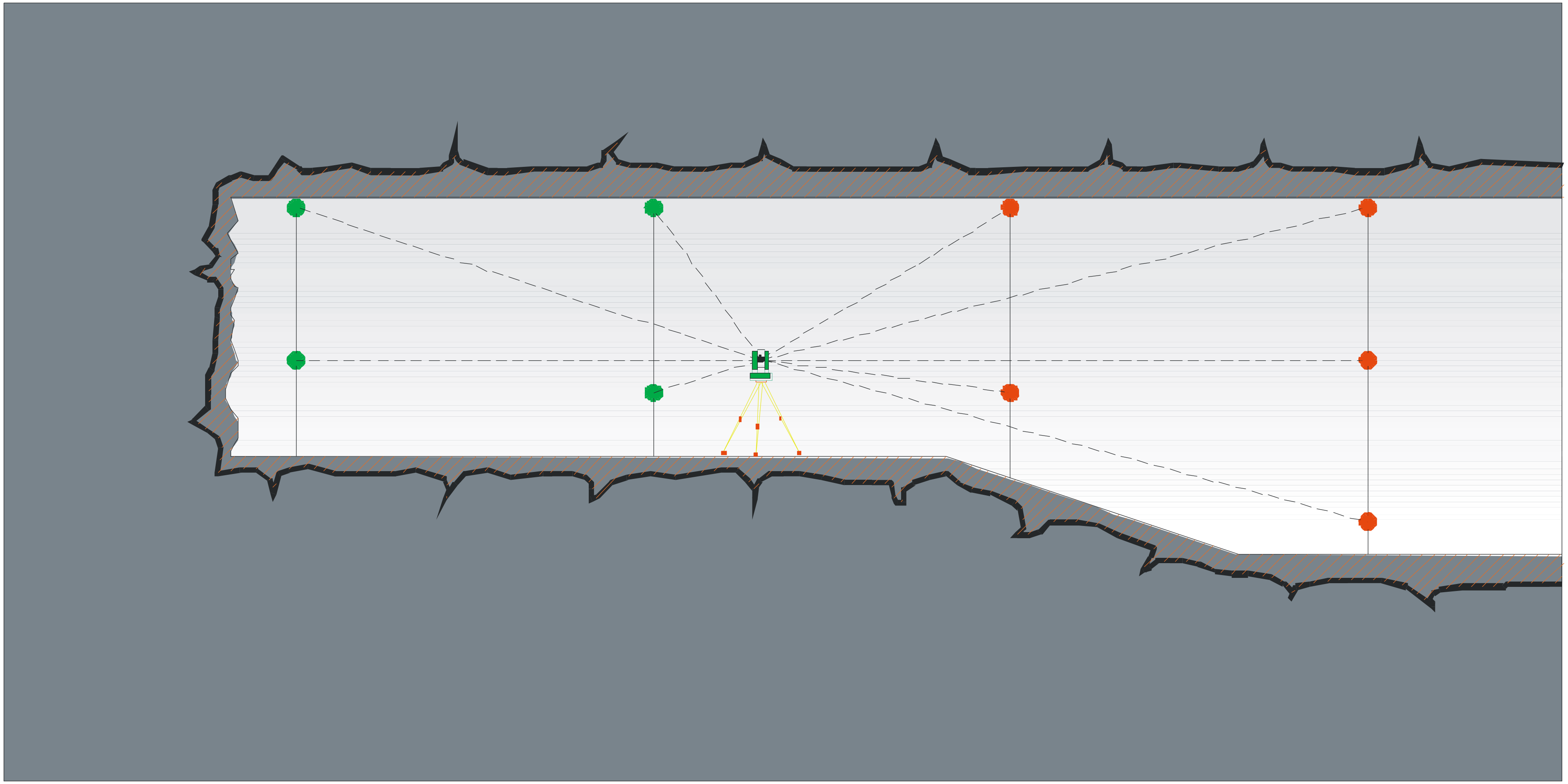
- **Design concept** for the determination of excavation and support
- **Criteria** for assessment of stability based on the knowledge of the ground conditions during design
- **Monitoring concept** with all technical and organizational provisions to allow a continuous comparison between the expected and actual conditions

Monitoring and Numerical Analysis



Monitoring in Construction

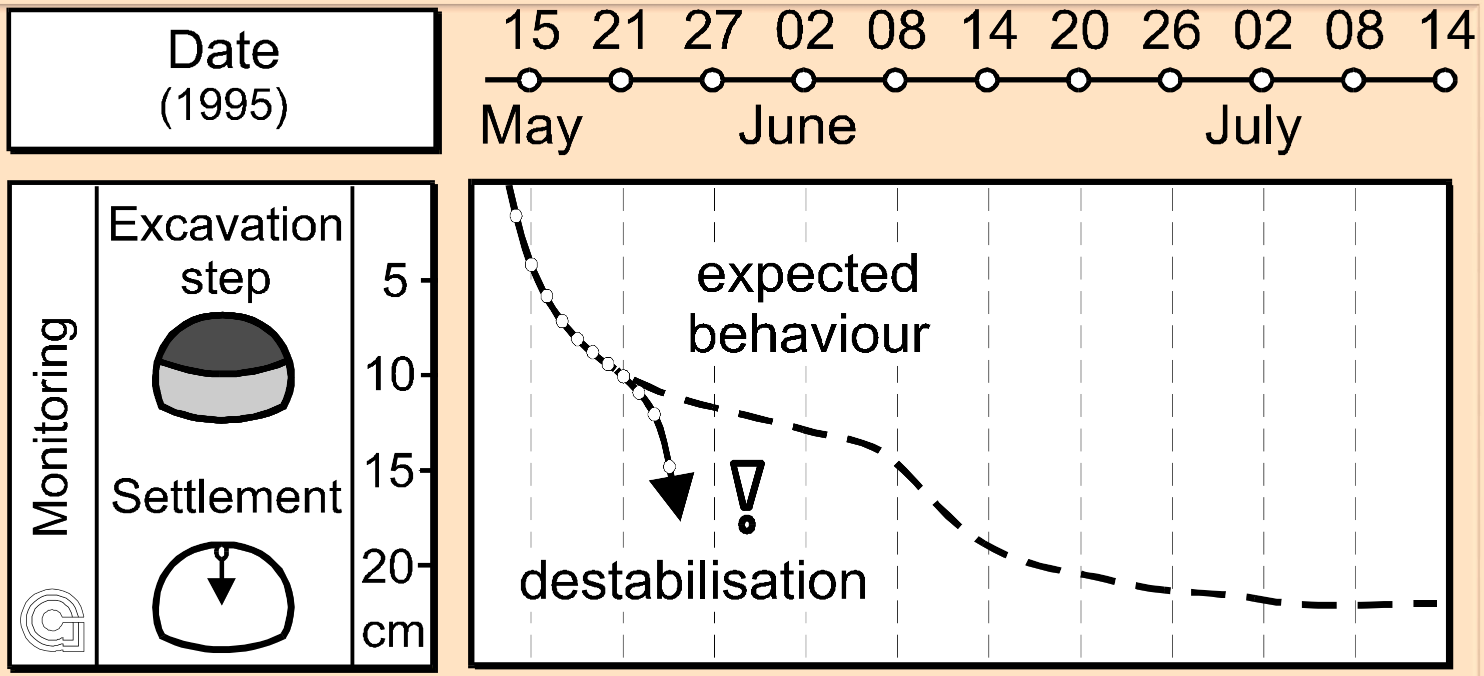
Laser Beam Deflection Monitoring



7.2 Displacement History Plots

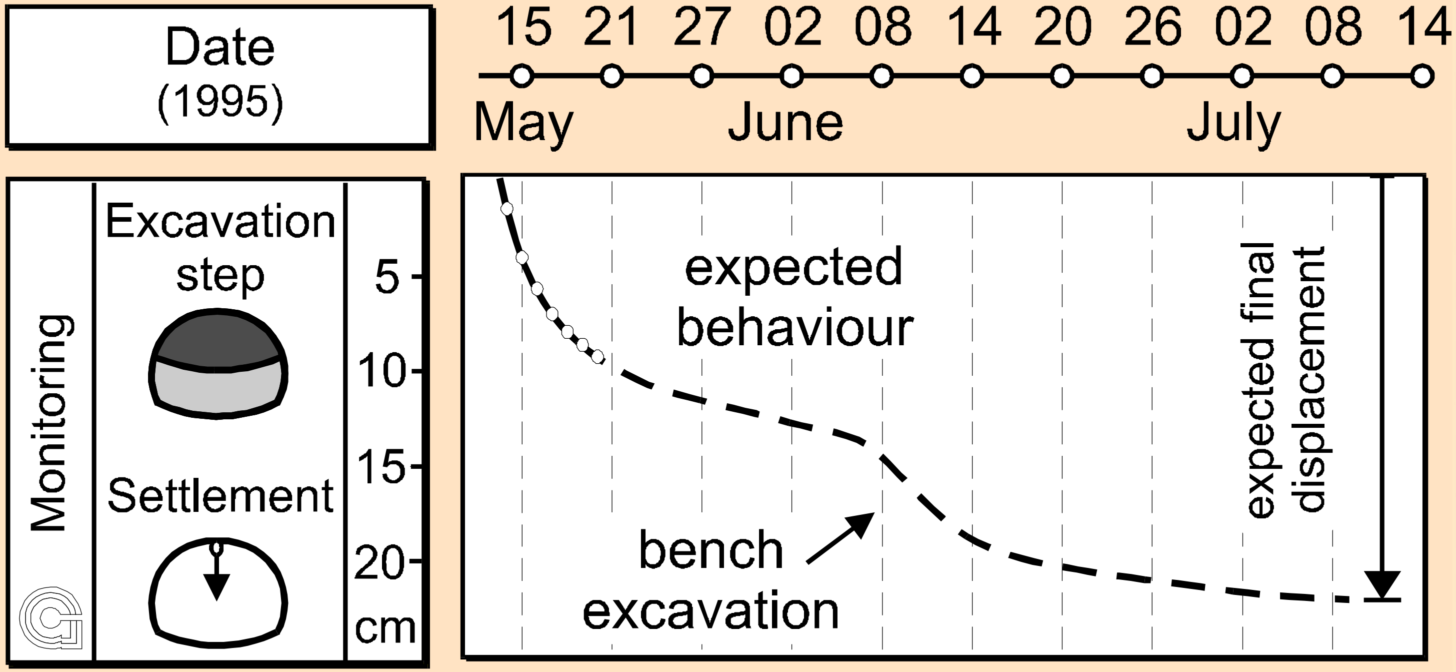
- Assuming continuous face advance, displacement rate over time has to decrease
- Displacement acceleration indicates destabilisation, unless there are ongoing construction activities in the monitored tunnel section (e.g. bench and invert excavation, or shaping activities)
- Stabilisation is reached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

Typical Displacement History



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

Final Displacements

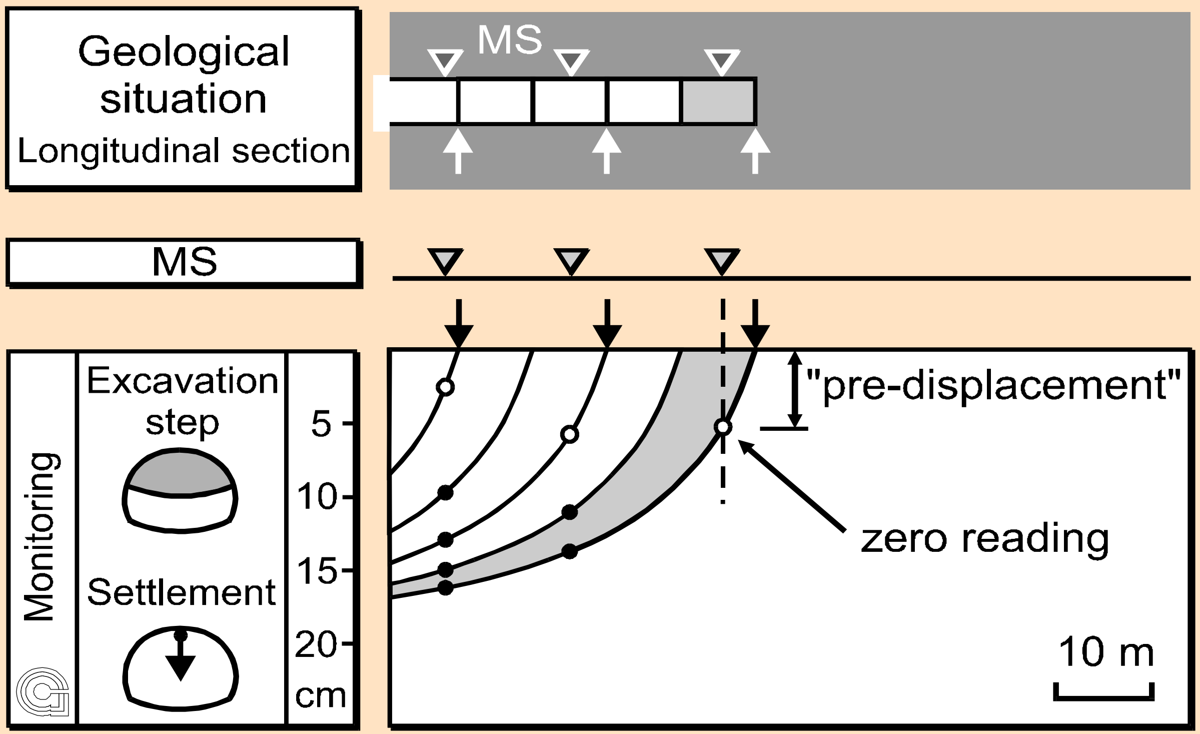


Final displacements extrapolated from few readings, using previous experience and including the actual geological situation

7.3 Deflection Curves

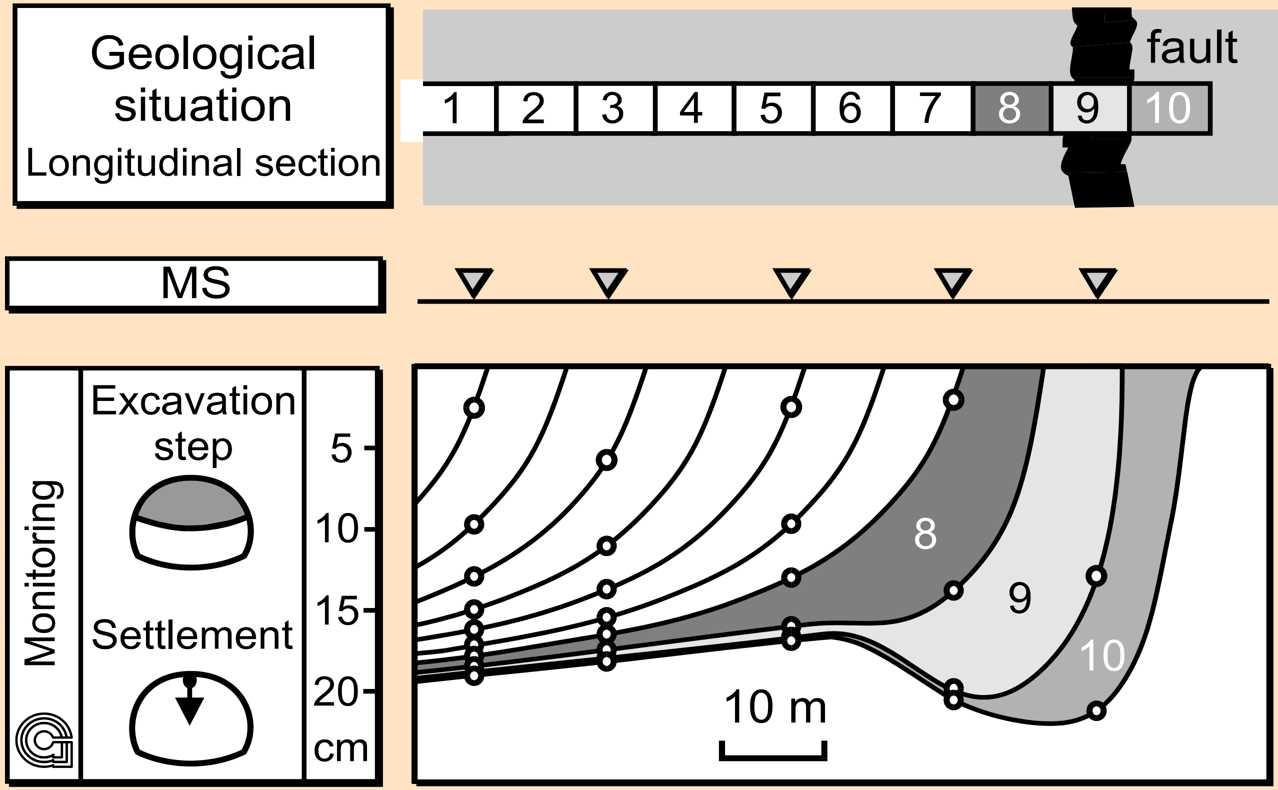
- When showing several deflection curves on the same plot, comparison of displacements along tunnel is possible
- Information on the longitudinal extent of tunnel deformation behaviour is provided
- Trends of relative decreasing or increasing ground behaviour can be verified

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 Deflection Curve

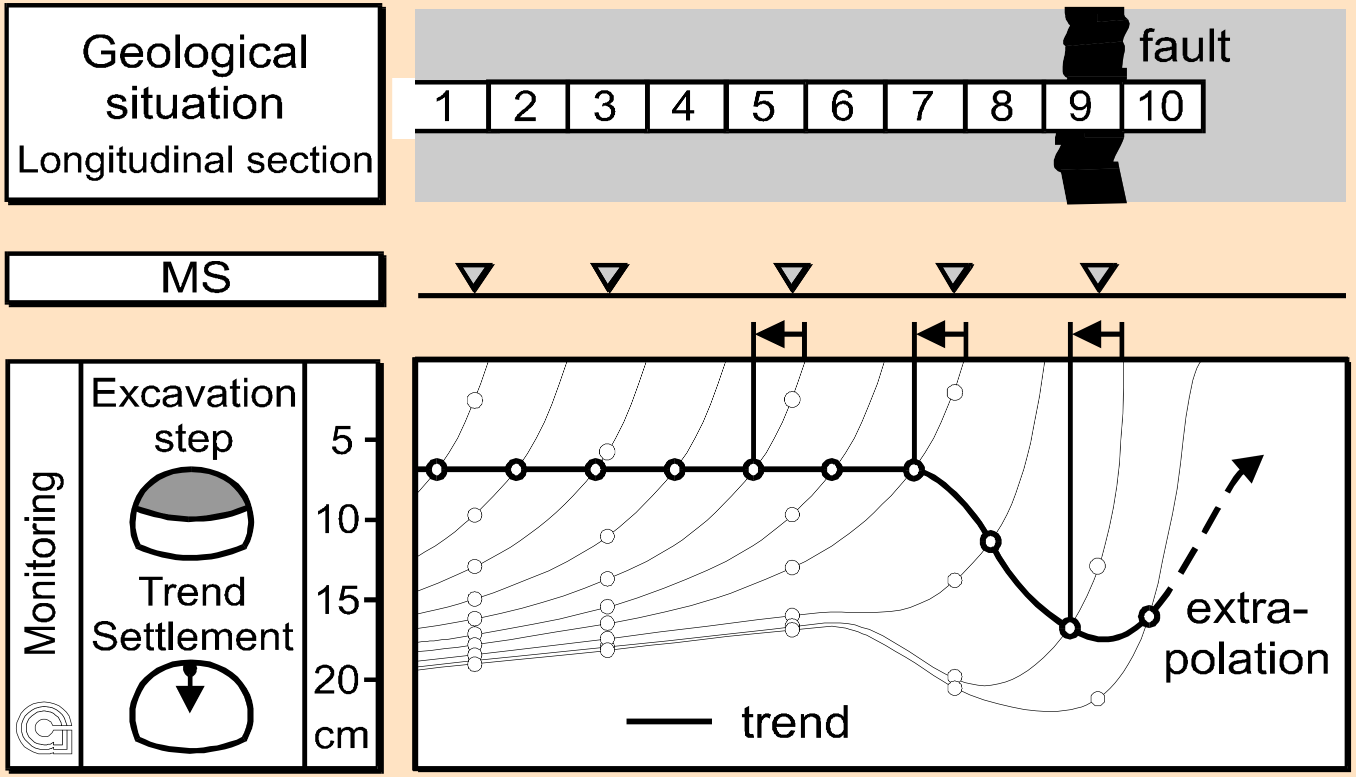


Typical plot of deflection curves when excavation approaches a "weak" zone (schematically)

7.4 Trend Lines

- 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)

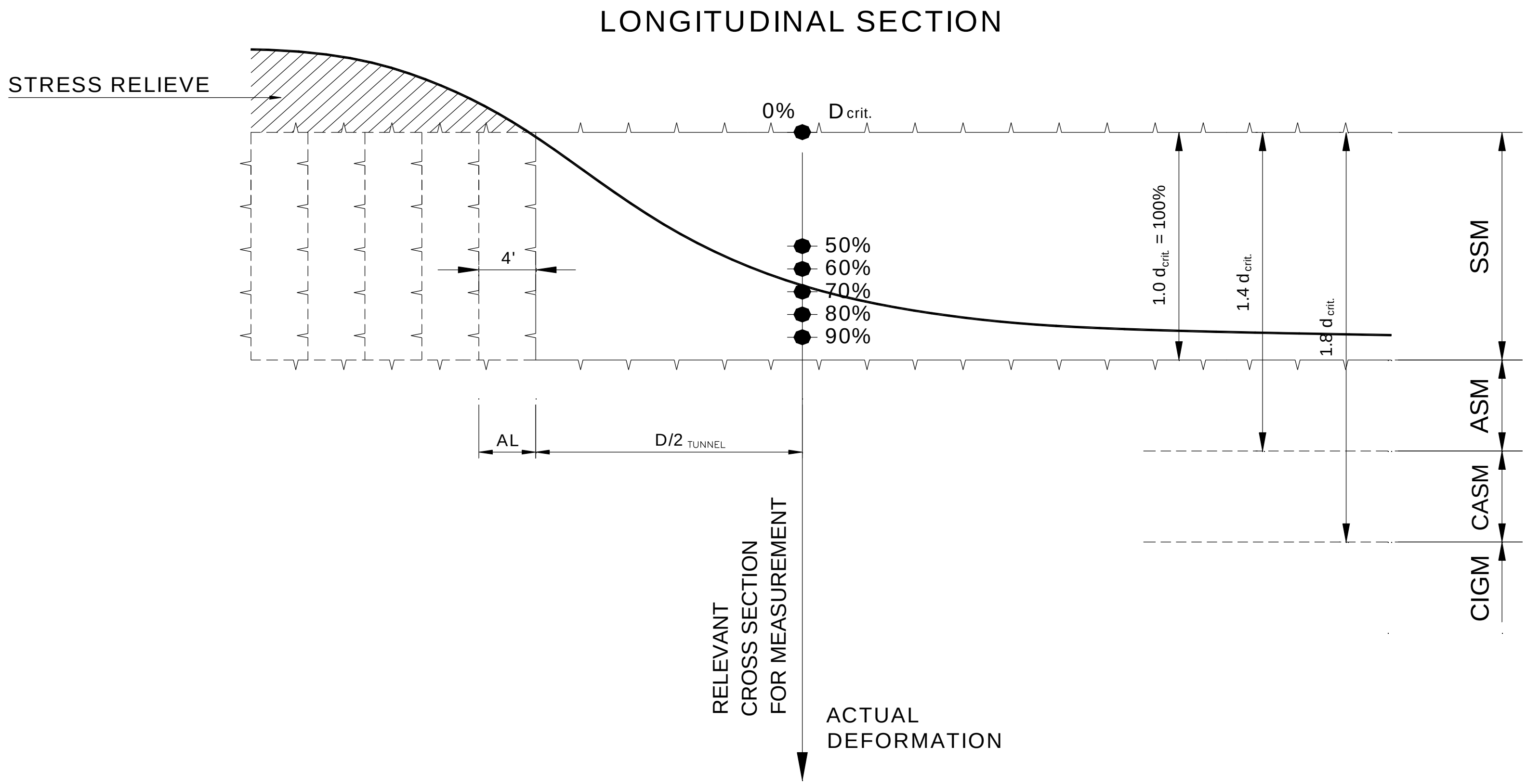
7.5 Tool Box for Flexible Response

- **Standard Support** measures are to be installed all along the length of the tunnel. Means and methods should be defined and documented.
- **Additional Support Measures** respectively Contingency Support Measures will be installed following when and how, as demonstrated in the design.

Critical Deformation

- **Cover** regular expected ground conditions with standard support measures, not exceeding 1.0 x d_{crit}.
- **Arrange** for additional support measures if the threshold value of $d_{crit,}$ - representing a threshold value which is on the very safe side -, is exceded .

EXAMPLE OF RELATED DEFORMATION



NOTE:
- SSM STANDARD SUPPORT MEASURES
- ASM ADDITIONAL SUPPORT MEASURES
- CASM CONTINGENCY APPLICATION OF SUPPORT MEASURES
- CIGM CONTINGENCY IMPROVEMENT OF GROUND SUPPORT MEASURES BEYOND GBR
- AL ADVANCED LENGTH
- $d_{crit.}$ TRESHOLD DEFORMATION DEFINED TO START ADDITIONAL SUPPORT MEASURE INSTALLATION LIT: ICONMIG 1988 (PAGE 1,531 ff)
- FOR SUPPORT MEASURES SEE INDIVIDUAL DRAWINGS

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.

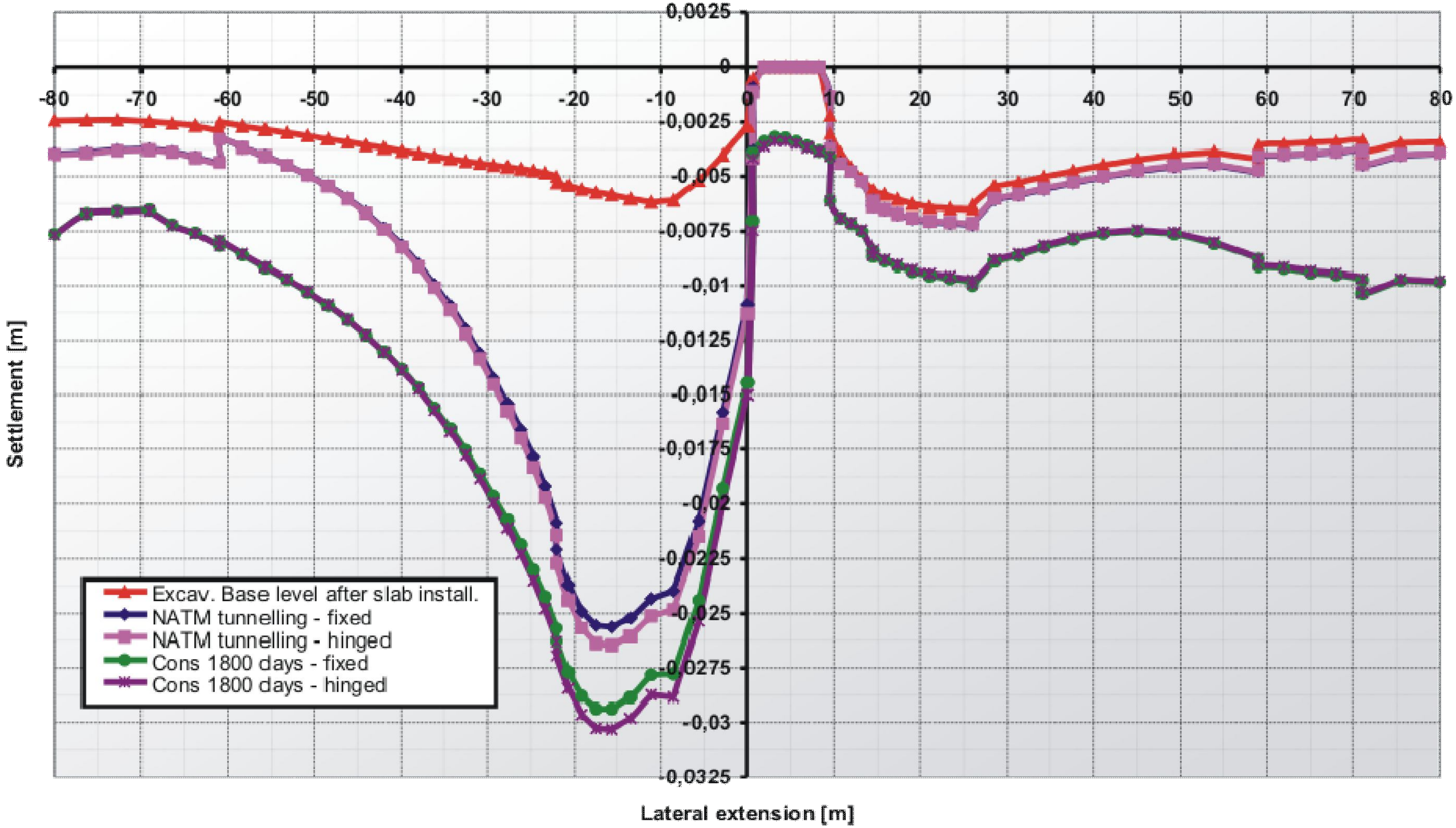
Standard / Additional Support

- Depending on the ground, standard tunnel design needs to be supplemented in the flexible response concept of Additional Safety Support Measures.

- Additional Safety Support Measures are designed under the requirements of standard safety needs during all construction stages.

- Additional Safety Support Measures are essential in the Safety Corridor.

SURFACE SETTLEMENTS AT MONITORING



VIBRATION MONITORING

- VALUES HAVE BEEN DEFINED TO AVOID CROSSING OF THRESHOLDS
- ANY CROSSING OF VIBRATION THRESHOLDS IS NOT PERMITTED
- COST FOR COUNTER MEASURES HAVE TO BE BORNE BY THE CONTRACTOR

VIBRATION MONITORING

VIBRATIONS	PREVENTIVE MEASURES	COMMENTS
0 - 0,5 MM/S	NO MEASURES	
0,5 - 0,6 MM/S	REDUCTION OF ADVANCE SPEED, INCREASE CUTTER WHEEL SPEED FROM 1,5 RPM TO 2,0 RPM	V (ADVANCE) = MAX 20 MM/MIN
0,6 - 0,7 MM/S	REDUCTION OF PENETRATION AND ADVANCE, INCREASE CUTTER WHEEL SPEED FROM 2,0 RPM TO 3,0 RPM	V (ADVANCE) = MAX 10 MM/MIN
0,7 - 0,8 MM/S	TBM STOP – RESEARCH OF CAUSE – REGULAR MEASURES	THRESHOLD VALUE F1 0,83MM/S, F2 1,05 MM/S, S1 1,30 MM/S
>0,8 MM/S	SPECIAL MEASURES	

SETTLEMENT MONITORING

MOST RISK PROBLEMS RESULT FROM ADDITIONAL TBM STOPS BEYOND RING ERECTION TIME

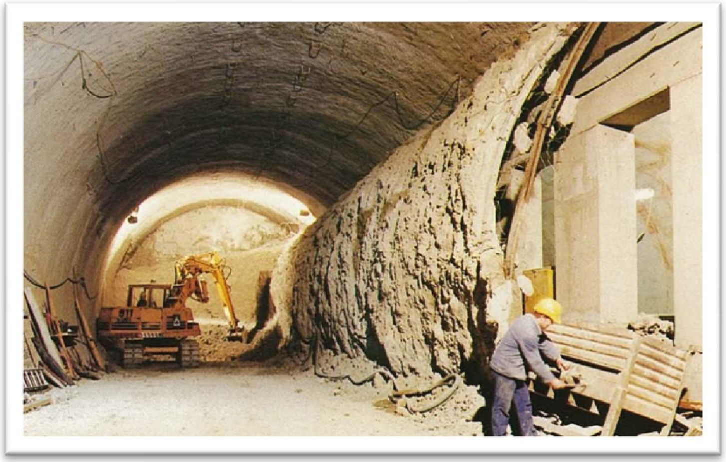
	TUNNEL-AXIS	SETTLEMENT DISTANCE	MEASURES
		15 M	POINT OF CONCERN
1	0-15 MM	0 – 10 MM	• NONE
2	15-30 MM	10 – 20 MM	• INCREASE SUPPORT PRESSURE
3	30-50 MM	20 – 30 MM	• INCREASE SUPPORT PRESSURE • INCREASE GROUT PRESSURE • REDUCE CUTTING SPEED
4	> 50MM	30 – 40 MM	• STOP DRIVING • REEVALUATE MEASURES

8. CONSTRUCTION CONCEPT

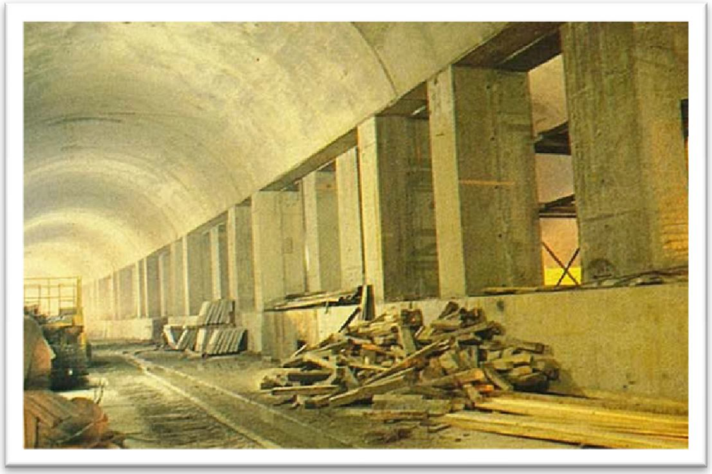
CTM IN SOFT ROCK

CLOSED RING CONDITION

SIDE DRIFT EXCAVATION

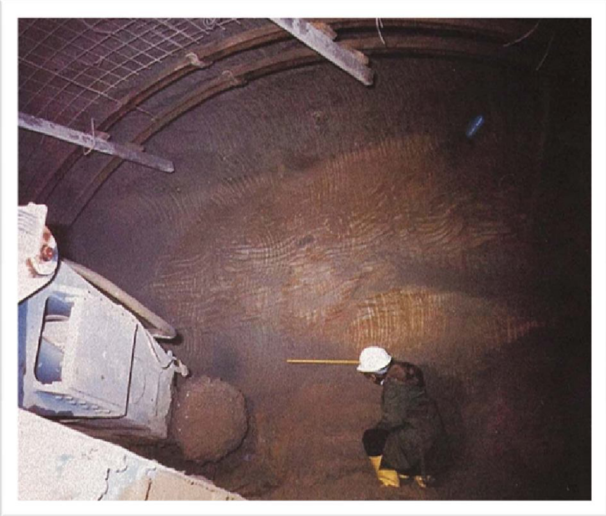


MULTIPLE DRIFT STATION



STATION TUNNEL FINAL LINING

CTM IN HARD ROCK



SOFT ROCK ROAD HEADER

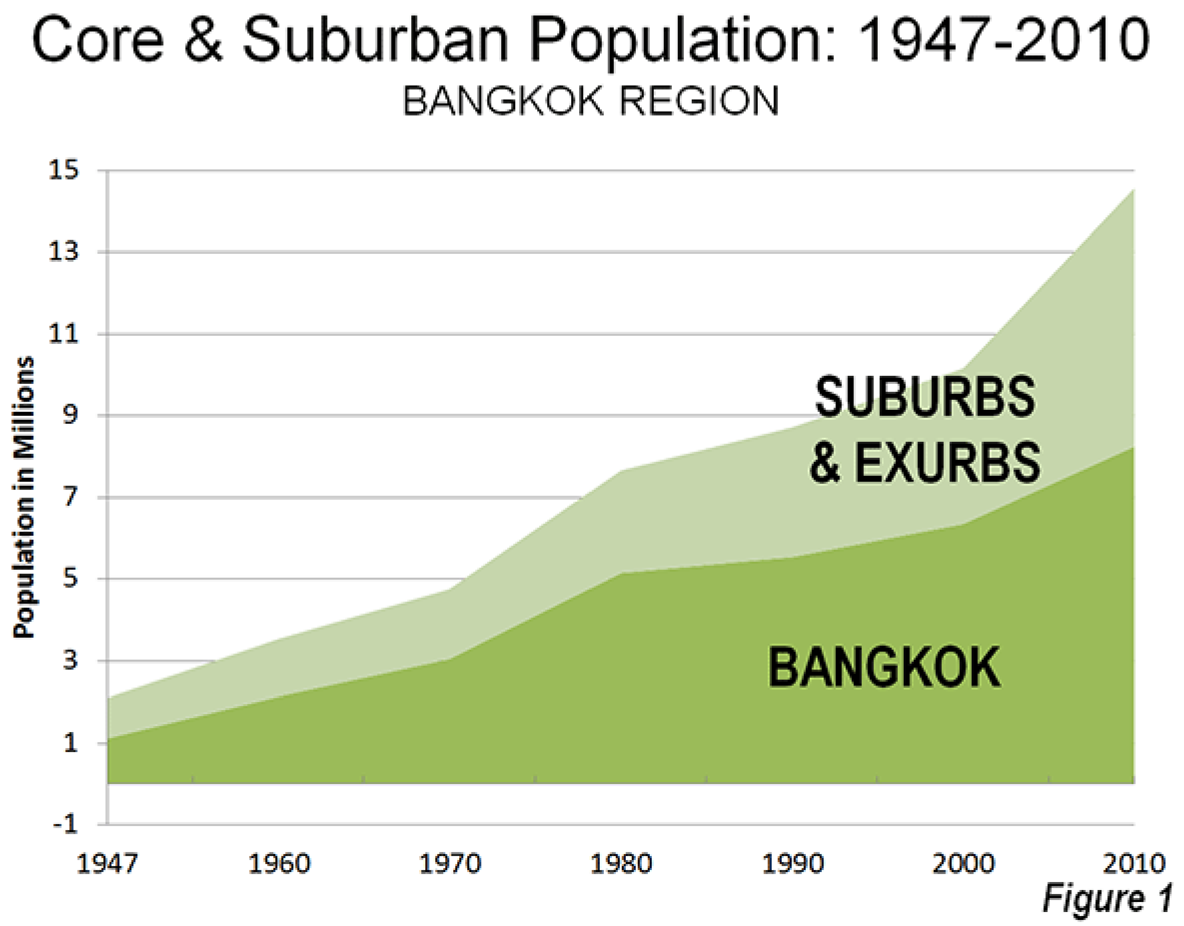
FOREPOLING in SOFT ROCK

SHOTCRETE FACE SEALING

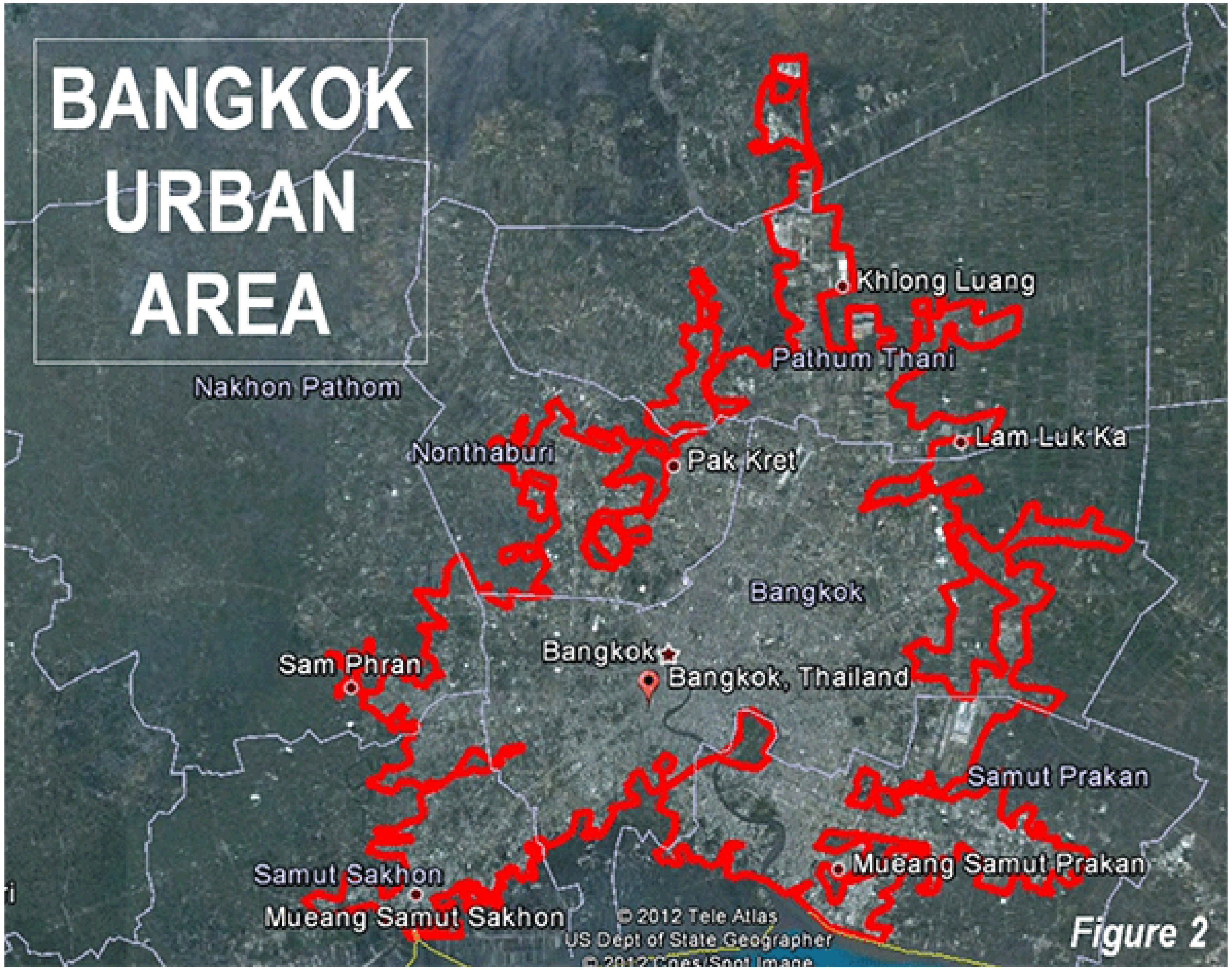
HARD ROCK FACE DRILLING

9. URBAN INFRASTRUCTURE

Much of **Bangkok's Growth** has occurred outside the city, in suburban (and exurban) areas. Between 2000 and 2010, the city grew by 30%, while the suburban provinces grew at 66%. The city's population growth was 1.9 million, while the suburban provinces added 2.5 million population.



The area of continuous urban (and suburban) development will reach **14.5 million residents in 2013**, according to UN projections.
The urban area covers approx. 2,330 km2 and has a population density of 6,200 per km2.



9.1 BANGKOK's POTENTIALS

Potentials

- in 2010

  POP 6.3 Million

  GDP B 5.5 Trillion

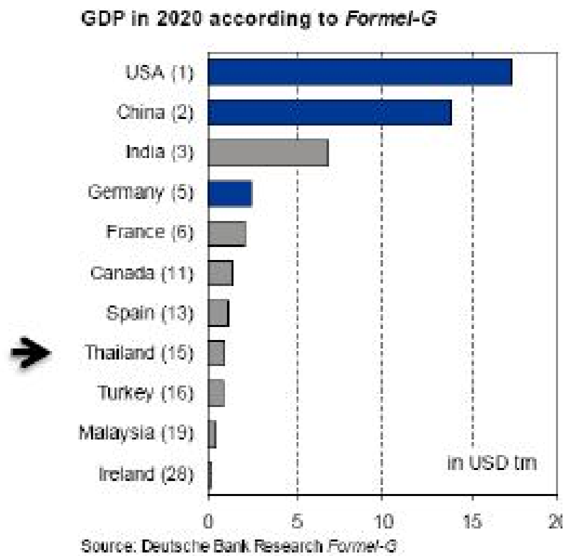
  World's Best City 2010 (Travel & Leisure Magazine)*

- in 2020

  POP 8.2 Million

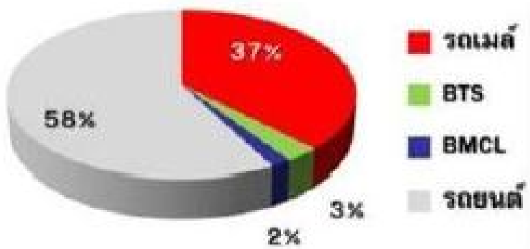
  GDP B 25 Trillion

  15th Largest GDP (DB Research)*



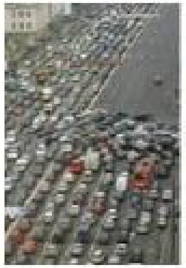
Treats

- Traffic Congestion
- Energy Consumption, Public : Private (1:5)
- Quality of Life & Value of Time



9.2 GLOBAL URBAN TRAFFIC

Tokyo



Shanghai

London

Bangkok

Osaka

Mumbai

San Paulo

1	Tokyo
2	LA
3	San Paulo
4	Bangkok
5	Moscow
6	Shanghai
7	Mumbai
8	Mexico
9	NY
10	Seoul
11	Chicago
12	Manila
13	London
14	Jakarta
15	Osaka

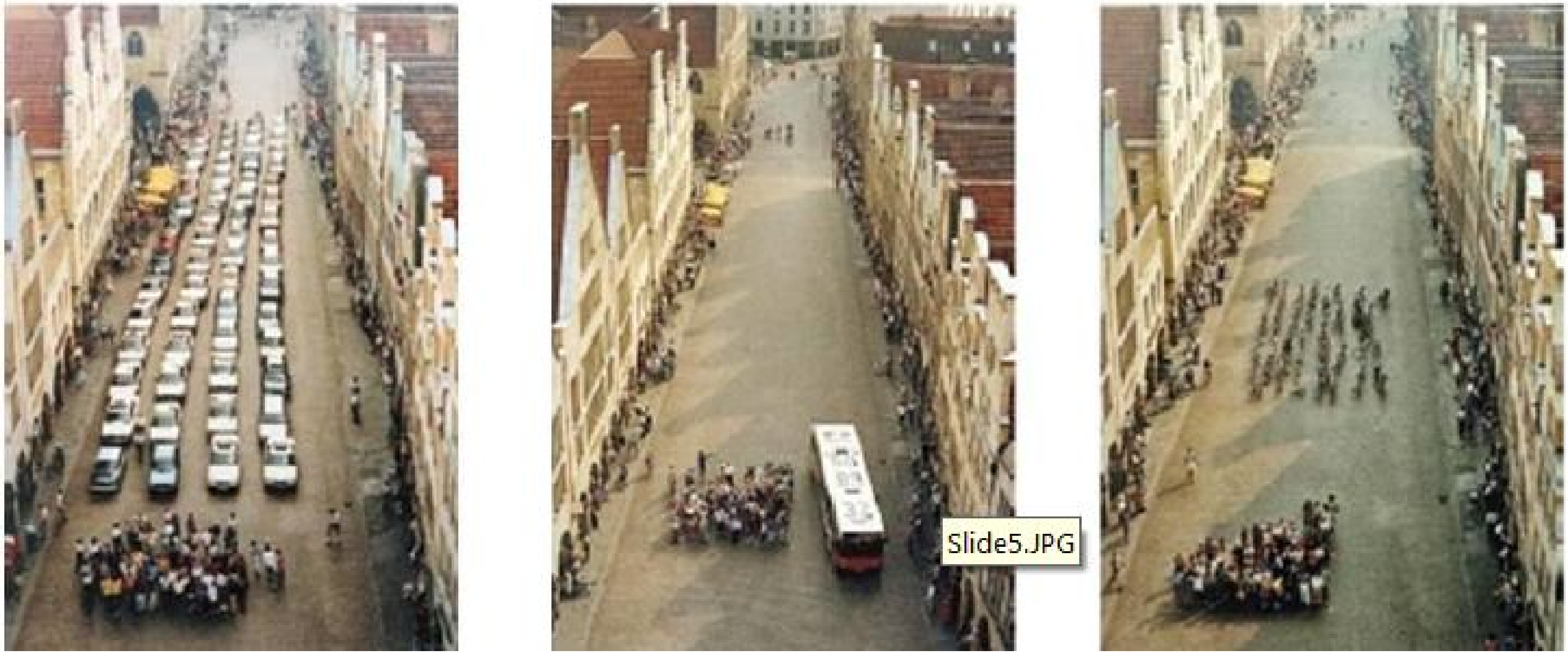
9.3 TRANSPORTATION PROBLEMS OF BANGKOK

- Safety & Accident
- Level of Service
- Law Enforcement

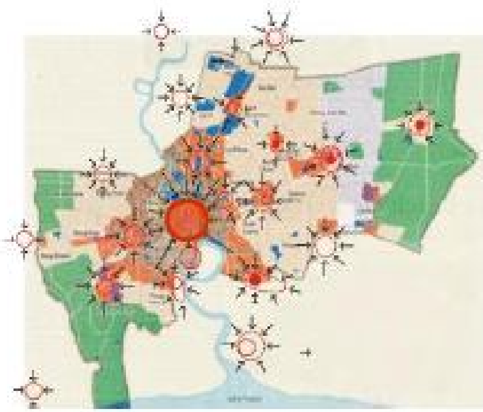
9.4 TRANSPORTATION SOLUTIONS

"Road for Transport People not Vehicles"

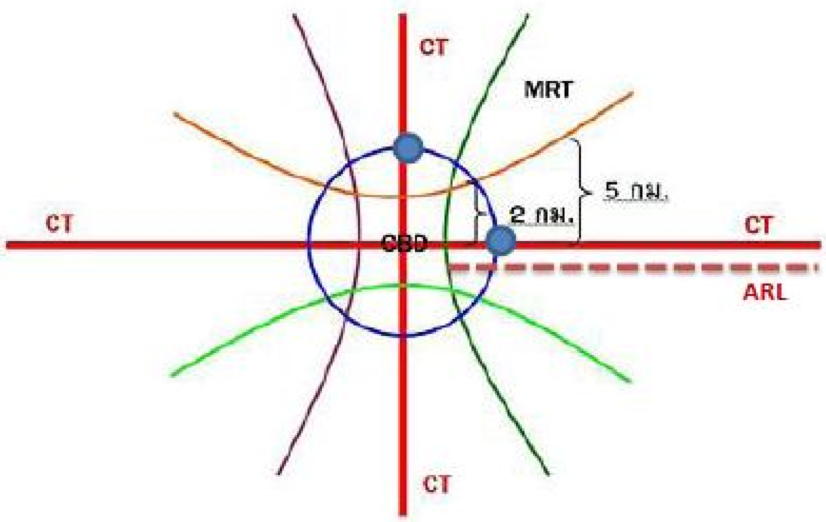
Average passenger per car in Bangkok 1.3 passengers



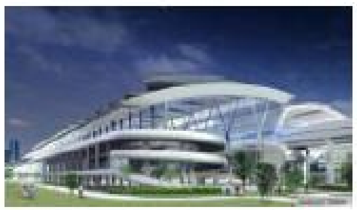
9.5 URBAN AREA – UNDERGROUND SOLUTIONS



MRT MASTERPLAN CONCEPT

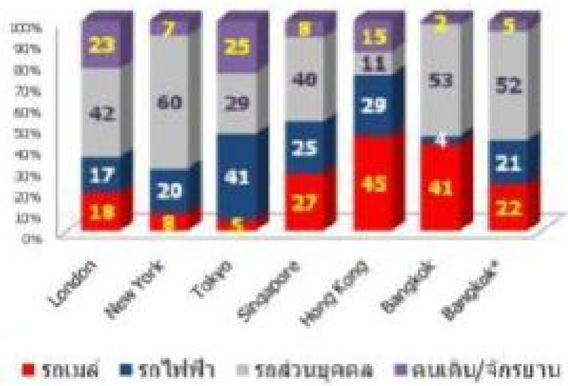


Bang sue Grande Station



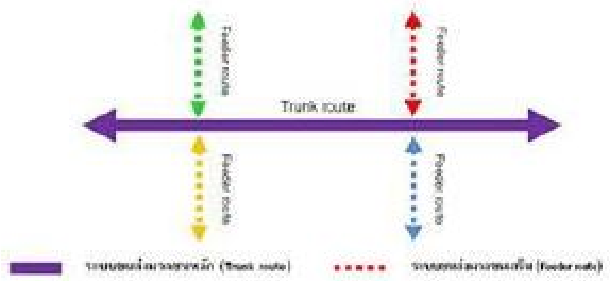
CAT

- Mass Rapid Transit
  - circumference
  - radius
- CT connects satellite town
- Transportation Hub
  - Energy comples & Bangsue Grand station
  - Makksan complex & CAT



9.6 MASS TRANSIT - CONCEPT OF DEVELOPMENT

- **Mainliner & Feeder System**
  CT, MRT, BRT, Bus

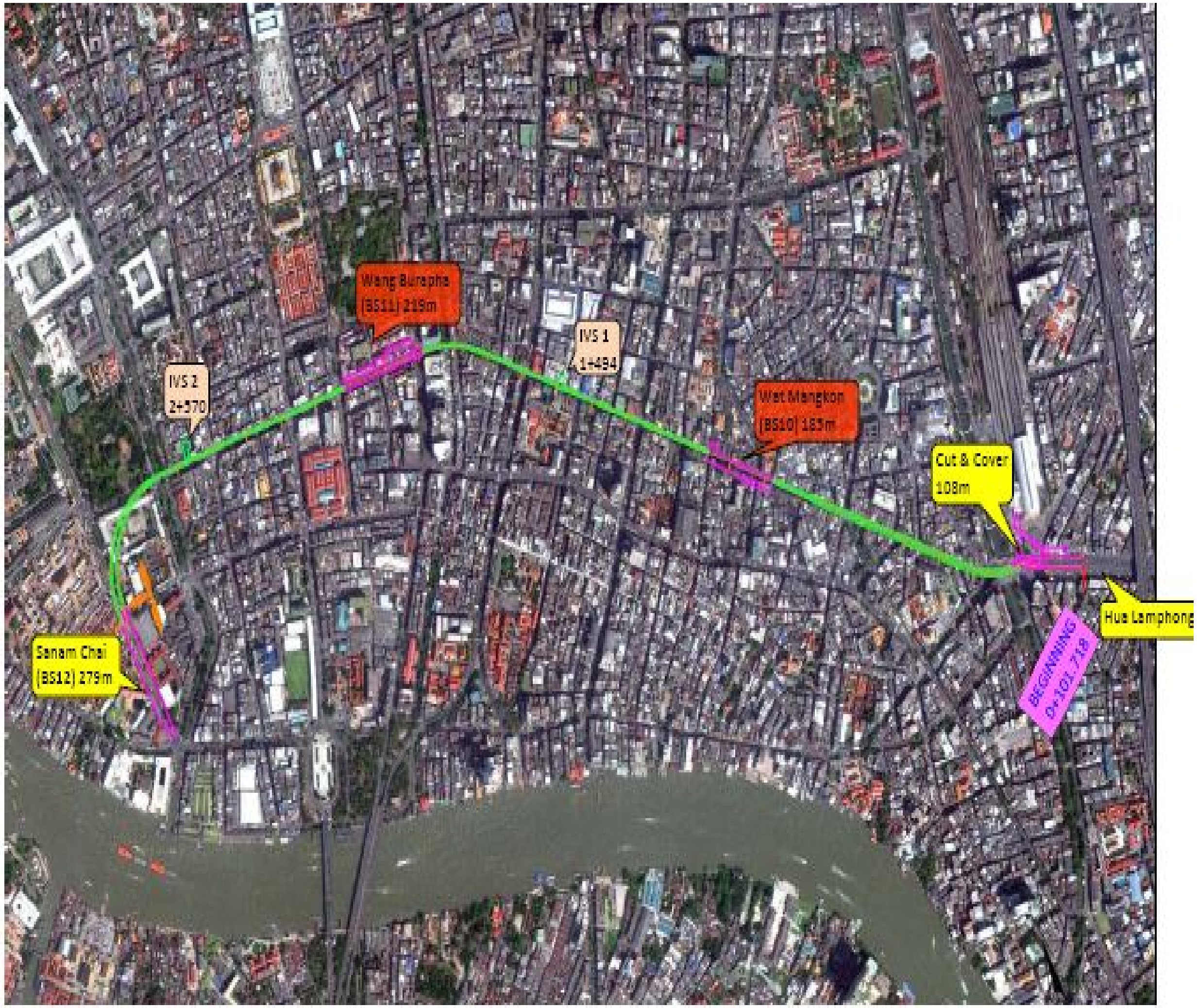


- **Urban Density**
  - MRT > 5 stories
  - Feeder 2-4
  - Walk = 1

- **Sustainable**
  - walk
  - bicycle

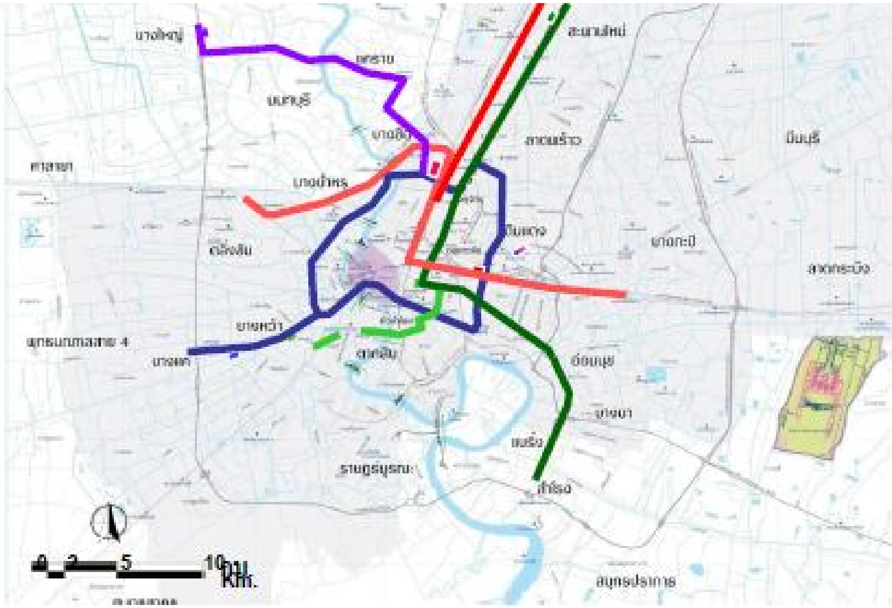
Bangkok Metro Blue Line Extension (Contract 1)

Mass Rapid Transit Authority has awarded a further package of civil works valued at 46·6bn baht covering construction of extensions to the Bangkok Blue Line heavy metro



(Geocarto International Centre, WV-2 Image, 50cm resolution, 01 Jan 2011)

Urgent Phase :145 km



Service & Operating 74.5 km

Green Line (Sky Train)	24 km
Blue Line (Underground)	20 km
Light Green Line Extension	2.2 km
Airport Rail Link	28.5 km

Under Construction 48.6 km

Light Green Line Extension	5.3 km
Dark Green Line Extension	5.25 km
Purple Line	23 km
Red Line Commuter Train (Bangsue-Talingchun)	15 km

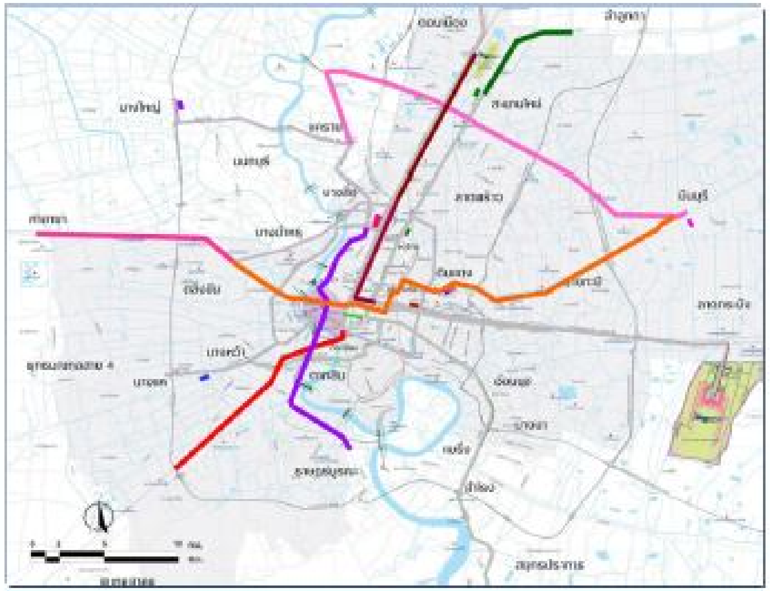
Prepare Bidding

Red Line Commuter Train (Bangsue Rangsit)	36 km	Bidding
Red Line Commuter Train (Missing Link)	16.5 km	*2012 4th Q
Dark Green Line Extension (north)	11.4 km	2011 1st Q
Dark Green Line Extension (South)	12.8 km	2011 1st Q

2nd Phase : 155 km

Detailed Design

Green Line Extension (North) MRT	7 km	2023 2nd Q
Purple Line Extension (south) MRT	19.8 km	2013 2nd Q
Red Line Extension (West) CT	14 km	2013 2nd Q
Red Line Extension (south) CT	14 km	2011 2nd Q
Pink Line * Monorail (D&B)	36 km	2011 2nd Q



Feasibility Study (Need Detailed Design)

Orange Line MRT	37.5 km	2011 3rd Q
Light Green Line Extension (West) Sky Train	1 km	2012 3rd Q

9.7 Mined Metro Stations - Evolution

- Virtually unlimited space in configuration of underground station.
- Minimize settlements and deformation of surrounding ground.
- Technology to monitor and to limit deformations within calculated prediction.

Mined Metro Station - Design

- Specific advantages of Conventional Mining for Station Design near sensitive and valuable Historical Structures
- Mined Method allows controlled 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 Metro Stations

Design Evolution Phase 1 1974 - 1995

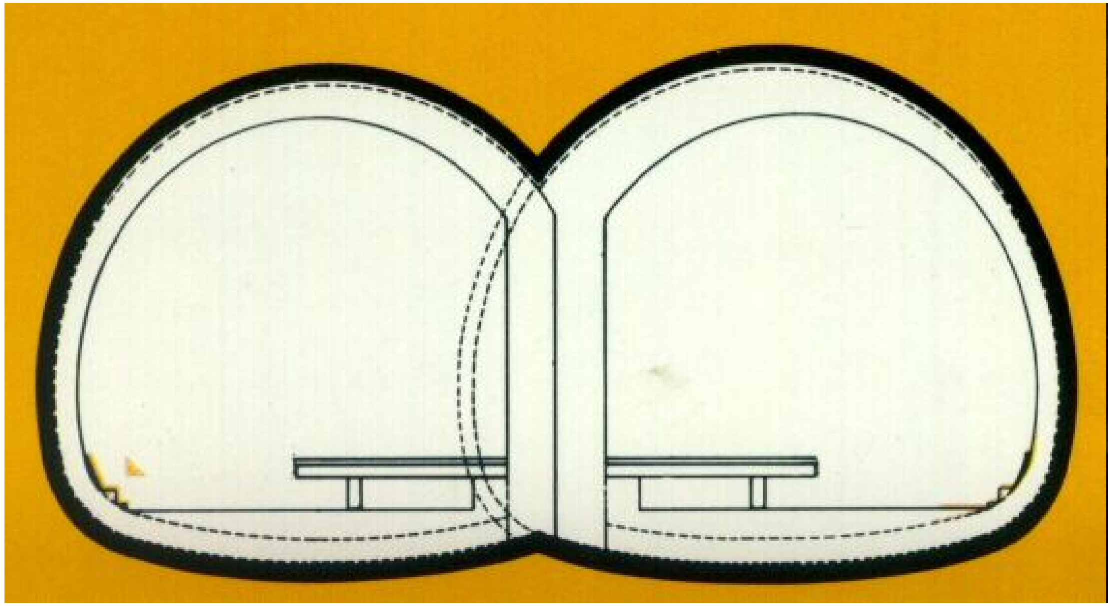
1974 - 1976 Subway Bochum, Germany
1975 - 1977 Subway Nuremberg, Germany
1977 - 1982 Subway Munich, Germany
1981 - 1982 Metro Mexico, Mexico
1991 - 1995 Subway Munich, Germany
1986 - 1991 Station Washington, USA
1992 - 1993 Subway Milano, Italy
1991 - 1992 Metro Los Angeles, USA
1993 - 1995 Subway Paris,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

Mined Metro Stations

Design Evolution Phase 2 1992 - 2006

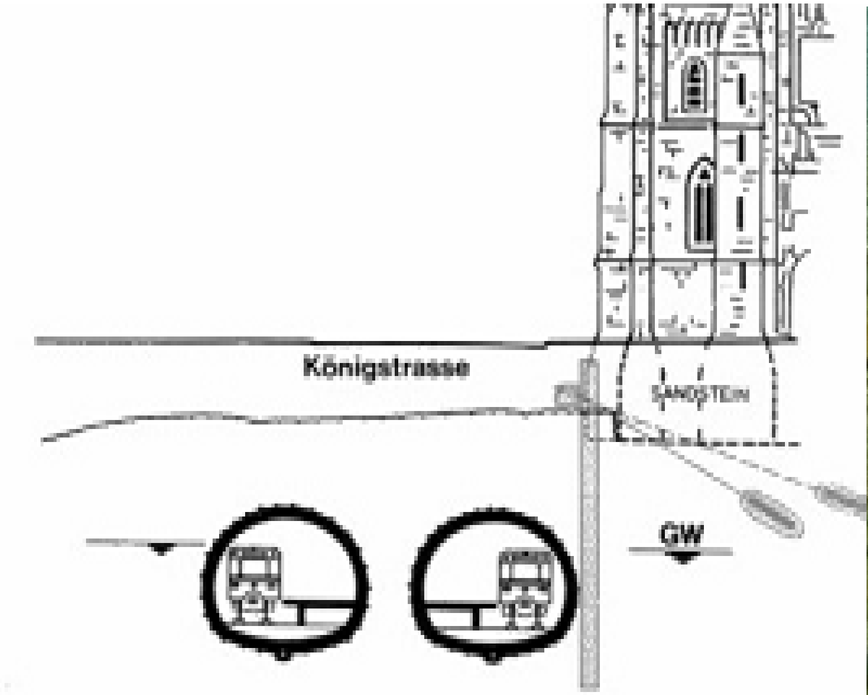
1992 - 1995	Metro Washington, USA
1994 - 1995	Metro Lille, France
1998 - 2000	Subway San Juan, Puerto Rico
2000 - 2000	Metro New Delhi, India
2000 - 2001	Sound Transit Seattle, USA
1998 - 2001	Subway Stuttgart, Germany
1999 - 2002	East Side Access New York, USA
1998 - 2004	Metro Budapest, Hungary

1976 Bochum Subway, Germany



Mined (NATM) Subway Station "Berliner Platz" – Intersecting Platform Tunnels

1977 Subway Nuremberg, Germany



Mined (NATM) Station "Lorenz Church" – Platform Tunnels with Cross Passage

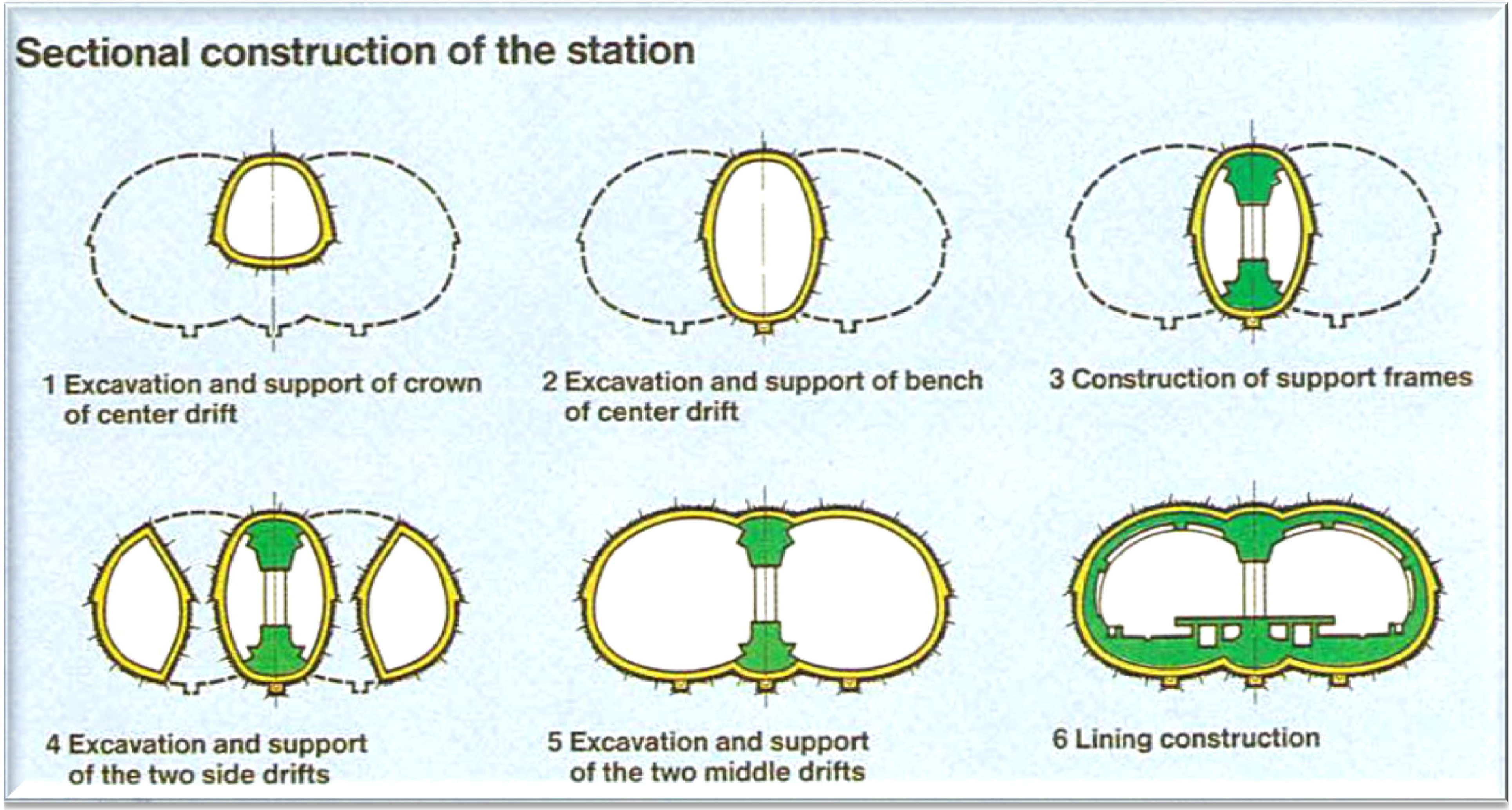
1982 Munich Metro, Germany

Mined (NATM) Metro Station “Theresienwiese” - Multiple Drift Excavation

1991 Metro Station Washington, USA

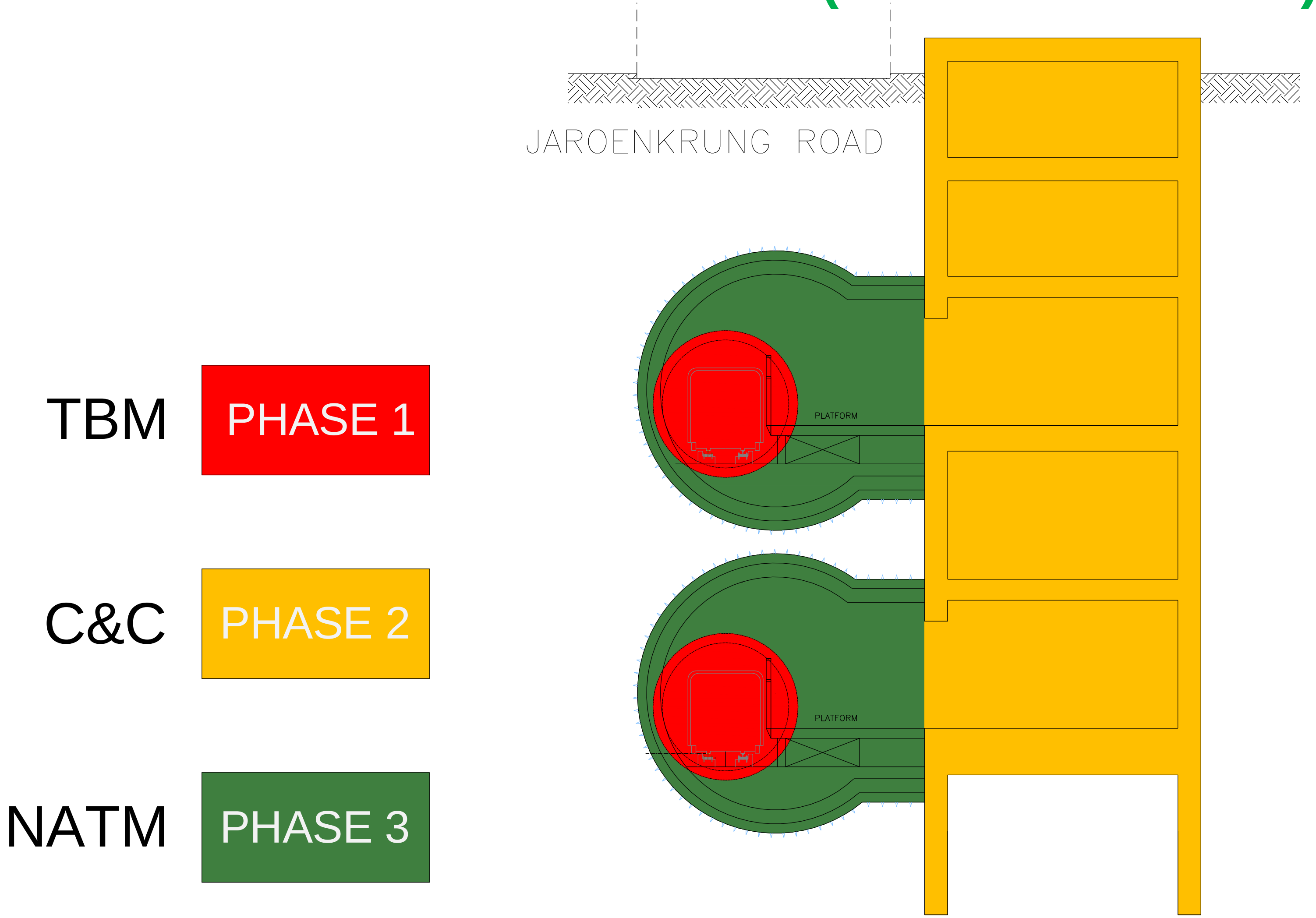
Mined (NATM) Metro Station “Fort Totten Station“ – Multiple Drift Structure

Mined Station - Multiple Drift Excavation



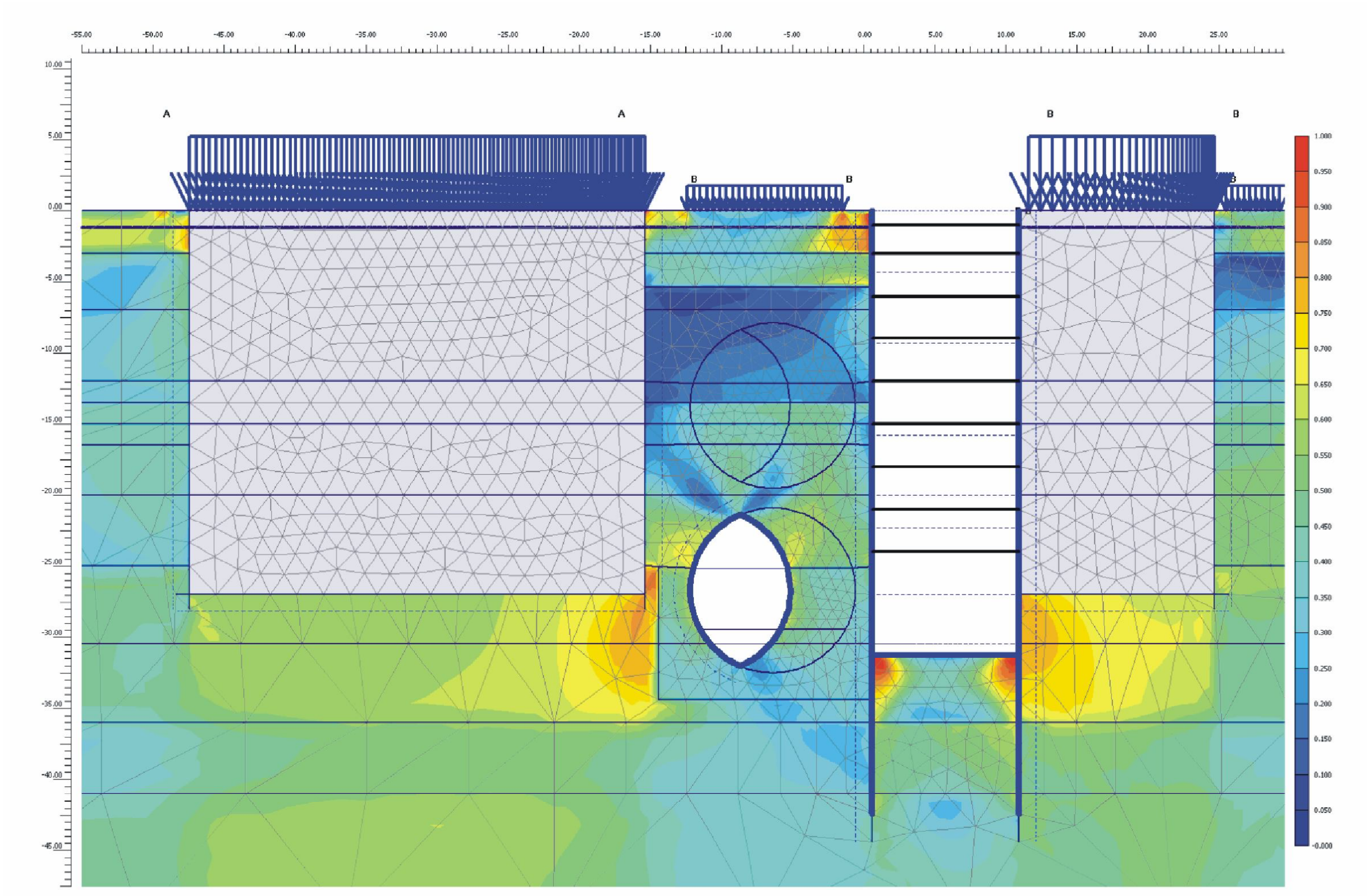
Metro Washington – Fort Totten Station

9.8 BANGKOK METRO BLE (TENDER DESIGN)



WANG BURAPHA STATION (STAKED MONOCULAR MINED STATION TYPE)

RELATIVE SHEAR STRESSES

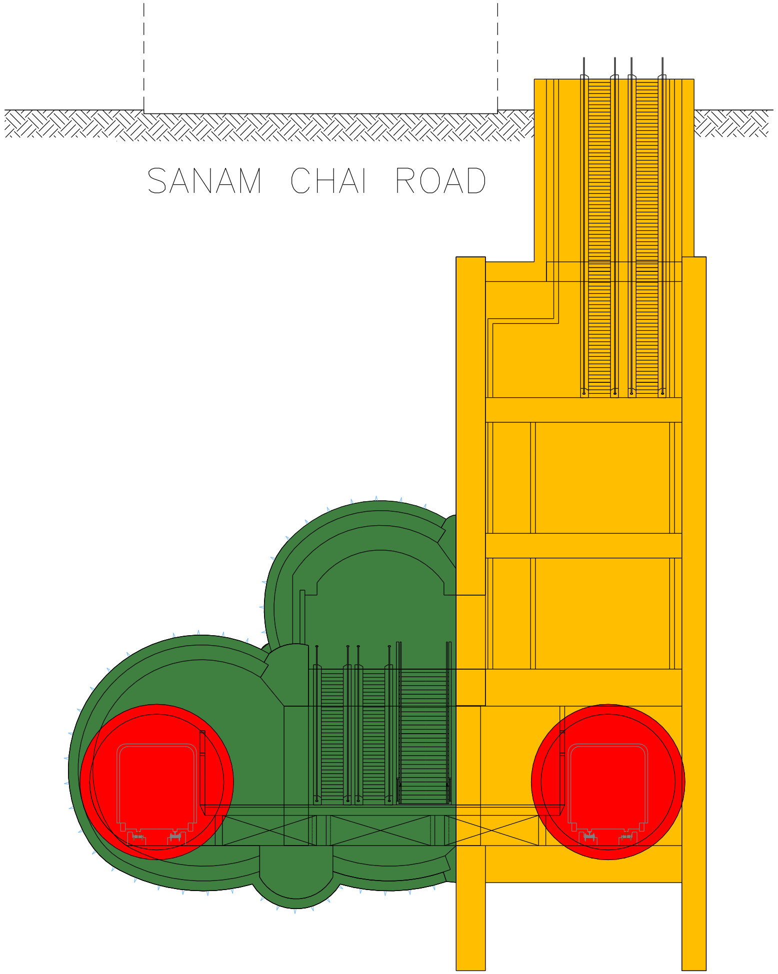


BANGKOK METRO BLE (TENDER DESIGN)

TBM PHASE 1

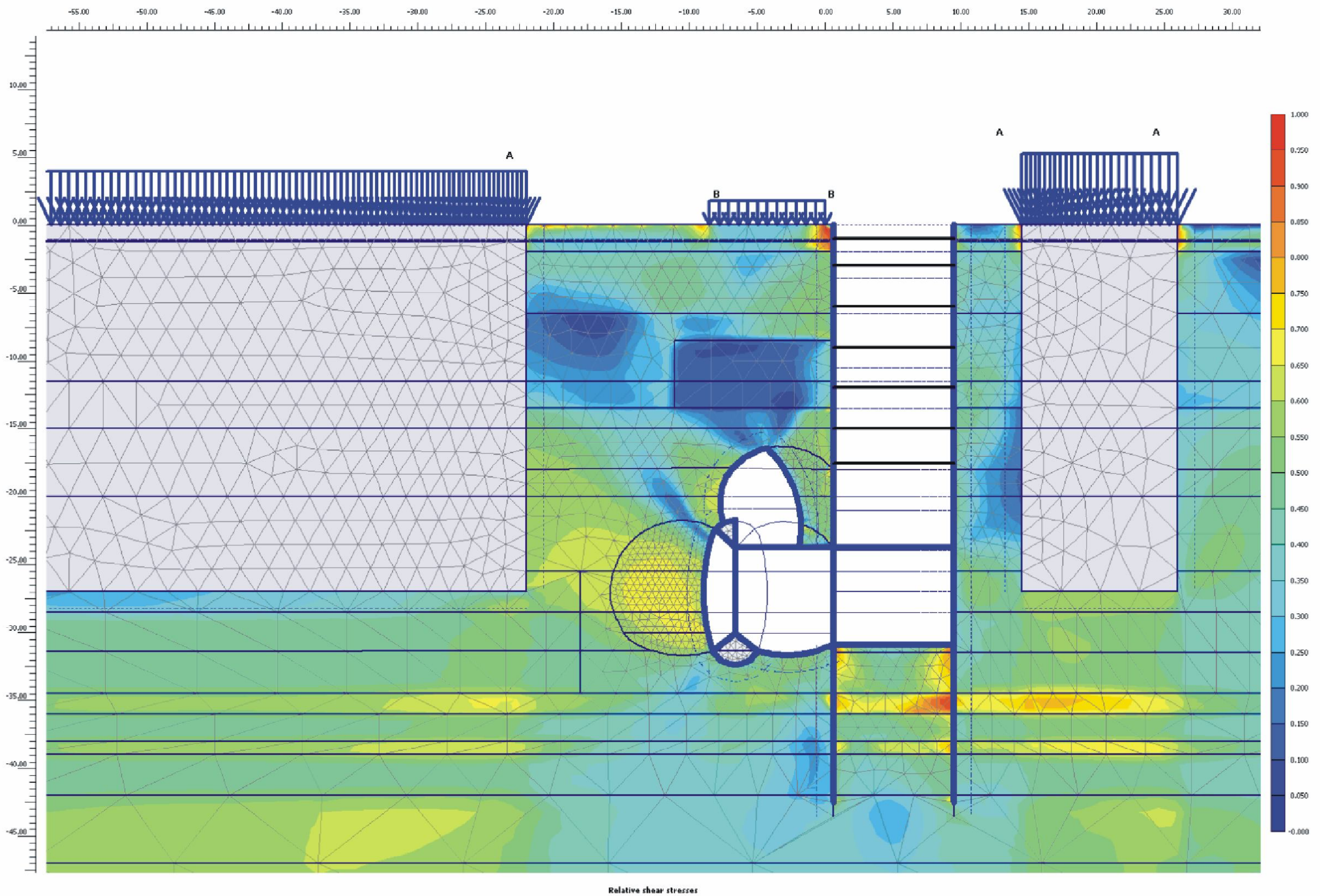
C&C PHASE 2

NATM PHASE 3

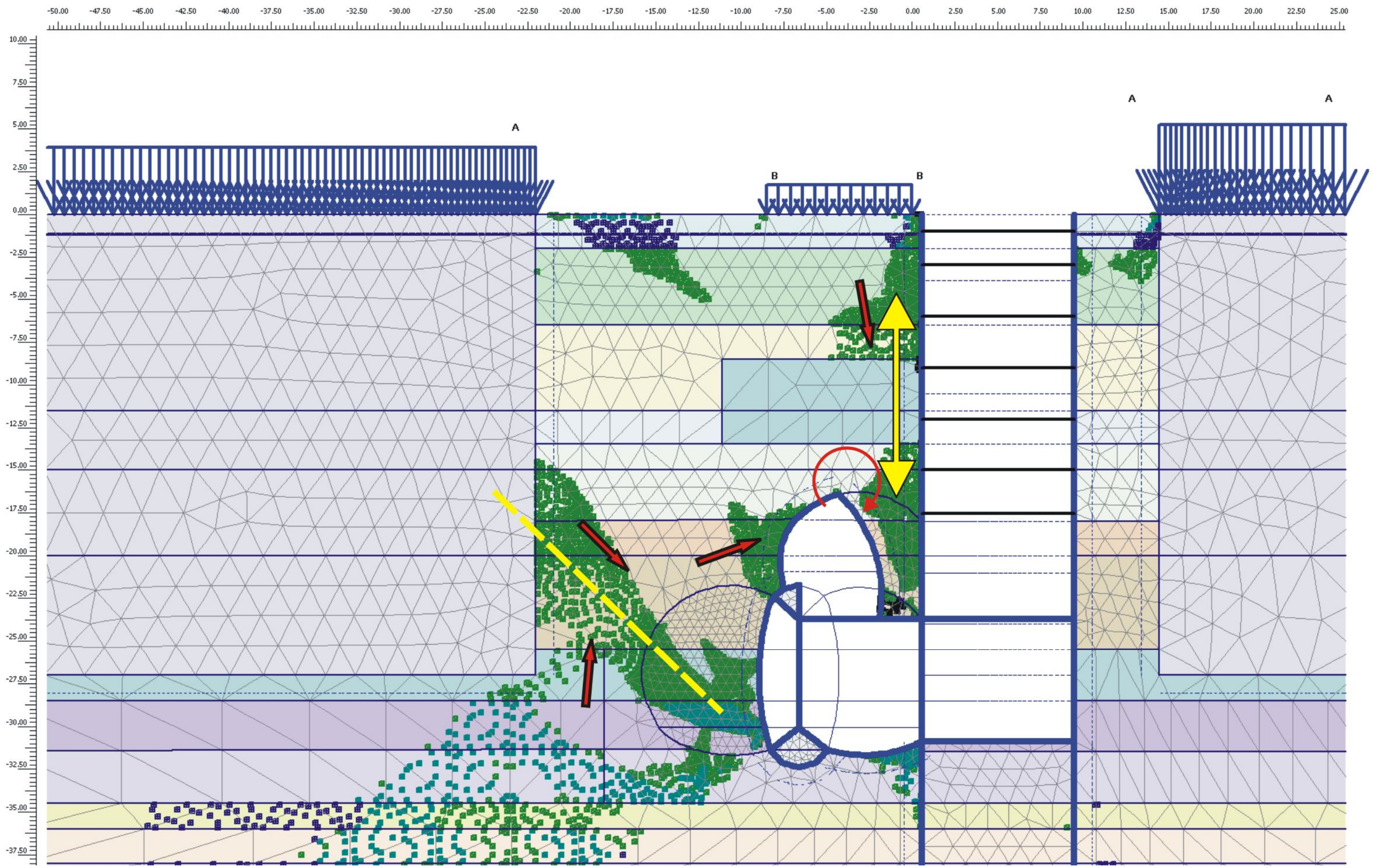


SANAM CHAI STATION (BINOCULAR MINED STATION TYPE)

RELATIVE SHEAR STRESSES



PLASTIFICATION POINTS



Design Influences

Design has to follow

- Excavation Aspects (e.g. Size, Shape, Drifts)
- Symmetrical Structure
- Computation
- Stress/Strain Relations
- Geotechnical Aspects (Presupport, Soil Improvement)
- Groundwater Control

Multiple Drift Excavation - Construction Influences

- Design and construction method does satisfy the project conditions defined by geology, geometry and environment.
- Construction activity on surface is limited and minimum impact to surface life and environment is provided.
- Multiple Drift Station is limited to construction access shafts to be covered

Multiple Drift Station - Structural Influences

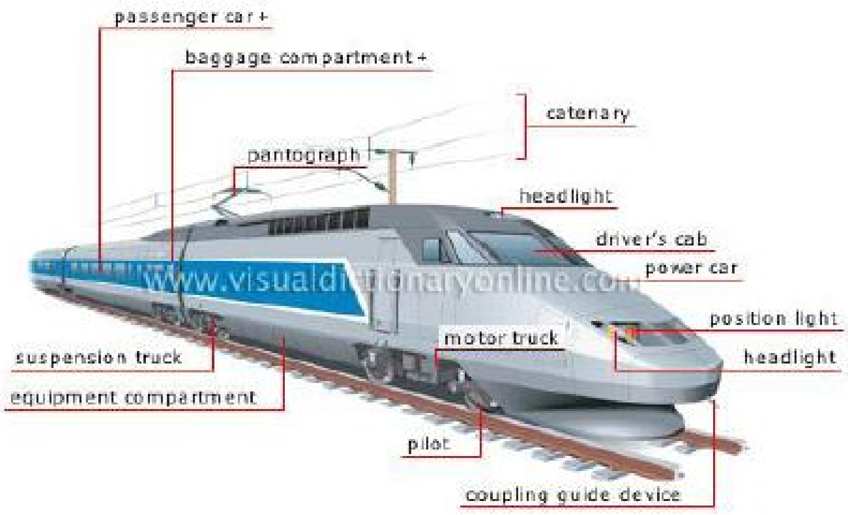
- Shotcrete Lining has to take full loading in construction
- Final Lining is designed to take full loading while shotcrete properties are converted into soil properties
- Lining dimensioning is based on superposition of loads

10. TRAINS IN THAILAND

10.1 Existing Railways

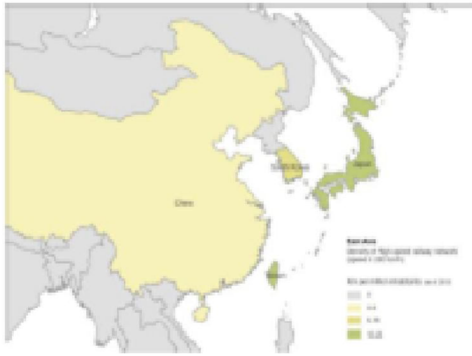
Thailand has 4,431 kilometers of meter gauge railway tracks (without MRTA). All national rail services are managed by the **State Railway of Thailand**. The 4 main lines are the Northern Line, ending in Chiang Mai, the Northeastern Line ending at Ubon Ratchathani / Lao border in Nong Khai Province, the Eastern Line ending at the Cambodian border in Sa Kaeo Province, and the Southern Line ending at the Malaysian border.

HIGH SPEED TRAIN IN THAILAND



GLOBAL HIGH SPEED TRAIN NETWORKS

v·d·e Country	In operation (km)	Under construction (km)	Total Country (km)
China	**4,840**	15,478	20,318
Japan	**2,118**	377	2,495
Spain	**1,963**	1,781	3,744
France	**1,872**	234	2,106
Germany	**1,032**	378	1,410
Italy	**923**	92[citation needed]	1,015[citation needed]
Republic of China (Taiwan)	**345**	0	345
South Korea	**330**	82	412
Turkey	**235**	510	745
Belgium	**209**	0	209
The Netherlands	**120**	0	120
United Kingdom	**113**	0	113
Switzerland	**35**	72	107



10.2 High Speed Trains

The **Kunming–Singapore Railway** is a proposed Railway that would connect Southwest China and Southeast Asia by rail. The line would run from Kunming, the provincial capital of Yunnan Province of China through Laos, Thailand and Malaysia to Singapore, with alternate routes through Vietnam, Cambodia and Myanmar.

High Speed Rail is of central importance for the transport system. People’s quality of life will be enhanced. Thailands future travel needs will be satisfied, its socio-economic sustainability will be improved.

Better Alignments with Tunnels for High Speed Rail

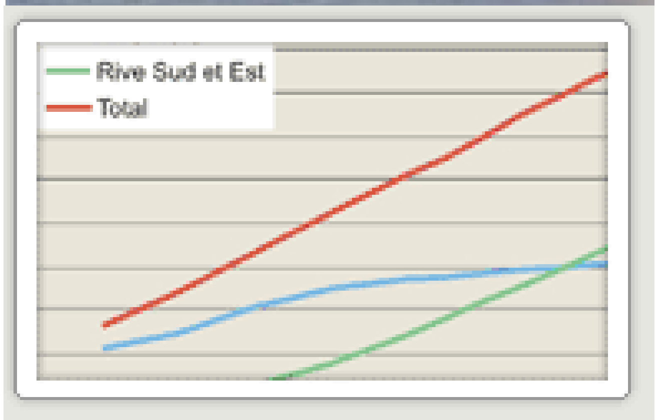
11. FLOOD WATER CONTROL

Innundated Industrial & Residential Estates (Thailand, November 2011)

- Unforeseeable Dimension of 2011 Flood in Thailand opened up new Needs to protect Society
- Limitations of Existing Flood Prevention Measures became evident
- Protection Needs open up new Opportunities for Strengthening existing Flood Securing Infrastructures
- New Technologies are challenged with Implementation

Risk of large Coastal Areas

- Implementing Innovative Use of Underground Space with advanced Technologies for Flood Prevention together with possible Energy Production provides benefits
- Actual Infrastructure are viewed in regard to long term Economic Development of countries and cities with large coastal areas.



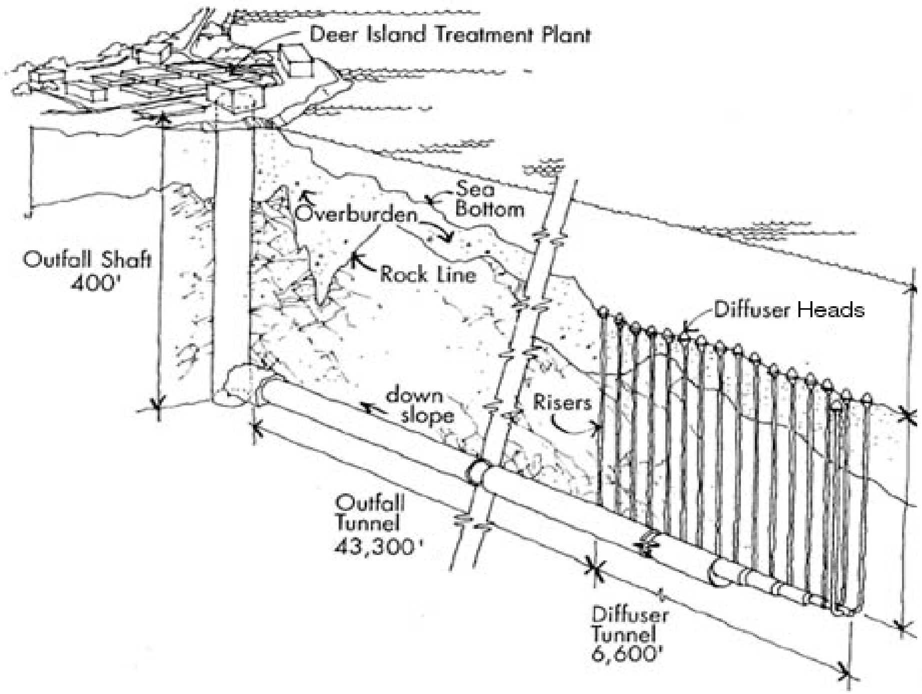
Population of coastal cities, 1950-2025

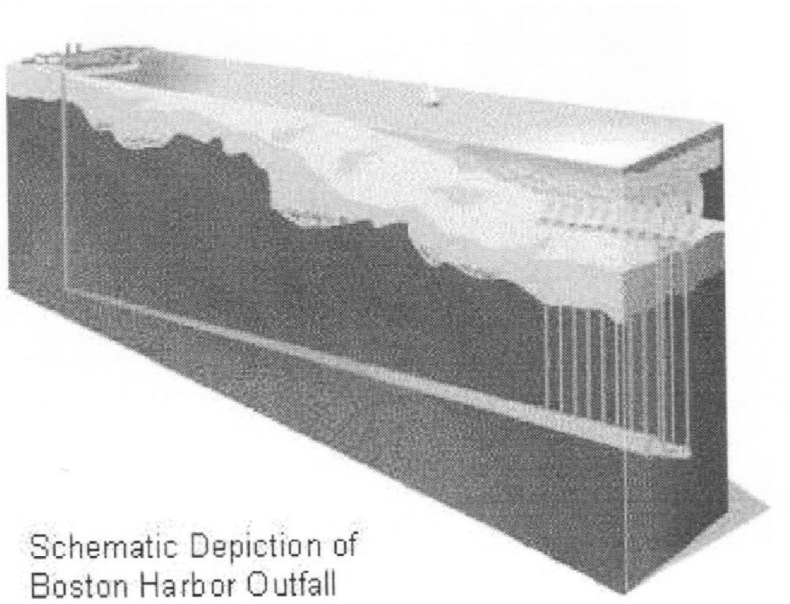
Flood Relief Underground

- The **Underground Concept** foresees collection of run off river waters in excess of regular discharge in the area of the intake structure shaft and water conveyance to the sea through a long tunnel .
- Flexibility of the Concept leaves both **Hydraulic and Structural details** open for adaptation to specific project conditions.

Boston Outfall Tunnel – Model Case

(in operation since 1999)

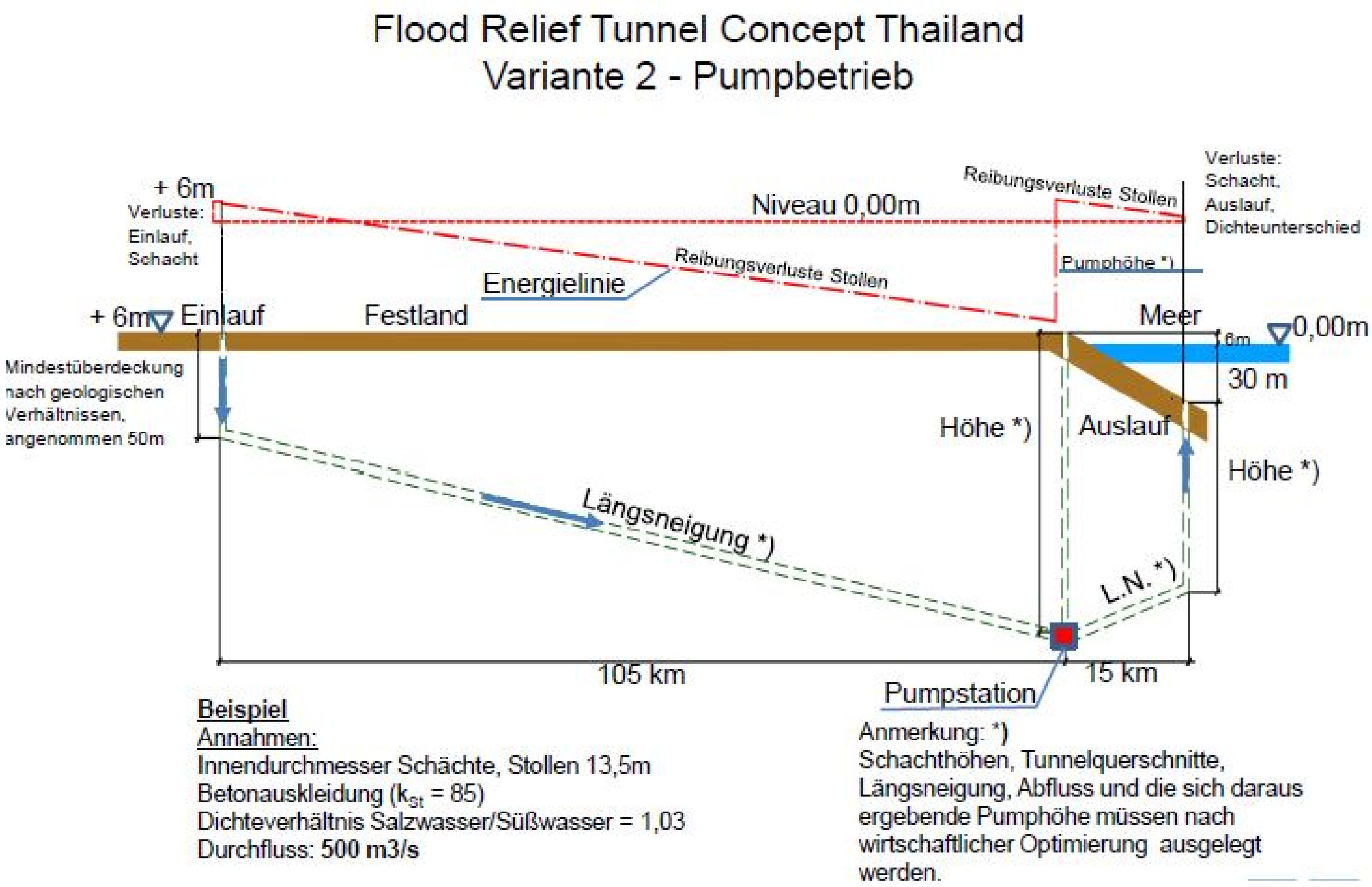




Schematic Depiction of Boston Harbor Outfall

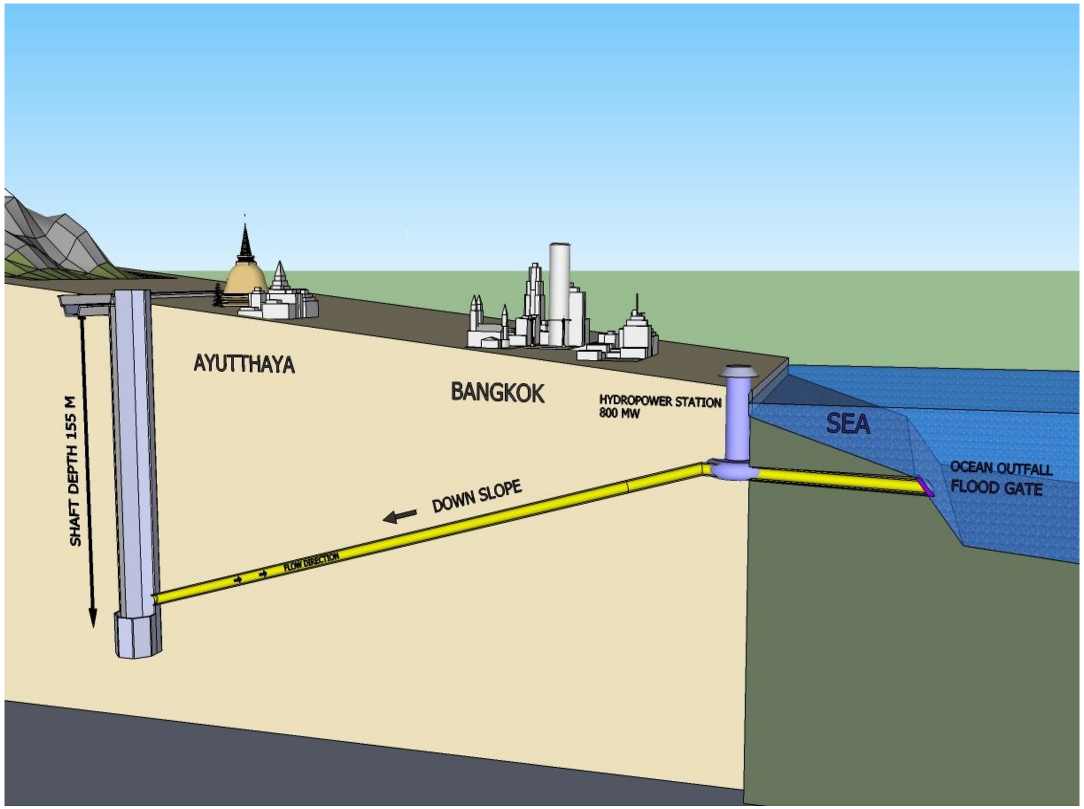
Flood Relief Tunnel – Pumping Flow Operation

(ILF/FRETUC Joint Proposal)



FRETUC – Flood Relief Tunnel Concept

- Hydraulic Model of the project could follow the Shaft / Tunnel Concept of Boston’s Outfall Tunnel
- Shallow/Deep Tunnel shall convey Flood Water in excess of regular Discharge into the Sea
- Surface areas will be provided with Water as much as needed, e.g. for agriculture
- Low Hydraulic Head will require Pumping



12. UNDERGROUND NUCLEAR POWER PLANTS

- Power Plants are manmade and designed to control the risk caused by natural disasters.
- To challenge the power of Nature on Surface has proven to be **risky.**
- World Economic Forum's 2011 'Global Risk Survey' ranks Seismic Disasters very likely with a perceived impact of **more than 200 Bion USD** in the next 10 years
- 2 Decades of Underground Nuclear Waste Disposal has converted Concerns of the Nuclear Power Industry into Confidence for using underground space.

Underground Powerhouse Advantages

- Cost Competiveness between Surface & Underground
- Preservation of Land Value in Powerhouse vicinity
- Better Control of operational/external Impact
- Better structural Stability in Seismic/Tsunami Impacts,
- More Reliability of continuous Grid Power Supply
- Reduced Risk of Revenue Loss
- Better Risk Control for Public Environmental Impacts
- Better Public Project Acceptance during entire Life Cycle

Seismicity & Operation

- **Nuclear Power Plants on surface have a high Risk** for Nuclear Accidents of any kind, e.g. because of operational loading conditions, seismic loads, or a combination of both.
- Risk for damages caused by earthquake acting on the finished structure still exists, even when structurally calculated being safe.

***Nuclear Power Plant Fukushima** (Japan, March 2011)*

Risk & Structure

- The Structural Calculation results in reinforced concrete of specified quality and thickness, together with the required geometric shape and location for installation.
- The **Global Risk Survey 2011** ranks Seismic Disasters very likely with a perceived impact of more than 200 Bion USD in the next 10 years.

Rock Cover vs. Concrete Cover

- Where Design follows Rock Mass Conditions, the Underground Power Plant has better protection.
- A Mountain itself provides essential protection, covering the Power Plant with Rock of multiple time thickness of structural Concrete.
- **Rock provides better protection** and control of the Risk than any structural Concrete.

Hydro Electric Power (HEP) Caverns

- More than hundred Underground Power Plants having major sized caverns were constructed globally in Hydropower.
- Major sized underground Caverns have more than approx. 150.000 m3 of excavation volume, with horizontal width between 25 m and 62 m, and cavern height exceeding 50 m.

View of Manapouri Powerstation machine hall in February, 2005.

Underground Powerhouse **Advantages**

- cost competiveness with surface powerhouses
- better preservation of land value
- better structural stability at seismic/tsunami impacts
- higher reliability of power supply to the grid
- better acceptance by public

13. **CONCLUSIONS**

- Thailands Infrastructure looks ahead of Technological Challenges including **Choice of Tunnelling Concepts**
- Urban Infrastructure will have to **use more underground space**
- Tunnelling solutions are offering significant advantages when it comes to mass rapid transit constructio
- **To better control cost and time** it is advisable to make use of education and training in underground construction
- **International scientific cooperation** for helping establishing manufacturing and supply of equipment for rail projects will help to tackle with market needs.
- **Better knowledge of tunnel technologies** will help to avoid surface problems while investing in underground solutions for flood control.
- **Future energy supply** via safe underground nuclear power houses will avoid future energy shortage.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