HERRENKNECHT AG | UTILITY TUNNELLING | TRAFFIC TUNNELLING

IMPACT OF THE GEOLOGY AND ROCK/SOIL MECHANICS ON THE DESIGN AND PERFORMANCES OF TBM.

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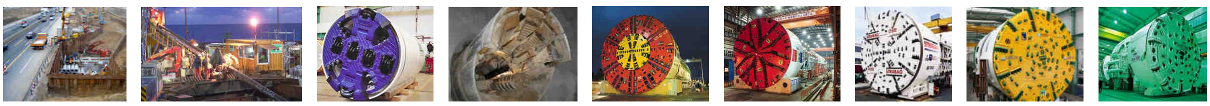
Herrenknecht AG, Germany

Namur, June 06, 2011.

LAYOUT OF THE PRESENTATION

- Introduction
- Geological consideration for TBM selection
- Types of TBMs and special design features
- Machine applications to specific project demands
    - High groundwater pressures
    - Complex geological and hydrogeological conditions
    - Large tunnels and multi-purpose tunnels
    - Tunnels excavated under particular conditions
- Tendencies in mechanized tunnelling
- Perspectives



INTRODUCTION - PARTICULARITIES OF THE TUNNELLING FIELD

Tunnel projects are linear and can extend for kilometers

Subsurface conditions can vary significantly along the alignment

Subsurface conditions influence means methods and construction cost

Underground "surprises" = commercial risk

Contractors don't accept risk, they price risk

Better to anticipate a risk event than being surprised

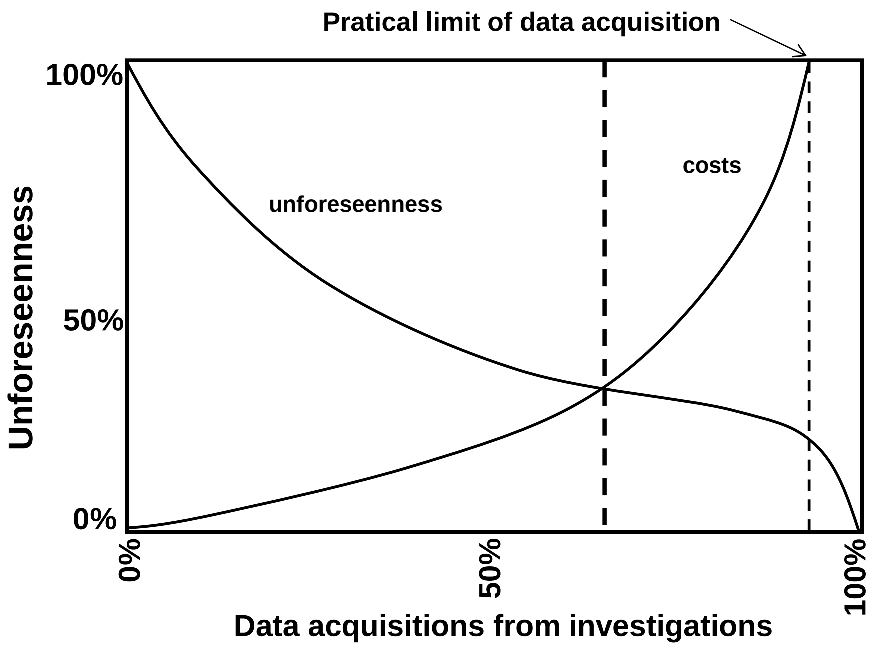
Owners want the lowest cost of construction for their projects

Contracts that anticipate risks will result in lower cost and fewer claims

- A good understanding of the geological and hydrogeological conditions is a key factor in optimizing the machine, increasing performances and reducing risks and costs

INTRODUCTION – GROUND RISK IN RELATION TO EXPLORATION

Ground risk in relation to extent of preliminary geotechncial investigation



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GEOTECHNICS – INFLUENCE OF GEOLOGY AND HYDROGEOLOGY

Geology or hydrogeology

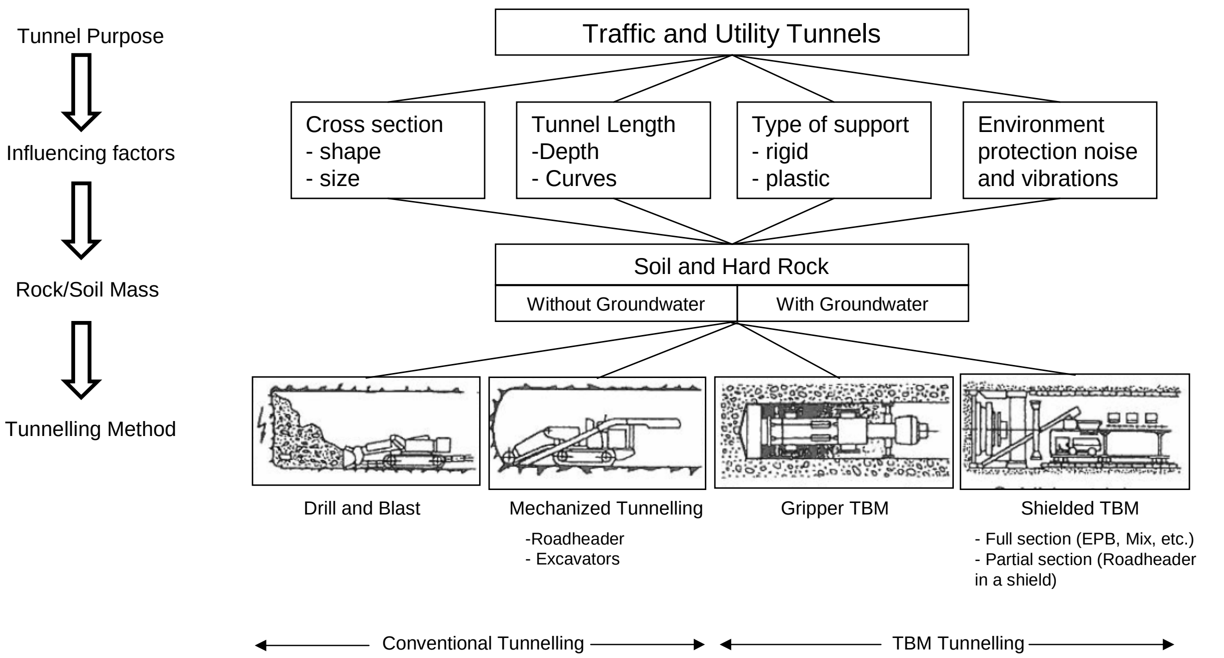
affect the way and extent of

- → overburden, settlement & heave
- → tunnel alignment, gradient
- → soil bearing capacity, soil stabilization
- → de-watering works
- → water permeability
- → soil conditioning
- → handling of boulders
- → tunnel face support
- → support medium, increase of thrust forces
- → soil disposal

Selection of machine and operation principle

Success of the project

SELECTION OF THE TUNNELLING METHOD



GENERAL DESCRIPTION OF THE TBM SELECTION PROCESS FOLLOWING DAUB RECOMMENDATION

Step 1
Analysis of geotechnical report and geological longitudinal profile (Basis: DIN4020)
Result: Pre-selection of the Tunnelling method

↓

Step 2
Analysis of the ground behavior (borability, face stability, settlement, wear prognosis, Material flow)
Result: Basic requirements for the excavation, face support, support medium, limits the TBM pre-selection

↓

Step 3
Classification of the Tunnelling Method
Result: Qualitative Prognose of the possible TBM Variants on the Tunnel section

↓

Step 4
Analysis of the expected mucking behavior (liquefaction, adhesion, wear)
Result: Definition of the expected mucking system performance and project logistic, limits the TBM pre-selection

↓

Step 5
Analysis and utilzation of the excavated material (soil compaction, disposability, re-use, separation
Result: Limits the TBM pre-selection

↓

Step 6
Definition of the advance classes, definition of the construction technique, TBM selection

↓

Step 7
Division in homogeneous sections, based on the construction technique
Result: Tunnel belt design, quantitative prediction for each homogeneous section and definition of advance classes

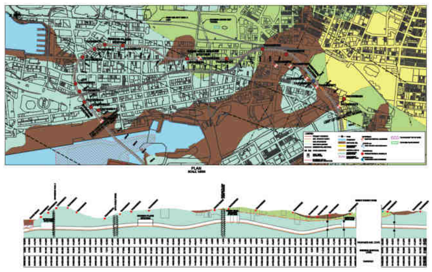
PROCESS OF TBM SELECTION – CHARACTERIZATION OF THE GEOLOGY

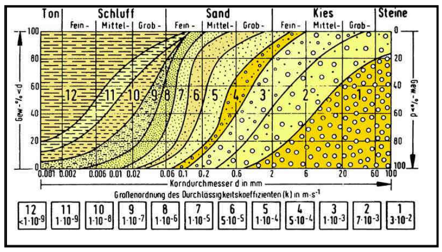
- Characteristics of ground types across project
- Percentage of ground types to be encountered
  - At shaft locations
  - By tunnel reach
- Ground conditions
  - Mixtures of different strata
  - Interlayered systems
  - Soil over rock
  - Soil mixtures
  - Rock mixtures
  - Conditions beyond excavation limits
- How the ground will respond to the excavation process
  - Open cut shafts, with or without dewatering
- Soils: firm, raveling, running, flowing, squeezing, swelling
- Rocks: massive, blocky and seamy, crushed

RELEVANT ROCK AND SOIL PARAMETERS FOR THE SELECTION AND DESIGN OF THE MACHINE

Soil: γ/γ' φ' c' LL PL PI w E_s k Quartz

- ☐ geological profile of the tunnel with vertical alignment of the tunnel, groundwater table and possibly borehole locations
- ☐ horizontal alignment of the tunnel with borehole locations
- ☐ for all soils which possibly are encountered:
  - ☐ grain size distribution curves
  - ☐ shear strength φ
  - ☐ cohesion c, undrained cohesion c_u
  - ☐ permeability
  - ☐ quartz content
  - ☐ for all fine grained soils in addition:
    - ☐ Atterberg limits: plastic limit, liquid limit, natural water content (consistency and plasticity indexes), porosity
    - ☐ type of clay (clay minerals)
- ☐ possible existence of boulders: rock type, expected amount, expected sizes, UCS, quartz content, CAI
- ☐ possible existence of layers of hard rock:
  rock type, rock quality, RQD, UCS (unconfined compression strength), tensile strength, DRI, CLI, quartz content, CAI, elastic modulus (E-Modulus), porosity and crevasse formation, faults
- ☐ Bedding/faults
  Bedding: stratification of the rocks, thickness of the layer (cm), formation
  Faults: stratification of the faults, crevasse distance, crevasse opening, formation, size/form of crevasse contour
- ☐ Reconnaissance and consequence of the groundwater conditions
  - Maximum water inflow
  - Permeability of the rock
- ☐ Investigation of the swelling behaviour
- ☐ Borelogs
- ☐ max./min. overburden





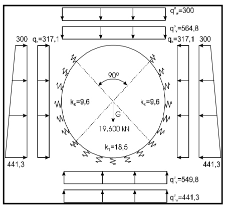
Rock: γ/γ' UCS BTS CAI RQD E k

DESIGN OF THE TBM BASED ON THE GEOLOGY AND THE GEOTECHNICAL PARAMETERS

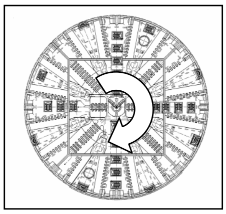
GEOLOGY + HYDROGEOLOGY

GEOTECHNICS

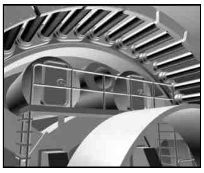
design of shield structure



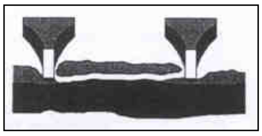
torque calculation



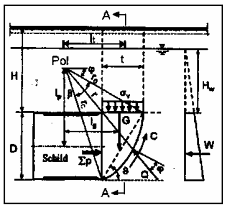
thrust force calculation



wear prognosis



support pressure calculation



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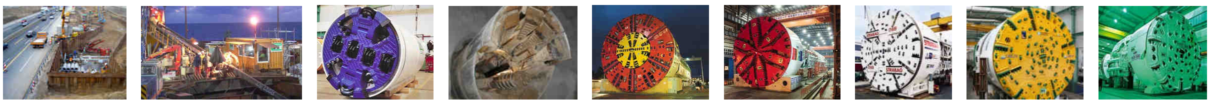
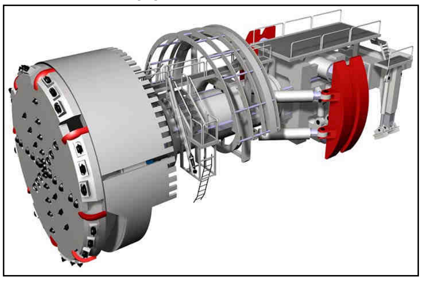
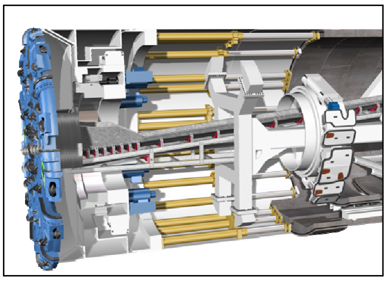


TYPES OF TUNNEL BORING MACHINES FOR HARD ROCK AND SOFT SOILS

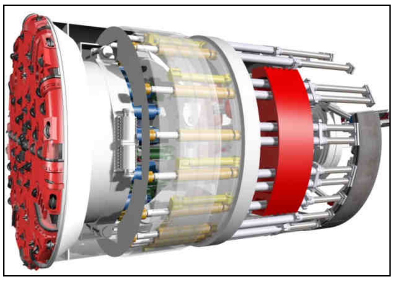
Gripper Machine

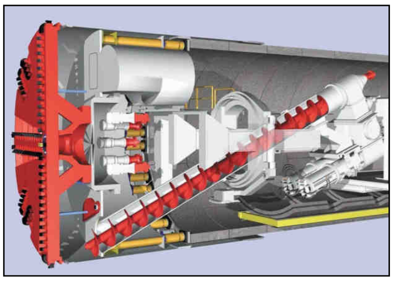


Single shield

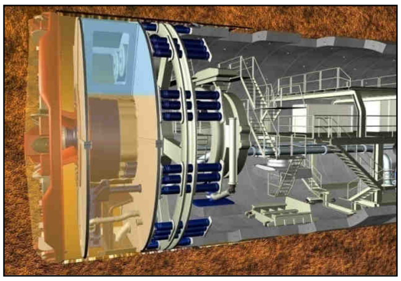


Double shield





Earth Pressure Balanced (EPB)

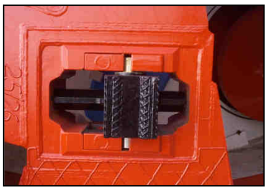


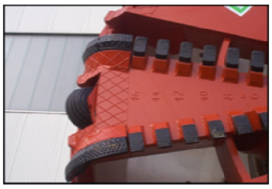
Slurry or Mixshield

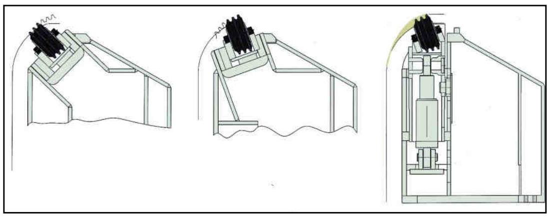
SPECIAL DESIGN FEATURES
CUTTERHEAD DESIGN - OPENING RATIO

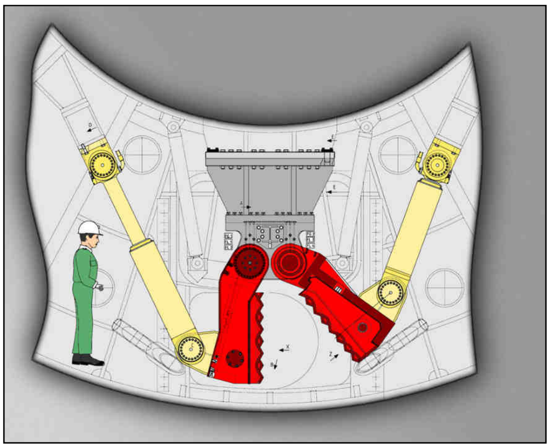
- The cutterhead has to be strong enough to excavate rock section and/or open enough to allow a sufficient material flow.

SPECIAL DESIGN FEATURES
CUTTING TOOLS – OVERCUT – STONE CRUSHER









SPECIAL DESIGN FEATURES
WEAR PROTECTION – PRIMARY AND SECONDARY WEAR

SPECIAL DESIGN FEATURES
CUTTING WHEEL INTERVENTION – SAFETY ASPECT: THE ACCESSIBLE CUTTERHEAD




- Atmospheric access to cutting tools
- Easy access to information about wear of each cutting tool and steel structure
- Drastic reduction of hyperbaric interventions
- Possibility to flange man lock to center
- Possibility to increase pressure within the accessible cutting wheel

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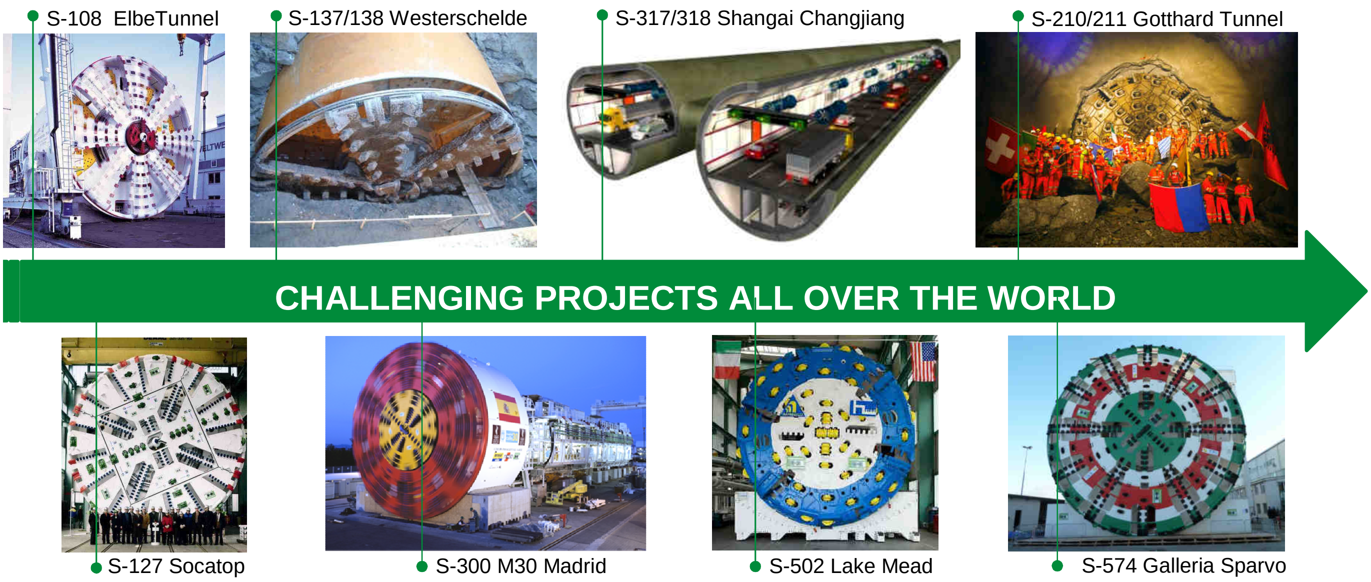

S-108 ElbeTunnel
S-137/138 Westerschelde
S-317/318 Shangai Changjiang
S-210/211 Gotthard Tunnel
CHALLENGING PROJECTS ALL OVER THE WORLD
S-127 Socatop
S-300 M30 Madrid
S-502 Lake Mead
S-574 Galleria Sparvo

CHALLENGING PROJECTS ALL OVER THE WORLD…

… AND ALSO IN BELGIUM!

S-464 | Diabolo | Belgium

Mixshield

Diameter: 8,270mm

Tunnel length: 2 x 2,127m

Cutterhead power: 600kW

Geology: Fine Sand and Limestone interbeddings

Customer: W&F, Vinci, Smet Tunneling, CEI-De Meyer, MBG

CHALLENGING PROJECTS ALL OVER THE WORLD…

… AND ALSO IN BELGIUM!

S-533 | Liefkenshoek | Belgium

Mixshield

Diameter: 8,390mm

Tunnel length: 2 x 5,971m

Cutterhead power: 1,100kW

Geology: Sand and locally Boomse Clay

Customer: W&F, Vinci, MBG, CEI-De Meyer

CHALLENGING PROJECT…
… IN COMPLEX GEOLOGY AND UNDER HIGH WATER PRESSURES

HALLANDSAS – PUSHING THE LIMITS OF MECHANIZED TUNNELLING

S-246 | Hallandsas | Sweden

Convertible Mixshield (Hard Rock – Slurry)

Diameter: 10,530mm

Tunnel length: 2 x 5,500m

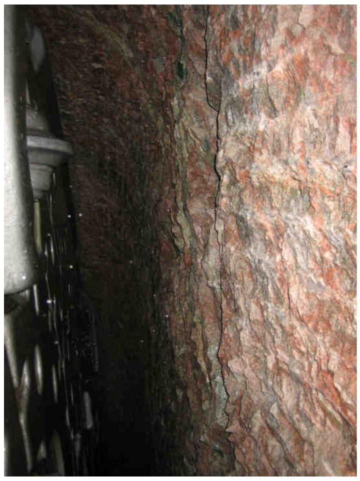
Cutterhead power: 4,000kW

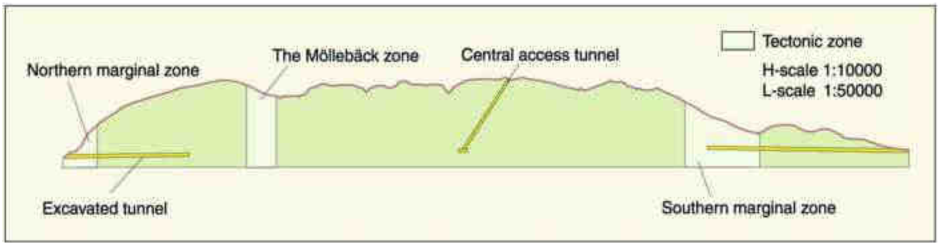
Geology: Gneiss, Amphibolite, Diabase Dykes

Customer: Skanska/Vinci JV

THE HALLANDSAS RIDGE.

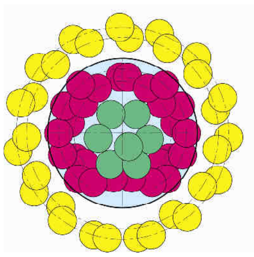
- Excavation of hard and abrasive rock mass
- Zones of soft soil and mixed face conditions
- Waterbearing rocks with high potential water inflow
- Static water pressure above 10 bar along the majority of the alignment
- Potential face instabilities
- Strict environmental (legal) restrictions on water inflow volume

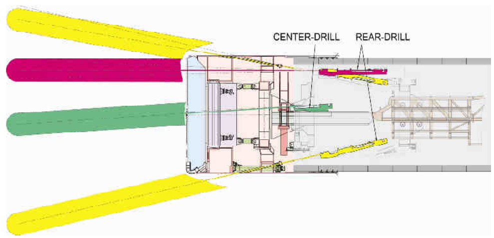




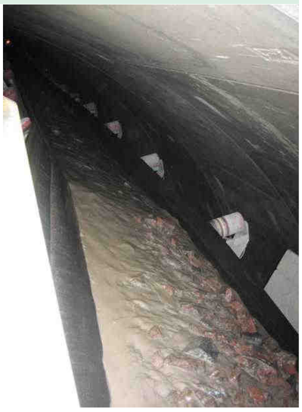
THE SOLUTION. FULL HYBRID TBM FOR DUAL-MODE OPERATION.

- Three basic levels of operation
- Open mode with dry primary muck discharge system (TBM conveyor) and powerful dewatering system
- Open mode with cyclic pre-excavation grouting (multiple drilling systems in different locations)
- Closed mode with hydraulic (slurry) muck discharge system and positive face support

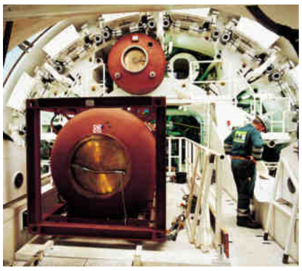


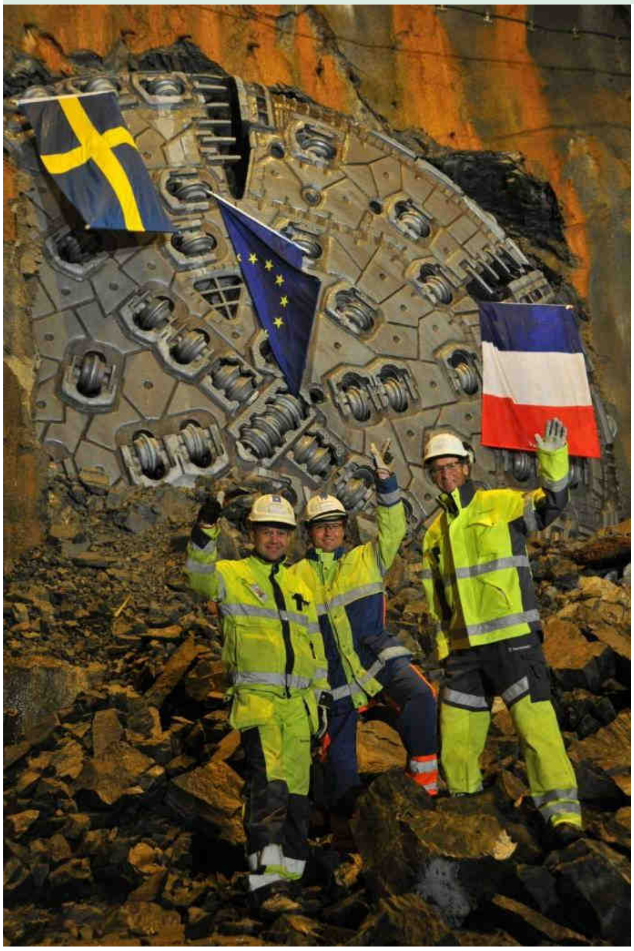


TUNNELLING AT HALLANDSAS: PUSHING THE LIMITS.



- Articulated hard rock cutterhead with 19” backloading cutter discs
- Wear reinforced cutterhead
- Pressure compensated disc cutters
- Special dewatering features in cutterhead and TBM conveyor belt
- Cascade bearing seal system real size shop tested at 16bar
- Full hyperbaric shield installation and transport shuttle for saturation mode





TUNNELLING AT HALLANDSAS

- Breakthrough 1st tube: August 25, 2010.

CHANGING GEOLOGICAL CONDITIONS IN FINNETUNNEL

S-419/420 | Finnetunnel | Germany

Convertible Mixshield (Slurry - Hard)

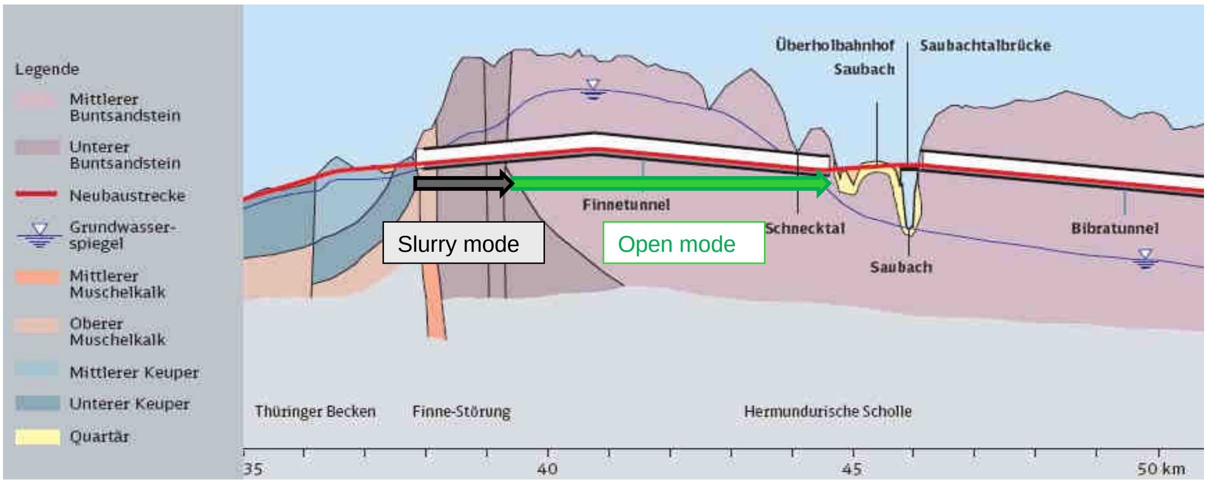
Diameter: 10,820mm

Tunnel length: 2 x 6,808m

Cutterhead power: 3,800kW

Geology: Sandstone, Claystone

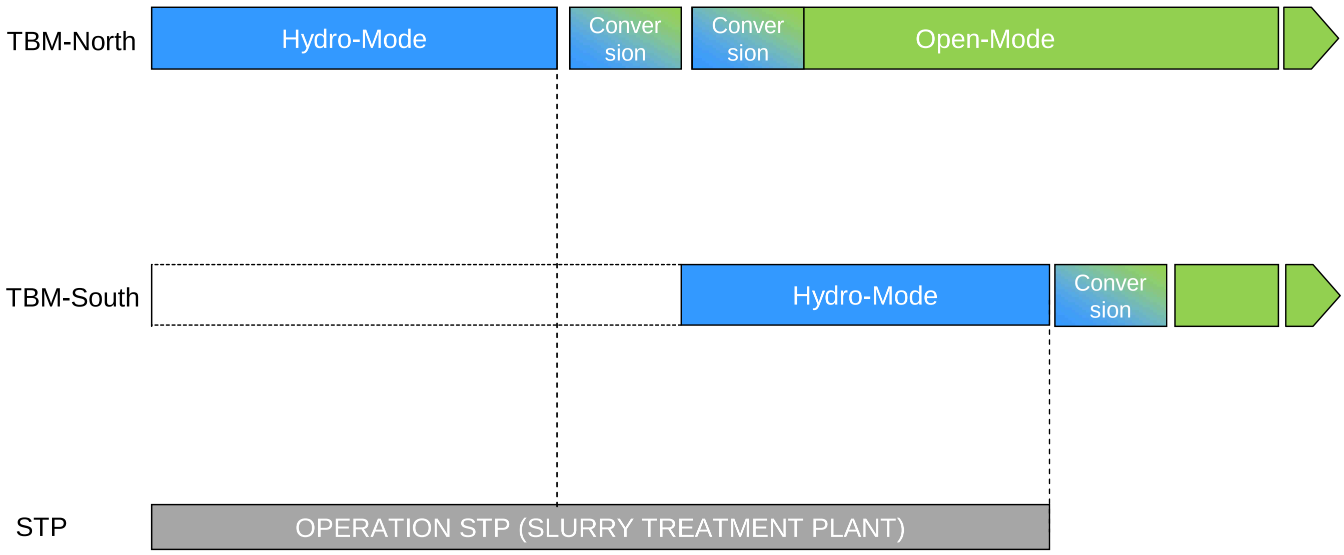
Customer: Wayss & Freytag, Max Bögl, Porr



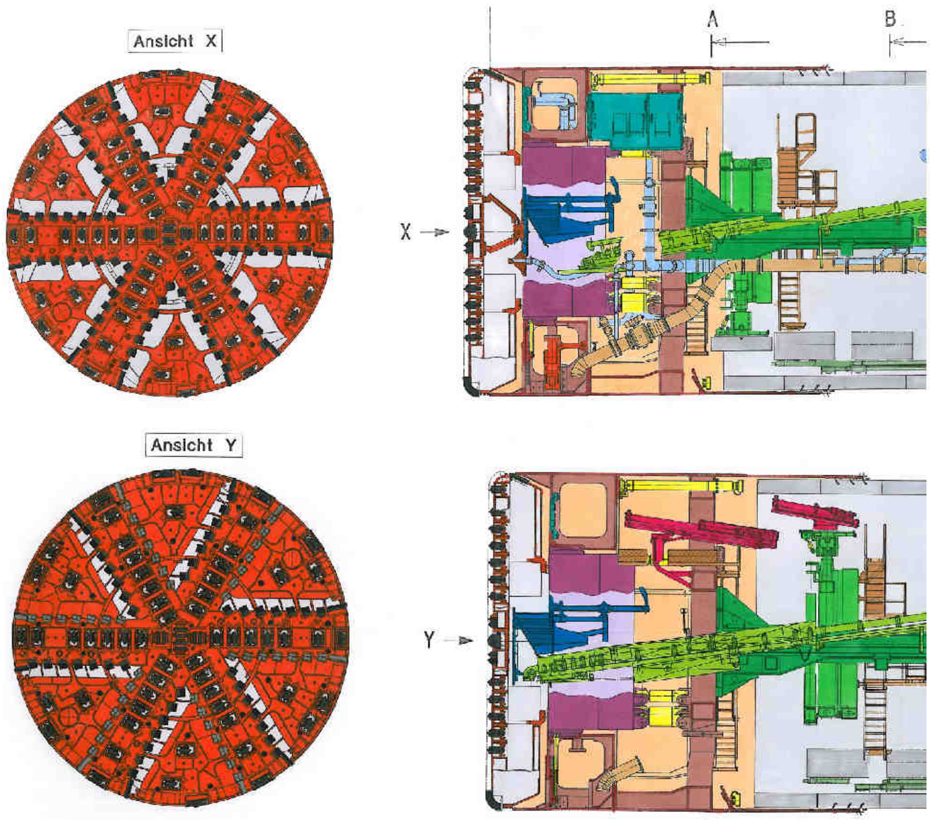
CHALLENGE: COMPLEX GEOLOGY.

- Finnetunnel, Germany
- Railway tunnel
- 2 Convertible Mixshield TBMs

PROJECT OVERVIEW FINNETUNNEL.
SEQUENCES OF TBM TUNNELLING.



FINNETUNNEL | GERMANY, CONVERTIBLE MIXSHIELD

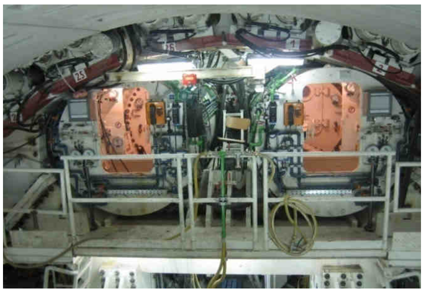


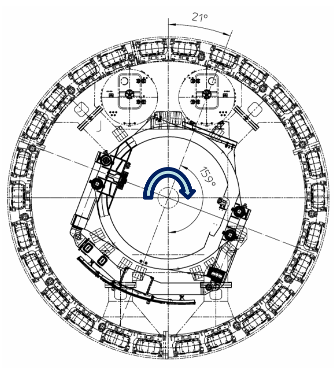
closed mode

open mode

RECONSTRUCTION CLOSED MODE – OPEN MODE
DISASSEMBLY SLURRY-SET

Locks



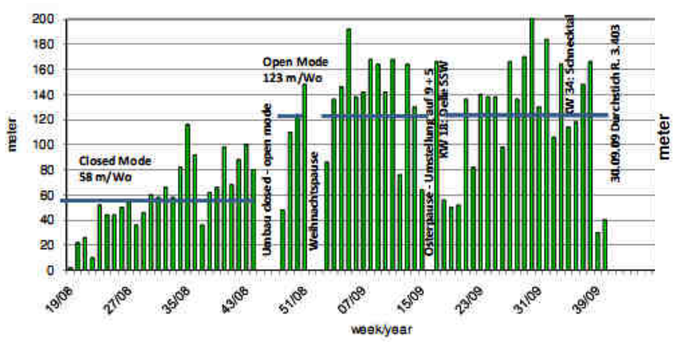


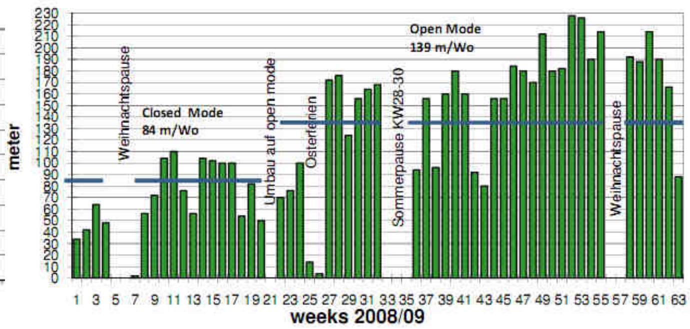
Crusher

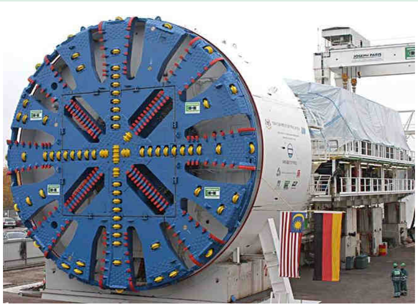
Pipes

FINNETUNNEL - ANALYSIS ADVANCE PERFORMANCES, OPEN-CLOSED MODE.

- Advance performance in open mode limited due to segment production 110 rings/week
- S-419: Breakthrough Sept. 09 ⇨ 4 months prior to schedule
- S-420: Breakthrough Febr. 10 ⇨ 7 months prior to schedule



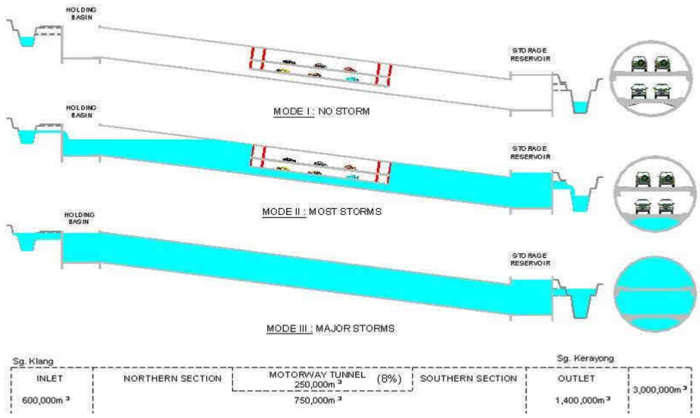


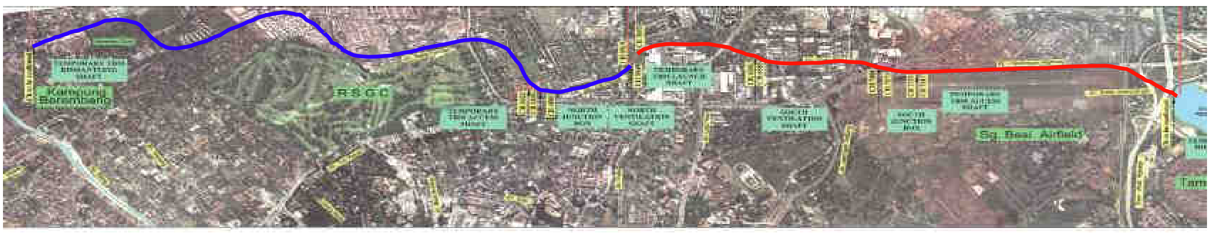


S-252 and S-253 | SMART | Kuala Lumpur | Malaysia

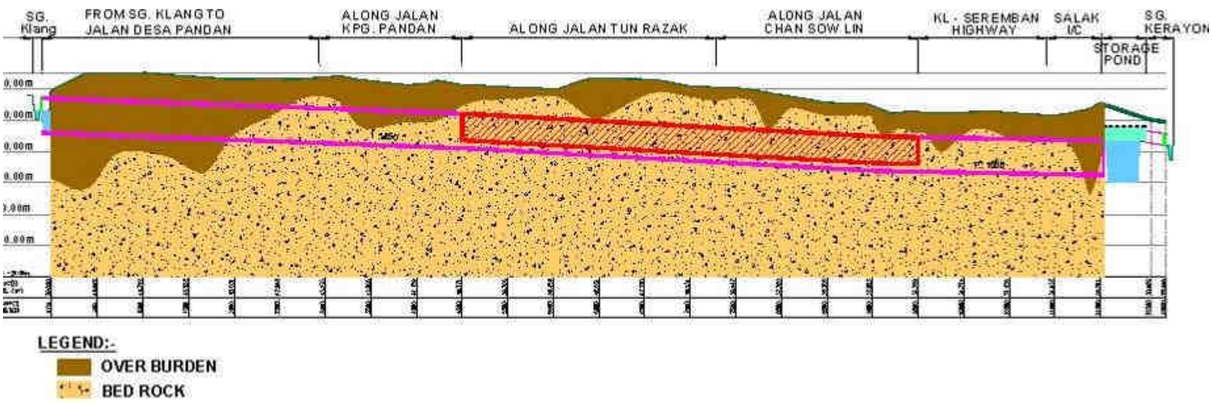
2 Mixshields
Shield diameter: 13,210mm
Tunnel length: 9,350m
Geology: Limestone, sand, marble
Customers: MMCEG-Gamuda JV; Wayss+Freytag AG

THE SMART IDEA.
MULTI-FUNCTION TUNNEL IN KUALA LUMPUR.





SMART TUNNEL KUALA LUMPUR.
GEOLOGICAL CONDITIONS.



- 70 % traverses karstic limestone and sections in compact and fresh marble
- 30 % traverses quaternary alluvial deposits (silty, gravely sand) and mine tailings
- Road tunnel section is marked red

THE WORLD'S LARGEST EPB SHIELD.

S-300 | Road Tunnel M30 | Madrid | Spain

EBP Shield

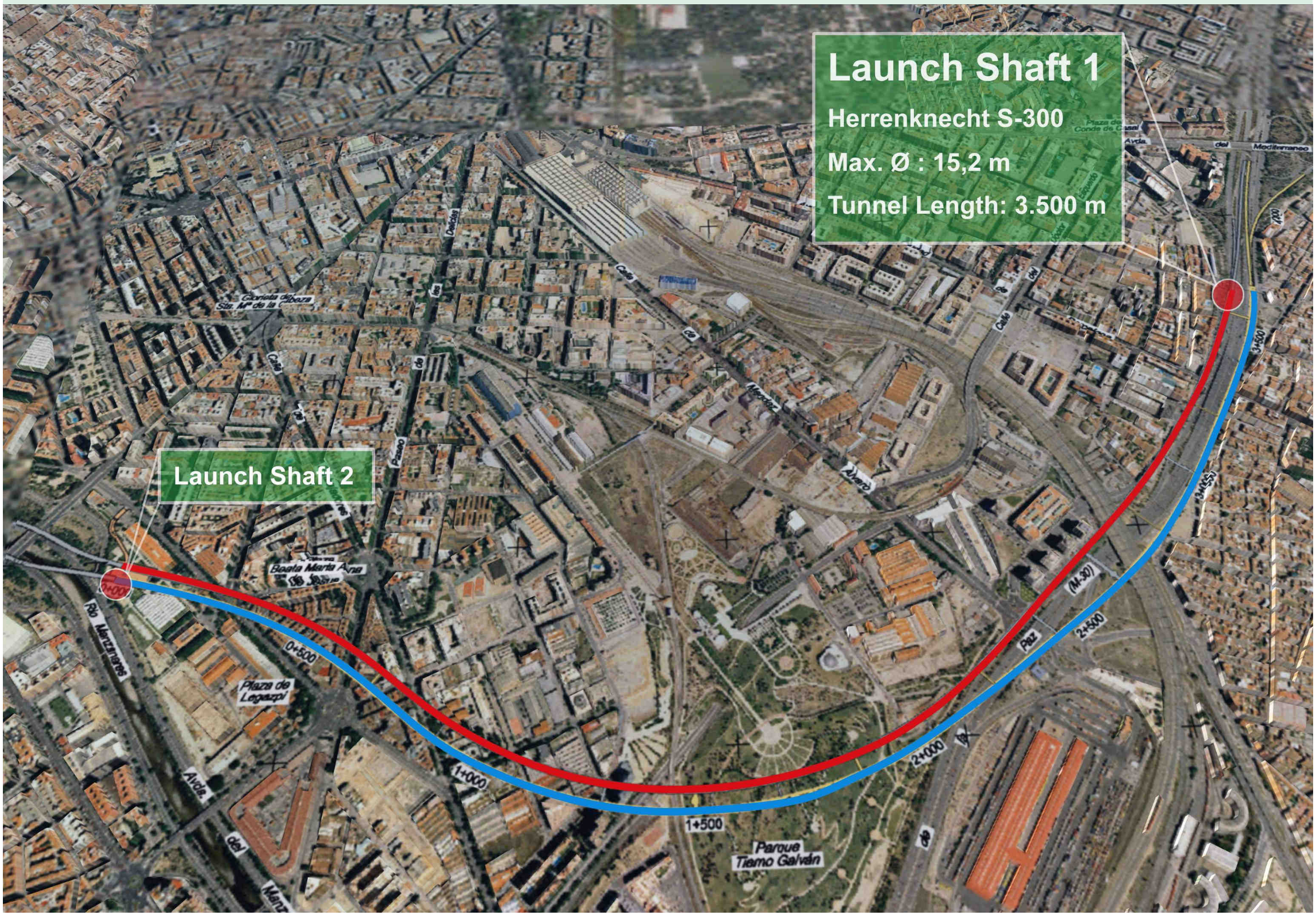
Diameter: 15,200mm

Tunnel length: 3,600m

Cutterhead power: 12,000kW + 2,000kW

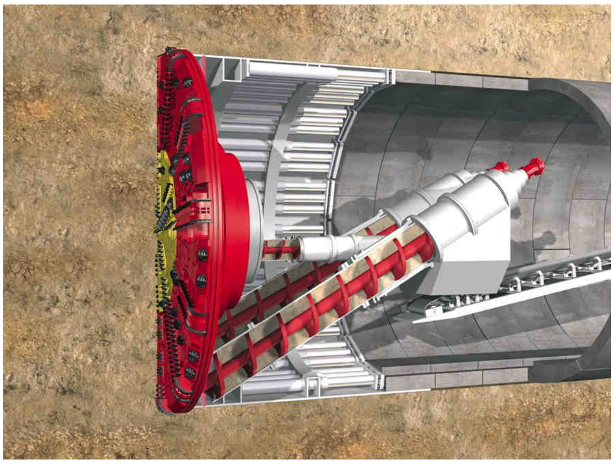
Geology: Clay, gypsum

Customer: Ferrovial Agroman, S.A., Acciona Infrastructuras


Launch Shaft 1
Herrenknecht S-300
Max. Ø : 15,2 m
Tunnel Length: 3.500 m
Launch Shaft 2
0+500
1+000
1+500
2+000
2+500
Plaza de Legazpi
Parque Tierno Galván

REQUIRED MACHINE CHARACTERISTICS.

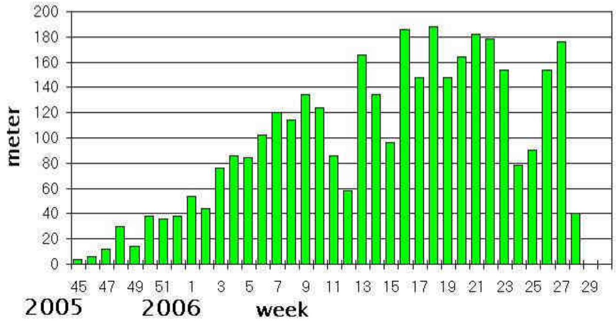
- Required cutting wheel drive torque of 125,000,000Nm
- Limitation of the shield roll due to the high installed torque
- Agitating of the excavated material in order to prevent clogging in the centre area
- Excavation and conditioning of $363m^3$ for an advance of 2m at a maximum speed of 65mm/min



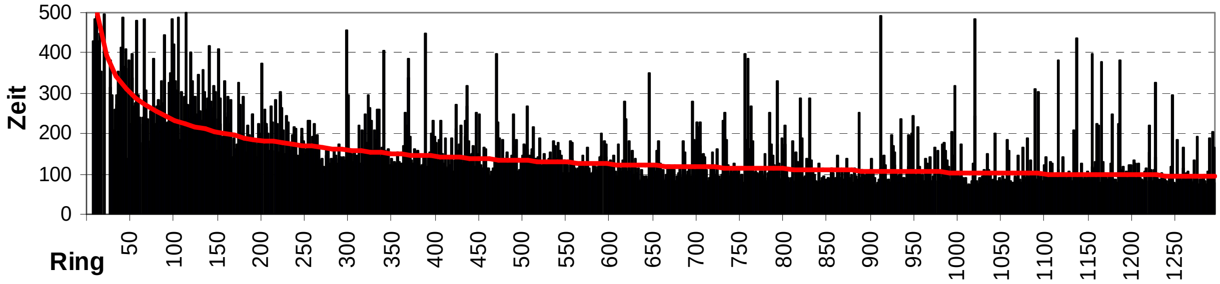
THE MACHINE DESIGN.

- Two independent drive units allowing counter clockwise rotation
- 32 foam generators with a max capacity of 700m³/h
- Three screw conveyors with a capacity of 2x900m³/h and 1x250m³/h

SPEED TUNNELLING IN MADRID.



- Completion of the advance in 8.5 months, 3.5 months
- Cycle times for excavation of 2m length incl. ring erection



June 2, 2004
Machine ordered at Herrenknecht

Feb. 2, 2005
Beginning of workshop assembly

June 6, 2005
Workshop acceptance

Nov. 5, 2005
Start of Tunnelling

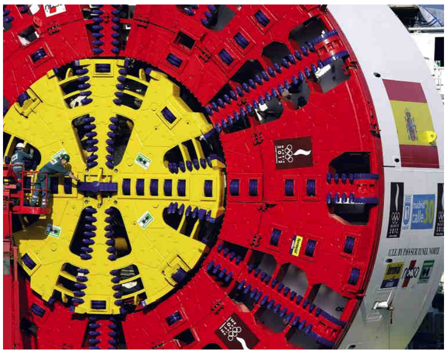
July 17, 2006
Breakthrough

March 23, 2007
Inauguration

2005

2006

2007



HERRENKNECHT
Tunnelling Systems

S-441 | Escalator Shaft | St. Petersburg | Russia

EPB Shield

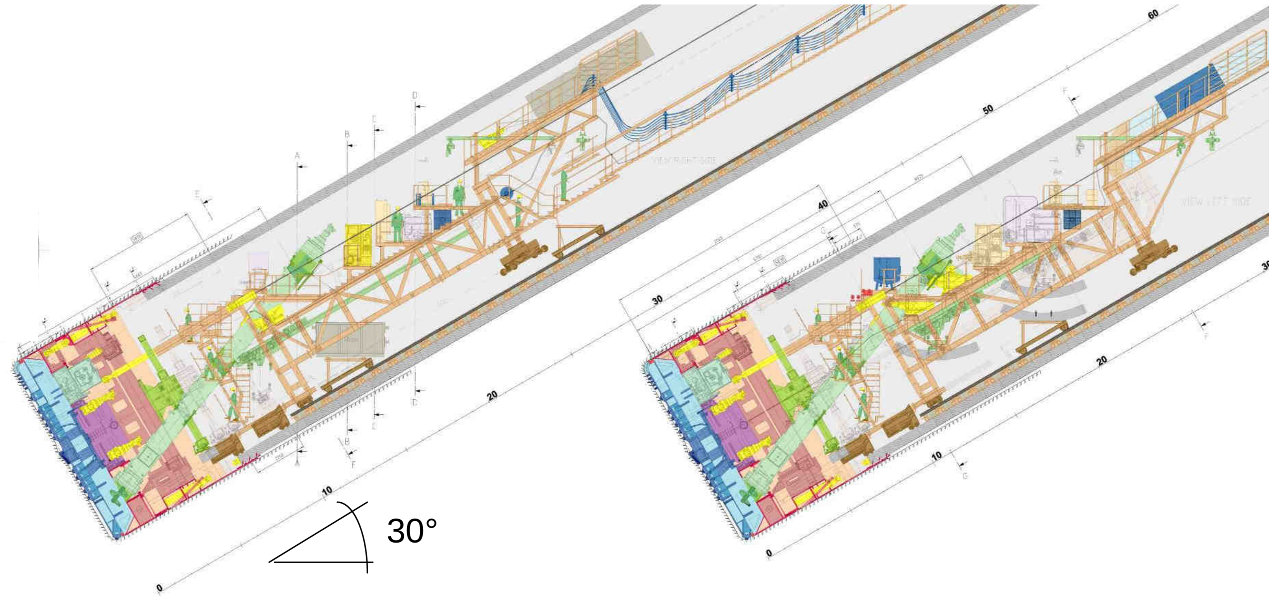
Diameter: 10,690mm

Cutterhead power: 1,200kW

Tunnel length: 120m

Geology: Soft and hard clay

Customer: OAO Metrostroy

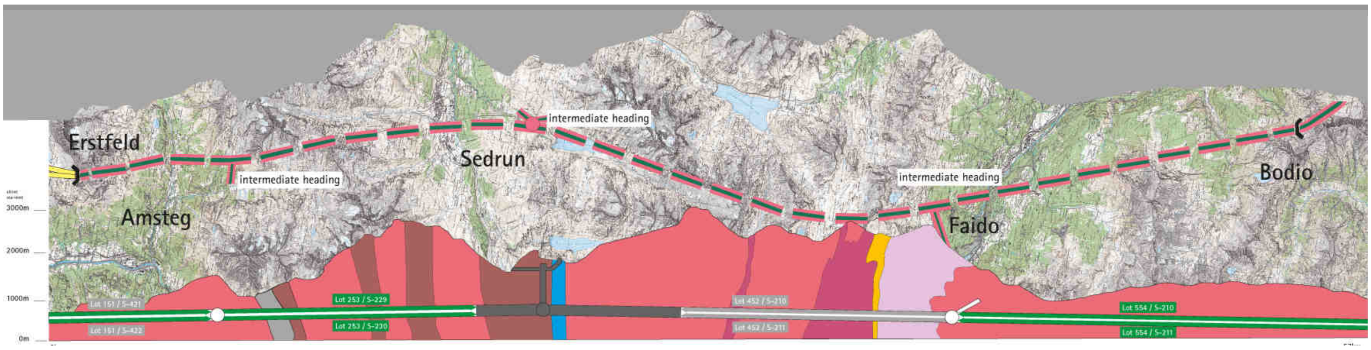


ESCALATOR SHAFT ST. PETERSBURG.

Gotthard Tunnel | Switzerland

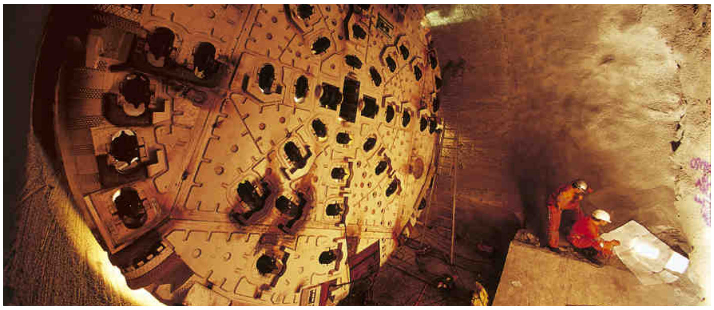
4 Gripper TBMs
Diameter: from 8,830mm to 9,580mm
85km of mechanized tunnelling
Up to ~2,500m overburden

Geology: Granite, Gneiss, Schistose Gneiss
Tectonically active massif (alps folding)



GOTTHARD BASE TUNNEL - CHALLENGES

- The TBMs were able to excavate
  - In hard and abrasive rock conditions, sometimes less favorable than expected (fault zones)
  - Under extremely high overburden
  - In squeezing ground conditions (~1m convergence)
  - Very long tunnel sections
- The tunnelling systems used were capable of mastering significantly more difficult situations than originally thought.



LAYOUT OF THE PRESENTATION

- Introduction
- Geological consideration for TBM selection
- Types of TBMs and special design features
- Machine applications to specific project demands
  - High groundwater pressures
  - Complex geological and hydrogeological conditions
  - Large tunnels and multi-purpose tunnels
  - Tunnels excavated under particular conditions
- Tendencies in mechanized tunnelling
- Perspectives



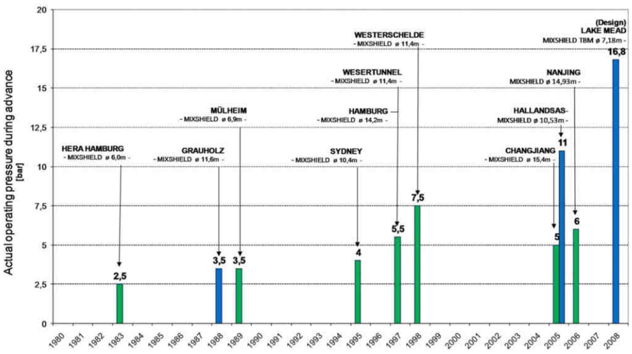






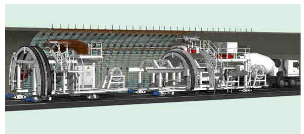
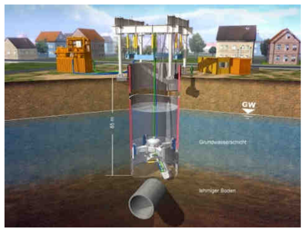
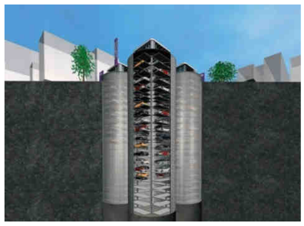
TENDENCIES IN MECHANIZED TUNNELLING.

- More complex challenges in terms of construction ground and logistics
  - Gotthard Base Tunnel (high rock overburden, fault zones, squeezing rock conditions), M30 Madrid (inner city tunnelling with Ø15.20m)
- Long tunnel drives with larger diameters under high groundwater pressure
  - Gotthard Base Tunnel (2x57km), Shanghai (Ø15.43m), Lake Mead (17bar)
- Demand for well-engineered technology to produce high-capacity infrastructure systems.



PERSPECTIVES.

- Now and in the future: Demand for high-efficient infrastructure
- Push for innovations:
  - Safety, cost effectiveness, efficiency, integrated package solutions
  - Technical solutions for every challenge
- Large scale infrastructure schemes to benefit from economic stimulus plans
- Teamwork Tunnelling to guarantee best possible project success: project owners, planers/ consultants, constructors, machine suppliers)

THANK YOU FOR YOUR ATTENTION.