TBM IN SOFT GROUND


13.10.2011
Course in Tunnelling and Tunnel Boring Machine
Kurs w zakresie drążenia tuneli oraz maszyny drążącej

EARTH PRESSURE BALANCE SHIELD

- 1. Tunnel face
- 2. Cutting wheel
- 3. Excavation chamber
- 4. Pressure bulkhead
- 5. Thrust cylinders
- 6. Screw conveyor
- 7. Segment erector
- 8. Segmental Lining
The face support is provided by the excavated ground that is kept under pressure inside the excavation chamber by balancing the volume of the extracted and excavated material and by the thrust jacks on the shield. Excavation debris is removed from the excavation chamber by a screw conveyor that allows the pressure control by variation of its rotation speed.
EPB-SHIELD.
FOUR MODI: OPEN TO CLOSED.

- slurry mode
- closed mode
- closed (compressed air) mode
- open mode
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EPB-SHIELD.
MODE: SLURRY / CLOSED.
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EPB-SHIELD.
MODE: CLOSED (compressed air) / OPEN.
EPB-SHIELD: THE SCREW CONVEYOR
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EPB-SHIELD: SCREW CONVEYOR
EPB-SHIELD.
SCREW CONVEYOR. PRESSURE DISTRIBUTION.
The lower part of the bulkhead in the front shield of an EPBS must be equipped with a safety gate, which can be closed when the screw conveyor is retracted for maintenance. This allows the complete insulation of the plenum, avoiding water/material inflow during maintenance.
EPB-SHIELD:
APPLICATION RANGE AND CONDITIONING.

- **open shield possible**
  - clay
  - silt
  - coarse soil
  - foam + polymers

- **conditioning necessary**
  - foam and additives
  (clogging – adhesion of soil)
  - silty sand
  - very coarse soil
  - foam, polymers and fuller

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GEOTECHNICS: SOIL RECOMMENDATION

Clay | Silt
---|---

- **EPB closed mode**
- **Additive against clogging**
- **Additive to plastify**

Sand | Gravel
---|---

- **very strong permeable**
- **very permeable**
- **permeable**

- **high viscosity bentonite**
- **Mixshield**
- **EPB + Additive**

Consistency $I_C$

Permeability $k$ [m/s]
FOAM: CLOGGING-ADHESION ON STEEL SURFACE

Consistency Index $I_C$

- hard
- hard-stiff
- stiff
- soft
- pulpy

Plasticity Index $I_p$ [%]

- Low clogging risk
- Medium clogging risk
- High clogging risk
Soil recommendation for EPB-mode:

- cohesive and plastic
- soft stiff consistency
- small inner angle of friction
- low permeability
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CONDITIONING AND FOAM GENERATION

- Tenside
- Water
- Screw conveyor
- Pressure bulkhead
- Cutting wheel
- Air
- Liquid
- Additive
- Tenside
- Polymer
Properties of foaming:
- plastic
- short term cohesion
- lower angle of friction
- lower permeability

Advantages of foaming in soft soil:
- reduction of friction angle of soil
- short term cohesion of soil
- plasticity and lower permeability of soil
- lower wear
- lower torque
- short term stabilisation of face
- lower clogging
- soil structuring

Different foams have different:
- foaming capacity
- stability
- Anti-clay capacity
- rheological impact (liquefaction / stiffening)
- drying-up capacity
FOAM: CONDITIONING IN SOFT SOIL

- Low cohesive sand
- Short-term cohesion via foam
Foam Injection Rate (FIR):

- FIR regulates amount of foam
- FIR correlates with pore volume
- FIR = volume foam / volume soil
- FIR correlates with advance rate
FOAM: FOAM EXPANSION RATE

Foam Expansion Rate (FER):
- FER regulates quality
- low FER = wet foam
- high FER = dry foam
- FER = volume foam/volume liquid

Additive (2 – 5%)
Water (95 – 98%)
FER 14:1

1 Liquid
13 air
Use of Anti-clay-Additives in clay as well as in silt & sand:

- Problem
  - adhesion on steel surface
  - cohesion of greater clay lumps

- Conclusion
  - clogging of cutting wheel
  - clogging of screw conveyor or excavation chamber
FOAM CONTROL AND FOAM GENERATOR.

- Automatic Mode
- Semi-Automatic Mode (FER)
- Manual Mode (FIR/FER)

- short distance to tunnel face
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EPB TBM vs. SLURRY TBM
TBM DESIGN CONSIDERATION

CRITERIA FOR SELECTION OF EPB OR SPB

Geological conditions
  ▪ Grain size distribution
  ▪ Water level and pressure
  ▪ Presence of boulders or obstructions along the alignment

Availability of use of conditioning agents and/or bentonite
Feasibility and space for treatment plant
Final use and discharge of excavated muck
Experience of contractor
Capital cost
The basic design of an EP TBM and a SPB TBM are quite similar. The overall appearance and many systems from one type are used directly on the other. These similarities include:

- Main structures
- Propulsion
- Trailing gantry Structure
- Segment Erector and handling
### EPB vs. SLURRY

<table>
<thead>
<tr>
<th>EPB TBM</th>
<th>SLURRY TBM</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Overall simpler system to learn, operate and maintain</td>
<td>• Overall a more complicated system (to learn, operate and maintain)</td>
</tr>
<tr>
<td>• Applicable to a wider range of grounds</td>
<td>• Applicable to a restricted range of grounds</td>
</tr>
<tr>
<td>• Requires limited addition of conditioning materials (lower consumption of additives – no slurry circuit)</td>
<td>• Requires extensive addition of materials</td>
</tr>
<tr>
<td>• In case of face collapse amount of ground loss is limited</td>
<td>• In case of face collapse amount of ground loss is considerable</td>
</tr>
</tbody>
</table>
### EPB vs. SLURRY

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<thead>
<tr>
<th>EPB TBM</th>
<th>SLURRY TBM</th>
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<tbody>
<tr>
<td>• Muck is immediately ready for disposal</td>
<td></td>
</tr>
<tr>
<td>• Able to take advantages of selfsupporting grounds (i.e. open mode)</td>
<td></td>
</tr>
<tr>
<td>• Higher overall production rates</td>
<td></td>
</tr>
<tr>
<td>• Requires a limited space for assembly and launching</td>
<td></td>
</tr>
<tr>
<td>• Low environment impact</td>
<td></td>
</tr>
<tr>
<td>• Requires a sophisticated slurry separation plant</td>
<td></td>
</tr>
<tr>
<td>• Cannot take advantage of selfsupporting grounds (i.e. no open mode)</td>
<td></td>
</tr>
<tr>
<td>• Advance rate of TBM directly affects all aspects of slurry performance</td>
<td></td>
</tr>
<tr>
<td>• Requires a large size job site</td>
<td></td>
</tr>
</tbody>
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EPB vs. SLURRY

**EPB TBM**
- Lower capital cost
- Required confinement pressure must be calculated in advance of tunnelling
- Requires higher torque
- Requires greater Cuttinghead power

**SLURRY TBM**
- High environmental impact
- Higher capital costs
- Required confinement pressure is detected and controlled by the system
- Requires lower torque
- Requires less Cuttinghead Power
**EPB vs. SLURRY**

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<tr>
<th>EPB TBM</th>
<th>SLURRY TBM</th>
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<tbody>
<tr>
<td>• Muck is exposed into tunnel, contaminated grounds can present problems</td>
<td>• Contaminated muck is not exposed until it reaches the surface</td>
</tr>
<tr>
<td>• Able to process a larger diameter boulder</td>
<td>• Requires a sophisticated extraction system</td>
</tr>
<tr>
<td></td>
<td>• Insulation of pipes from weather</td>
</tr>
<tr>
<td></td>
<td>• Higher accuracy in pressure confinement</td>
</tr>
<tr>
<td></td>
<td>• Higher power requirement</td>
</tr>
</tbody>
</table>
EPB vs. SLURRY

EPB TBM

• High usage of energy on site, the slurry pumps must continuously function
• Constant monitoring and adjustment of slurry parameters are required to achieve production and muck removal requirements
• Requires a overburden of at least one TBM diameter as a minimum
• Difficult to maintain slurry pressure at constant level when the extracting pipe clogs - up
• Able to integrate rock crusher

SLURRY TBM
## TYPE OF FACE SUPPORT

<table>
<thead>
<tr>
<th>CRITERIA</th>
<th>EPB</th>
<th>SLURRY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cuttinghead Power/Torque</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Overall site Power Requirements</td>
<td>Moderate</td>
<td>High</td>
</tr>
<tr>
<td>Use of Additives</td>
<td>Required</td>
<td>Required</td>
</tr>
<tr>
<td>Capitol Cost</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Required Site Size</td>
<td>Moderate</td>
<td>Large</td>
</tr>
<tr>
<td>Disposal excavated Material</td>
<td>Easy</td>
<td>Complex</td>
</tr>
<tr>
<td>Speed of Excavation</td>
<td>Fast</td>
<td>Moderate</td>
</tr>
<tr>
<td>Cleanliness of Tunnel</td>
<td>Poor</td>
<td>Good</td>
</tr>
<tr>
<td>Calculation of Required Pressure</td>
<td>Predetermined</td>
<td>Automatic</td>
</tr>
</tbody>
</table>
THANK YOU FOR YOUR ATTENTION!!

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