Tunneling Lectures 2011
Speciality Chemicals for Tunnel Boring Machines

Lars Langmaack
Jaime Ibarra
180 years of TBM History

1825, GB (Thames Tunnel) Sir Marc Brunel
1846, F (Mount Cenis) Henri Joseph Maus
1853, USA (Hoosac Tunnel) Charles Wilson
1869, GB (London) Barlow-Greathead

1882, GB (channel tunnel) Beaumont / English
1907, Germany old Elbtunnel
1931, Germany Schmidt Kranz
1952, USA 1st Robbins TBM

1958, Austria Alpine shield
1965, France (Paris) Robbins, RER System
1968, Germany Wirth TBM
1988 Robbins, Eurotunnel
2006, Spain (Madrid) world’s largest EPB
TBM design vs geology
3 main classics

- **hard rock**
  - Foams & Polymers against abrasion and dust
  - Main bearing sealant

- **EPB**
  - Soil conditioning
  - Annulus grout
  - Tail sealant
  - Main bearing sealant

- **slurry**
  - Tail sealant
  - Main bearing sealant

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Earth pressure balance (EPB) TBM

water / foam / polymer / anti-clay additive

tail sealant

annulus grout
Soil Changes
with MEYCO SLF soil conditioning agents

dry soil
+ water
+ soil conditioning

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Torque Reduction
with MEYCO SLF Foam in Clay Soil, Herrenknecht test rig

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Soil types

- Clay
- Silt
- Sand
- Gravel
- Boulders

![Soil types diagram](image-url)
soil conditioning and soil mechanics

angle of internal friction $\phi$ [°]

cohesion [kPa]

clay
silt
gravel
working chamber

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Example of conditioned EPB soil
actual range of EPB use
weak ground under groundwater pressure

- Clay adhesion & clogging: use foam and anti-clay-additives
- Silty sands: use foams
- Coarse, frictioned soil: use Foam & Polymers
- Very coarse, frictioned soil: use Foam & special Polymers + fine filler
importance of EPB driving modes in soft ground

- **no pressure open mode**
- **air pressure >= water pressure**
- **earth pressure = soil pressure + water pressure**
What mother nature gave to us: geological profile

- granite
- weathered granite
- silty sand
- sand
Soil conditioning agents

1. foams
   - Allow filling of the working chamber
   - Increase the TBM speed
   - Reduce abrasion, torque

2. anti-clay-additives
   - Reduce clogging, adhesion, transport problems
   - Increase the TBM speed

3. polymers
   - Increase soil adhesion, impermeability
   - Reduce liquid soil consistency
   - Reduce settlements
soil conditioning I
foam
Foam Types

**Ionic Classes**

- **Anionic**
  - **Cationic**
  - **Amphoteric**
  - **Non-Ionic**

**Structures**

- **Linear Alkyl**
- **Branched Alkyl**
- **Dual hydrophilic Groups**
creation of tunnelfoam
soil conditioning system on TBM
schematic view
TBM Foam & Polymer parameters

- Foam concentration $c_F = 100 \times \frac{m \text{ (foam conc.)}}{m \text{ (foaming liquid)}}$
- Foaming liquid + polymer $c_P = 100 \times \frac{m \text{ (polymer)}}{m \text{ (foaming liquid)}}$
- Foam (+ polymer) $\text{FER} = \frac{V \text{ (air N liters)}}{V \text{ (foaming liquid)}}$
- Foam (+ Polymer) + soil $\text{FIR} = 100 \times \frac{V \text{ (foam)}}{V \text{ (soil)}}$
Important: Foam Quality
over wide range of FER and output quantity
Injection Points
at the TBM cutterhead
soil conditioning II
anti-clay-additives
change of clay behaviour
with Rheosoil anti-clay-additives

Clay + water & foam

Clay + foam & Rheosoil

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Madrid MetroLam project – belt view

foam

foam + RHEOSOIL

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soil conditioning III
long chain polymers
how do polymers work?

MEYCO Fix SLF P2
Singapore Metro

only foam used
water content too high

foam with 5% SLF P1
too much polymer used
block creation

foam with 3.5% SLF P1
acceptable situation
2-3% polymer would be sufficient
TBM site examples
LOVAT EPM TBM
Assembly in the shaft
Aviles geology

[Diagram showing geological layers and locations labeled with coordinates and geotechnical designations.]

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effect of structurizing polymers

2,5 bar sea water pressure
use of foam

2,5 bar sea water pressure
use of foam & polymer

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## TBM parameters & advance rates

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Lutites</th>
<th>Sand</th>
<th>Silty Clay</th>
<th>Dolomite</th>
<th>Total Tunnel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average advance (m/day)</td>
<td>16.50</td>
<td>27.00</td>
<td>14.00</td>
<td>20.50</td>
<td>20.00</td>
</tr>
<tr>
<td>Max. Advance (m/day)</td>
<td>31.00</td>
<td>50.50</td>
<td>29.00</td>
<td>32.40</td>
<td>50.50</td>
</tr>
<tr>
<td>Average excav. time (min/ring)</td>
<td>46.00</td>
<td>16.00</td>
<td>35.00</td>
<td>40.00</td>
<td>24.00</td>
</tr>
<tr>
<td>Average installing time (min/ring)</td>
<td>21.00</td>
<td>18.00</td>
<td>15.00</td>
<td>15.00</td>
<td>16.00</td>
</tr>
<tr>
<td>Average thrust pressure (Ton)</td>
<td>200-300</td>
<td>600-800</td>
<td>300-500</td>
<td>800-900</td>
<td></td>
</tr>
<tr>
<td>Average torque (Ton x m)</td>
<td>60</td>
<td>80</td>
<td>130</td>
<td>170</td>
<td></td>
</tr>
</tbody>
</table>
Aviles Collector, Spain
successful breakthrough
universal TBM
adoption to geology by soil conditioning

LYON 1997
NFM EPB, Ø=10.98m
1.5-3 bar water pressure
foam + polymer  + bentonite

BARCELONA 2003
Herrenknecht EPB, Ø=12.06m
up to 2.0 bar water pressure
foam + polymer  + filler suspension
Barcelona Metro L9, geological overview
Barcelona Metro L9, project UTE L9

TBM-characteristics:

- $d = 11.95\, \text{m}$
- $\text{force} = 110\, \text{MNm}$
- $\text{torque} = 37\, \text{MNm}$
- $\text{power} = 7.15\, \text{MW}$
- $26\%$ open shield
Barcelona Metro L9, project UTE GORG

TBM-characteristics

- $d = 12.06 \text{ m}$
- $\text{force} = 110 \text{ MNm}$
- $\text{torque} = 38 \text{ MNm}$
- $\text{power} = 5.32 \text{ MW}$
- 35% open shield
Barcelona Metro L9
laboratory tests for porous soil

- Pure soil
- Soil with foam
- Soil with more foam
- Soil with foam + polymer + filler
Toulouse Metro Project

Line B consists of 20 stations, 13,000m bored tunnel

- Lot 2: Herrenknecht EPB TBM 4.731m
- Lot 3: CSM Bessac compressed air TBM 1.000m
- Lot 4: FCB Slurry TBM 3.700m
- Lot 5: FCB EPB TBM 3.400m

Lot 2:
Camponon Bernard TP & Eiffage TP
The TBM

**EPB TBM S-208**
- shield length: 8.50m
- shield diameter: 7.750m
- cutterhead diameter: 7.785m
- TBM speed \( \leq 80 \text{ mm/minute} \)
- EPB pressure \( \leq 3 \text{ bar} \)
- installed power: 2.000 kW
- driving force: 55.75 kN
- jack force: 6.000 tons

**Segments**
- diameter: 6.80m (5+1)
- length: 1.40m
- thickness: 340mm
- total segment number: 26.000
- total muck excavation: 225.000m\(^3\)
  or 517.000 tons
Toulouse Metro project
sieve curves

Toulouse (F) ’2003
HK EPB, Ø=7.72m
mainly under water table

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Toulouse soil parameters
(clogging risk after Thewes)
Lab tests with Toulouse soil

Addition of water and standard foam

Addition of water, Foam and RHEOSOIL anti-clay-agent
Toulouse Metro project
conditioned soil comparison

dry excavation
homogeneous & plastic soil
with Foam and RHEOSOIL

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Toulouse Metro Lot 2
cutterhead comparison

dry mode & empty chamber
plastic mode & full chamber
with RHEOSOIL®
EPB conditioned soil
Worlds biggest EPB TBM
Madrid M30 motorway project

With a diameter of 15.20m, the TBMs excavate an area of 181.5m² for implementing a 3 lane motorway including sidewalks.
Start Shaft North
EPB Tunnelling in the Toronto Area

Worlds biggest EPB TBM, MHI
Madrid M30 motorway project, Spain
Worlds biggest EPB TBM, HK
Madrid M30 motorway project, Spain
Anti-Abrasion and Anti-Dust Technology
ABR 5
typical situations in hard rock TBM excavation

excessive wear is a direct cost issue
- cutter cost
- maintenance cost (cutter changes stressful and time consuming)
- damaged cutters can lead to cutter head damages

down time
- the more frequent cutters have to be changed, the more down time it means for the TBM
- during down time the tunnel does not make any progress!

dust & temperature
- not good for the worker’s health
- reduce life-time of equipment
- expensive exhausting
Is really necessary to develop anti-wear products?
why using ABR5?

**current practice: injecting water**
- lots of dust is not cached by the water
- the cutter temperature can still be higher than 100° C
- the use of water contributes to higher cutter wear.

**use of MEYCO® ABR5 makes the difference**
- effective dust suppression makes the working environment healthier and increases the life time of the electronic equipment
- cutter temperature can be reduced down to 60-80° C (depending on the conditions) due to better heat transfer and mucking out
- increase of life time of the cutter sealing
- decrease of wear due to lubrication effect and reduced water injection
- decrease of TBM downtime due to reduced maintenance needs
needs to use MEYCO® ABR5

MEYCO® ABR5 is delivered to the cutterhead as a foam. Therefore foam needs to be generated and transported to a number of different injection points on the cutterhead.

Example Wirth TBM, Guadarrama installation of a simple rotary coupling in order to serve independently 5 injection ports on the cutterhead
needs to use ABR5

For the application, a **dosage pump** is needed to produce an aqueous solution of MEYCO ABR5 which then will be foamed up with a **foam generator**.

**dosage pump**
- flow up to 10 l/min
- pressure up to 10 bar

**foam generator**
- 3-5 channels depending on TBM diameter
- typical output per channel: 0.5m³/min
Application Parameters

**how much MEYCO® ABR 5 is needed to be effective?**
- around 1 litre MEYCO ABR5 per m³ rock in situ

**what expansion rate should be used?**
- depending on the geological conditions, typical FER of 10-12

**how much Foam should be injected?**
- typically 250 to 300 litres per m³ rock (FIR=25-30%)

**how much additional water should be injected?**
- additional water injection can be drastically reduced up to completely stopped (Guadarrama: 50-100 litres instead of > 300 litres)
Guadarrama Project
Guadarrama Rock

CAI = 5.66

Cercher Abrasivity Index

not very abrasive
slightly abrasive
medium abrasive to abrasive
very abrasive
extremely abrasive
quarzitic

CAI = 5,66
Guadarrama High Speed Rail Tunnel

4 hard rock TBM machines
diameter: 9.5m
2 x Herrenknecht
2 x Wirth
2 TBMs drive from the north,
the other two drive from the south
total length: 56 km
geology:
mainly granite, high quartz content, 100-200 MPa
very high abrasivity
situation with only using water

number of cutters changed typically varied from 5-28 per day

high maintenance cost, lot of down time

due to the high temperature, cutters can get blocked (failure of bearing seal)

high temperature and high dust level time consuming disc cutter change

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scientific research background
Ball Mill Test Results, Trondheim University, N
TBM chips (crushed), Loetschberg, CH

Rock Characteristics:
- Drilling rate index (DRI): 52
- Bit Wear Index (BWI): 38

More water = more abrasion

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... use of ABR foam on the TBM ...
ABR 5  Benefits

without ABR5

disappearance of dust
longer life time of electronics,
healthier working conditions

clean & cool cutters
easy & quick to change
no muck clogging

drastic reduction of cutter
temperature (150→70°C)
no cutter blockage any more
around 15% wear reduction
reduced downtime

with ABR5

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Environmental Studies
Emission possibilities

- ground water
- landfill
- working environment
General background
what do LC$_{50}$/EC$_{50}$ data mean?

algues

daphnia magna

rainbow trout

additives [mg/l water]
Landfill of excavated soil

Lixiviation data (24h, DIN 38-414 4)
Acute toxicity tests (Daphnids, NF EN ISO 6341)
General Risk Characteristics
important factors of eco-compatibility

Aquatic toxicity

Risk to surface water

Risk to air

Bioaccumulation

Persistence (biodegradation)

(mammal) toxicity
Environmental Risk Assessments!
Thank you for your attention