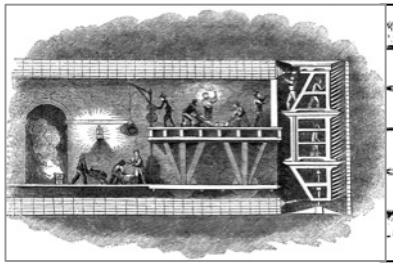
Tunneling Lectures 2011
Speciality Chemicals for Tunnel Boring Machines

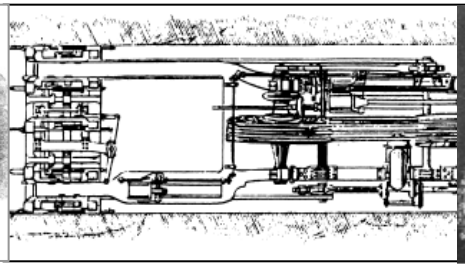
Lars Langmaack
Jaime Ibarra

EPB Tunnelling in the Toronto Area

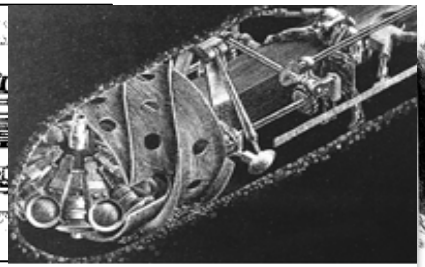
180 years of TBM History



1825, GB (Thames Tunnel) Sir Marc Brunel

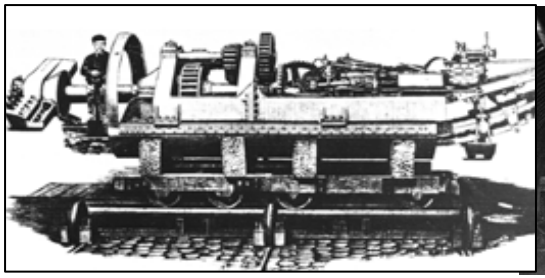


1846, F (Mount Cenis) Henri Joseph Maus



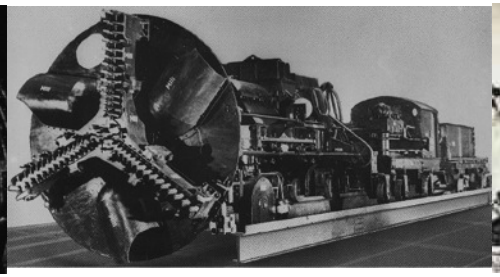
1853, USA (Hoosac Tunnel) Charles Wilson

1869, GB (London) Barlow-Greathead

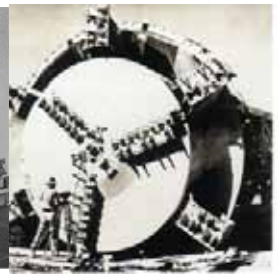


1882, GB (channel tunnel) Beaumont / English

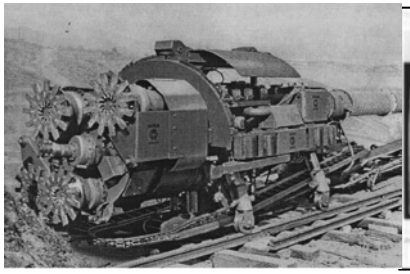
1907, Germany old Elbtunnel



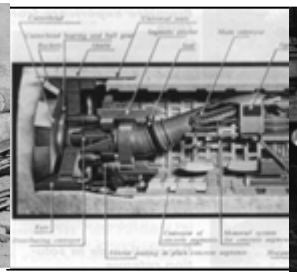
1931, Germany Schmidt Kranz



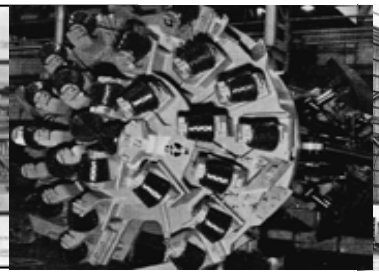
1952, USA 1st Robbins TBM



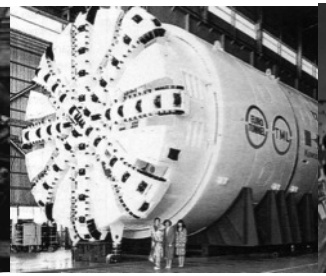
1958, Austria Alpine shield



1965, France (Paris) Robbins, RER System



1968, Germany Wirth TBM

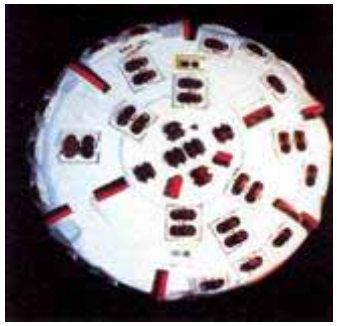


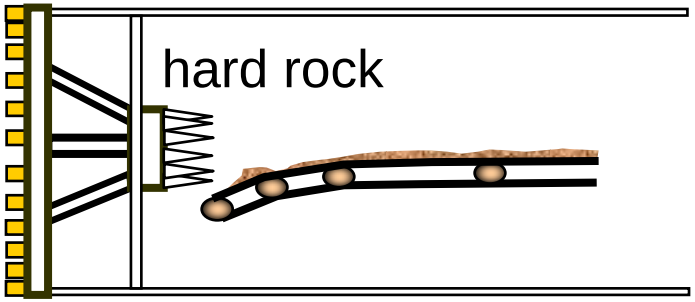
1988 Robbins, Eurotunnel

2006, Spain (Madrid) world‘s largest EPB

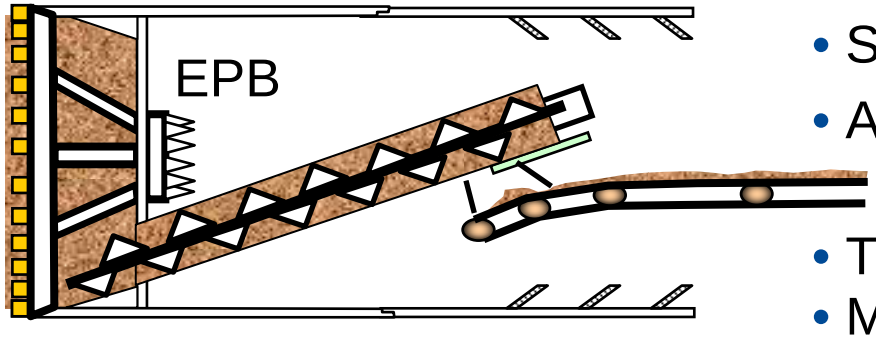
TBM design vs geology

3 main classics

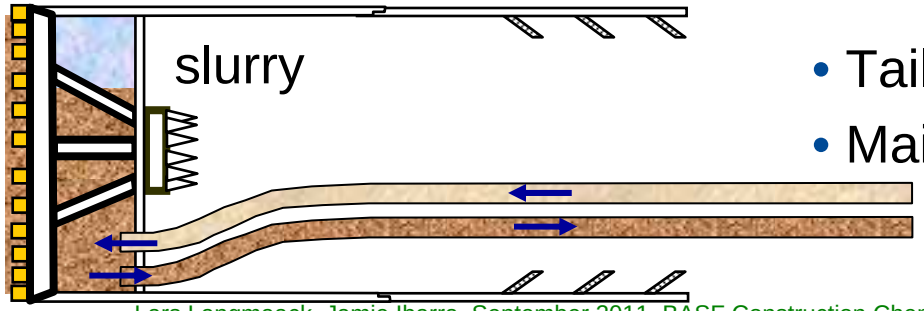




- Foams & Polymers against abrasion and dust
- Main bearing sealant

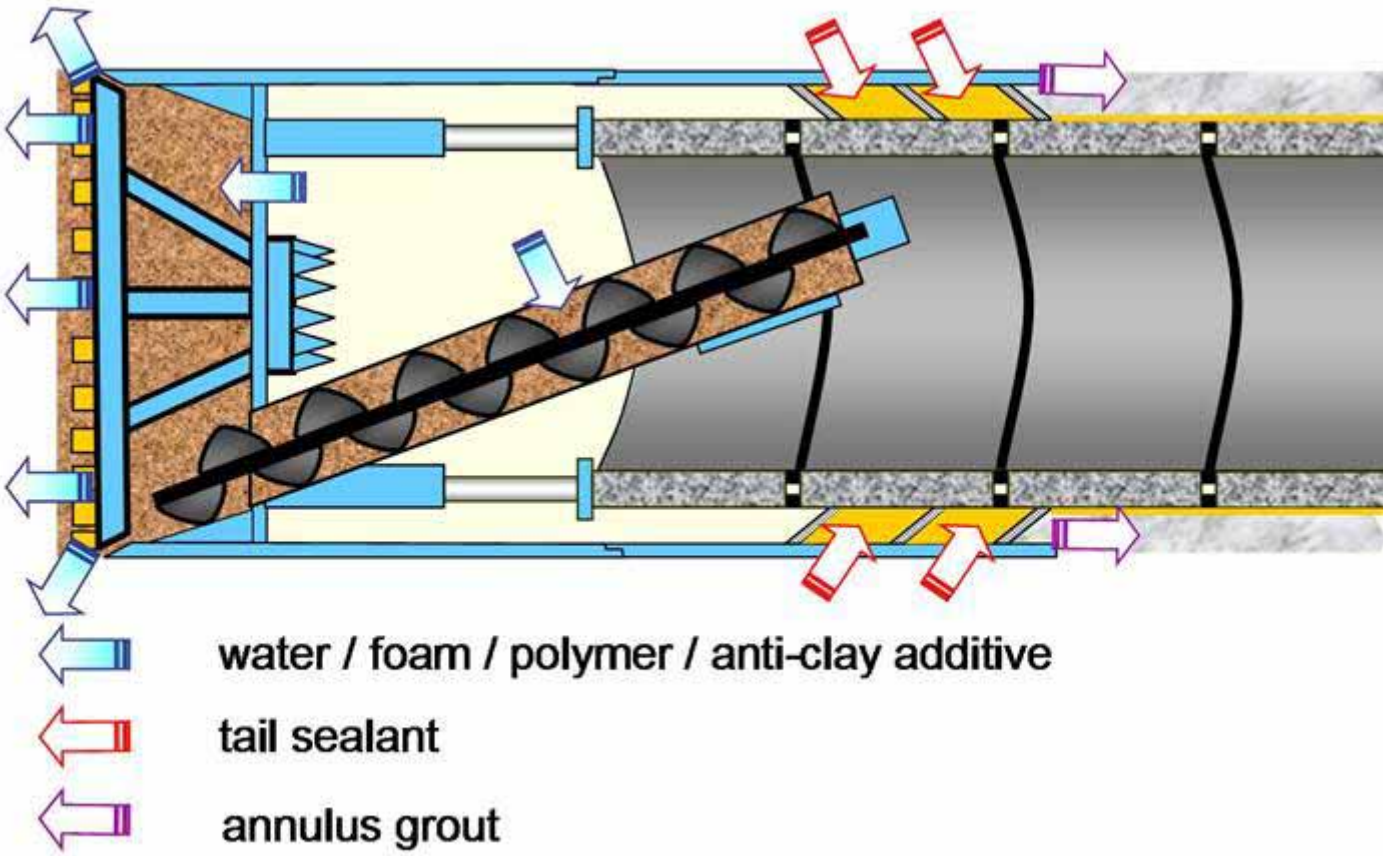


- Soil conditioning
- Annulus grout
- Tail sealant
- Main bearing sealant



- Tail sealant
- Main bearing sealant

Earth pressure balance (EPB) TBM



Soil Changes

with MEYCO SLF soil conditioning agents

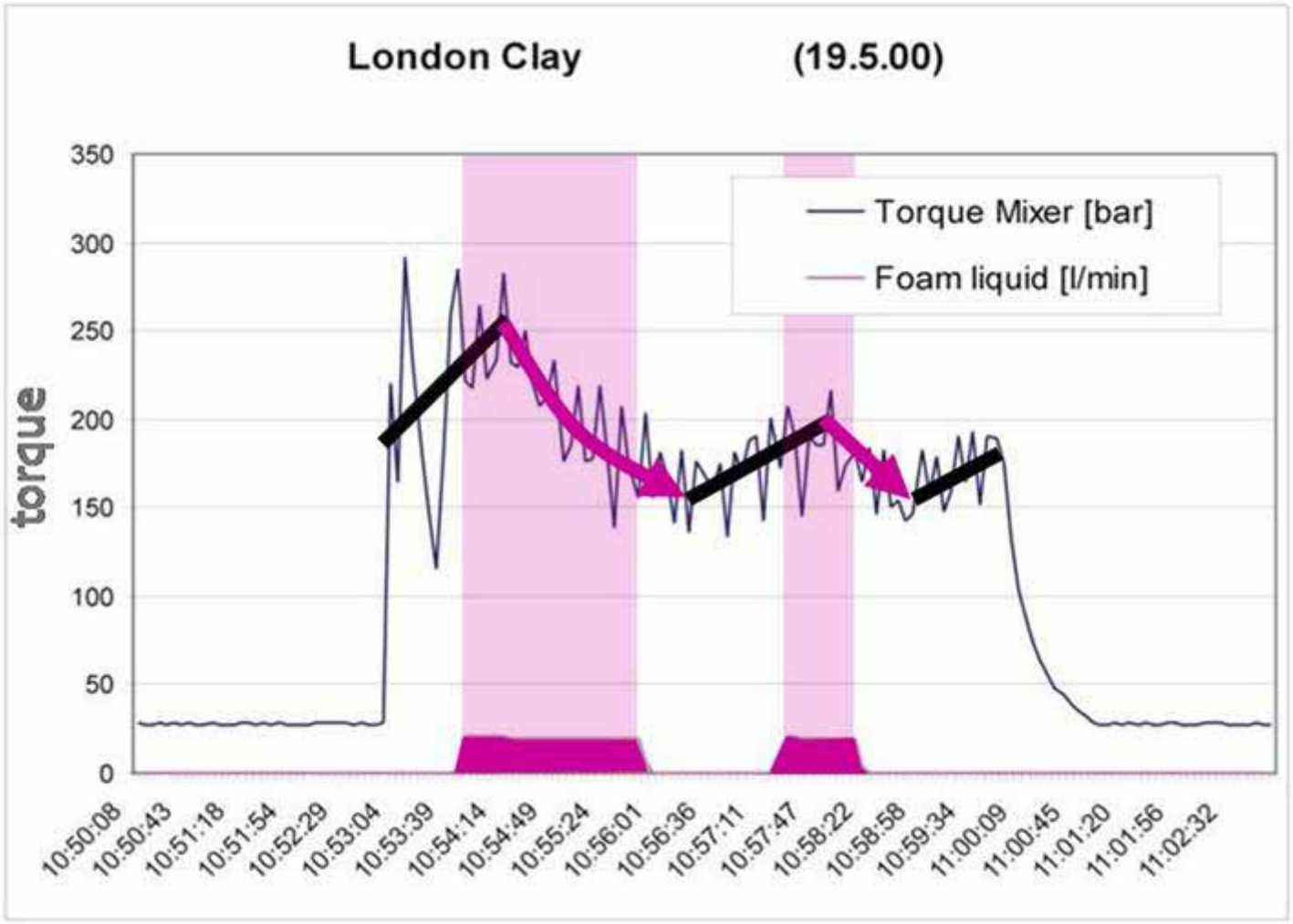
dry soil

+ water

+ soil conditioning

Torque Reduction

with MEYCO SLF Foam in Clay Soil, Herrenknecht test rig



Soil types

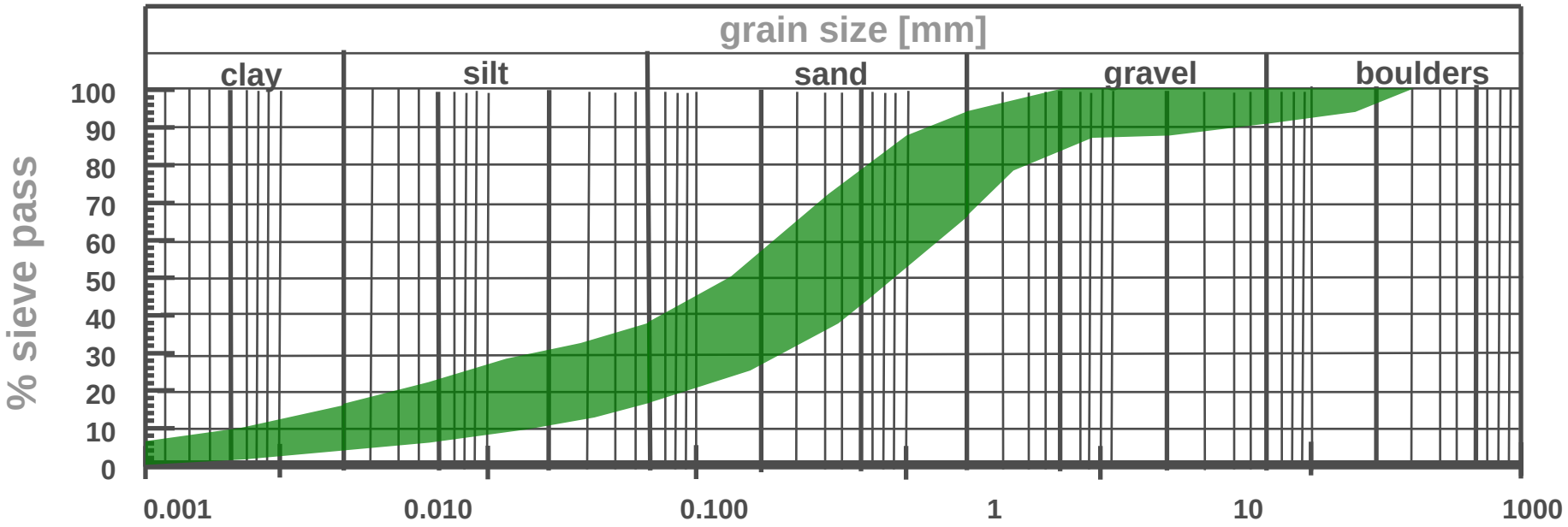
clay

silt

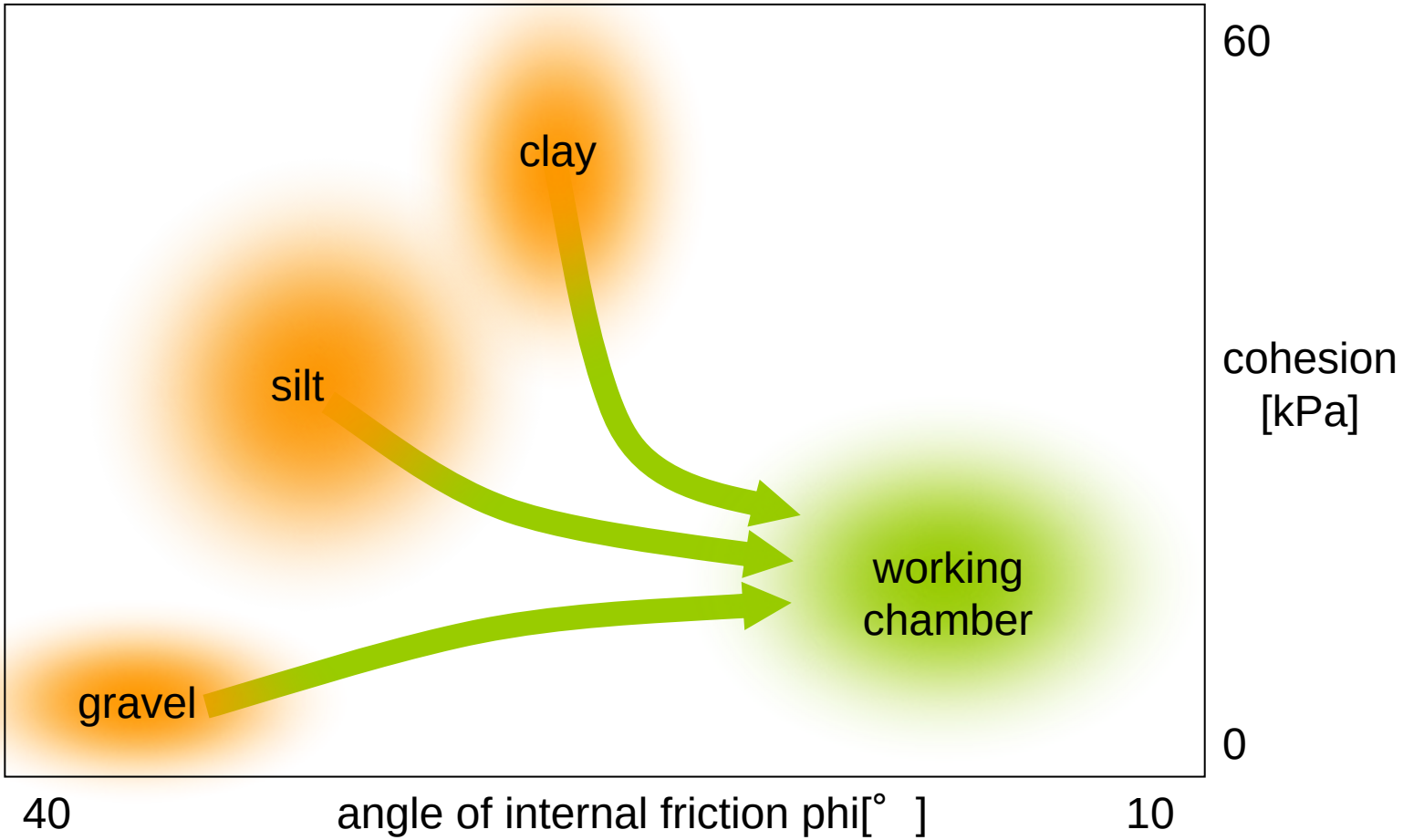
sand

gravel

boulders



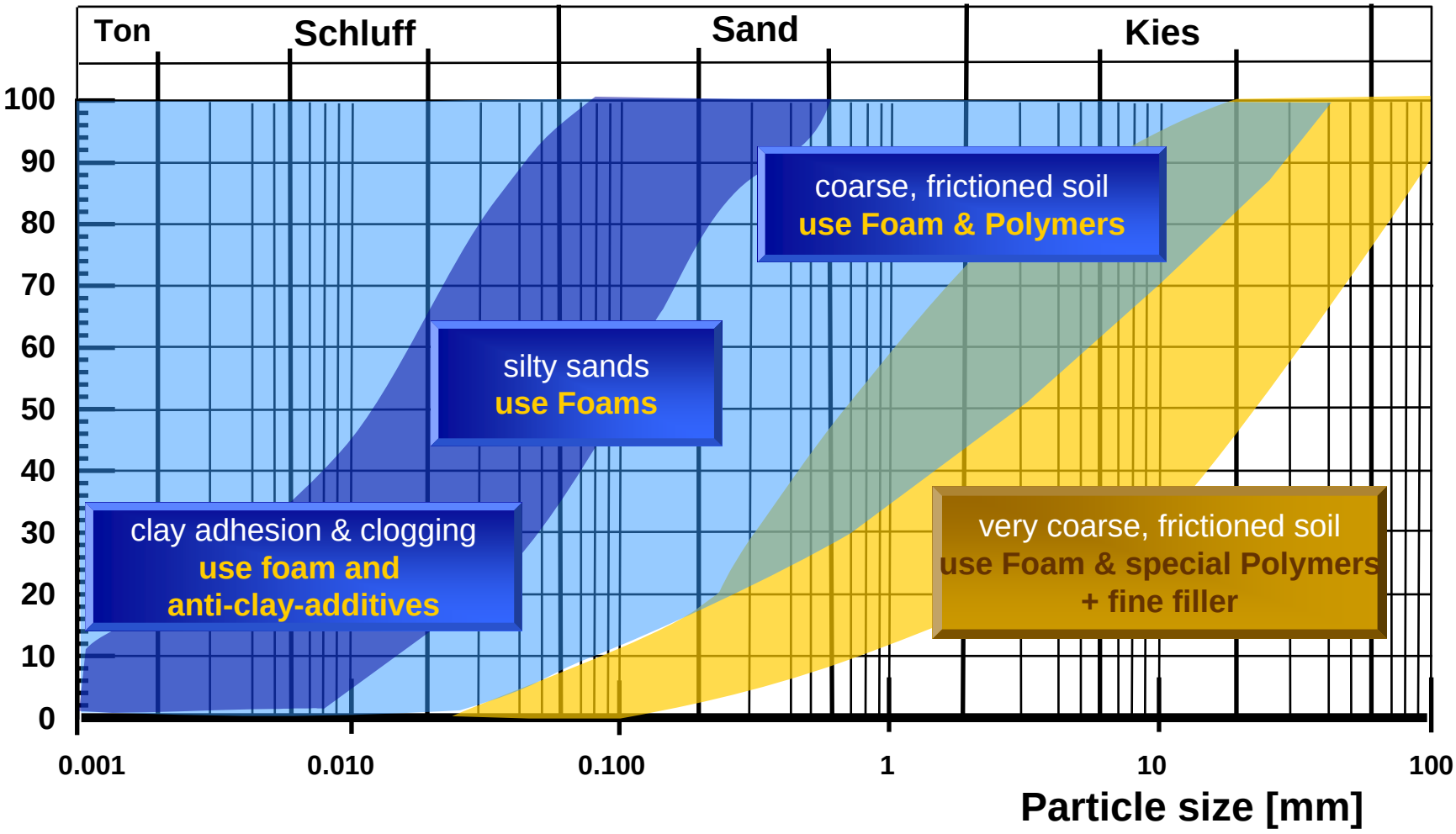
soil conditioning and soil mechanics



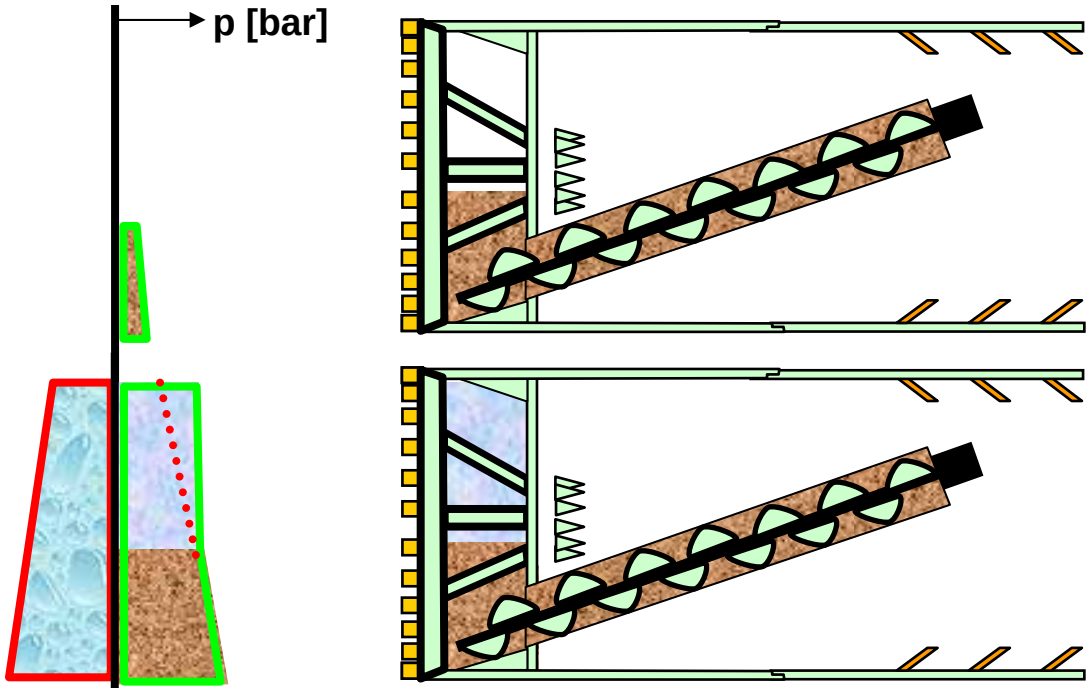
Example of conditioned EPB soil

actual range of EPB use

weak ground under groundwater pressure



importance of EPB driving modes in soft ground

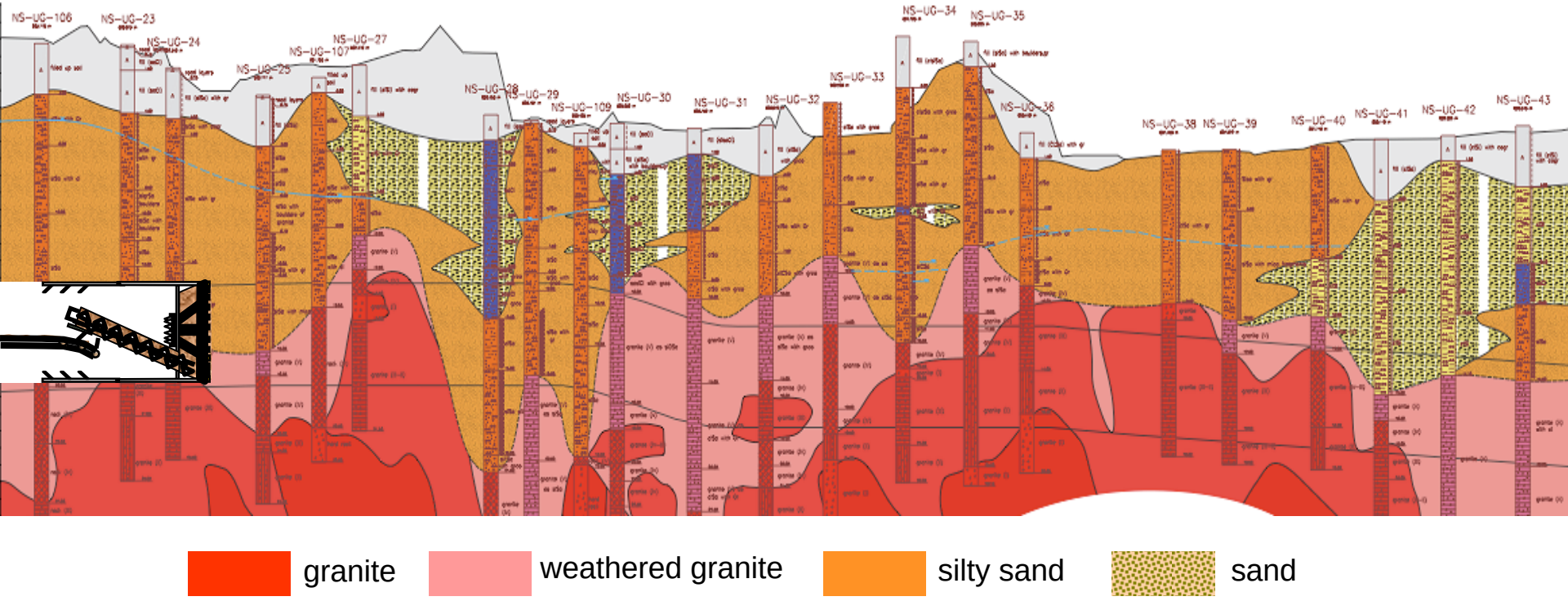


no pressure
open mode

air pressure
>=
water pressure

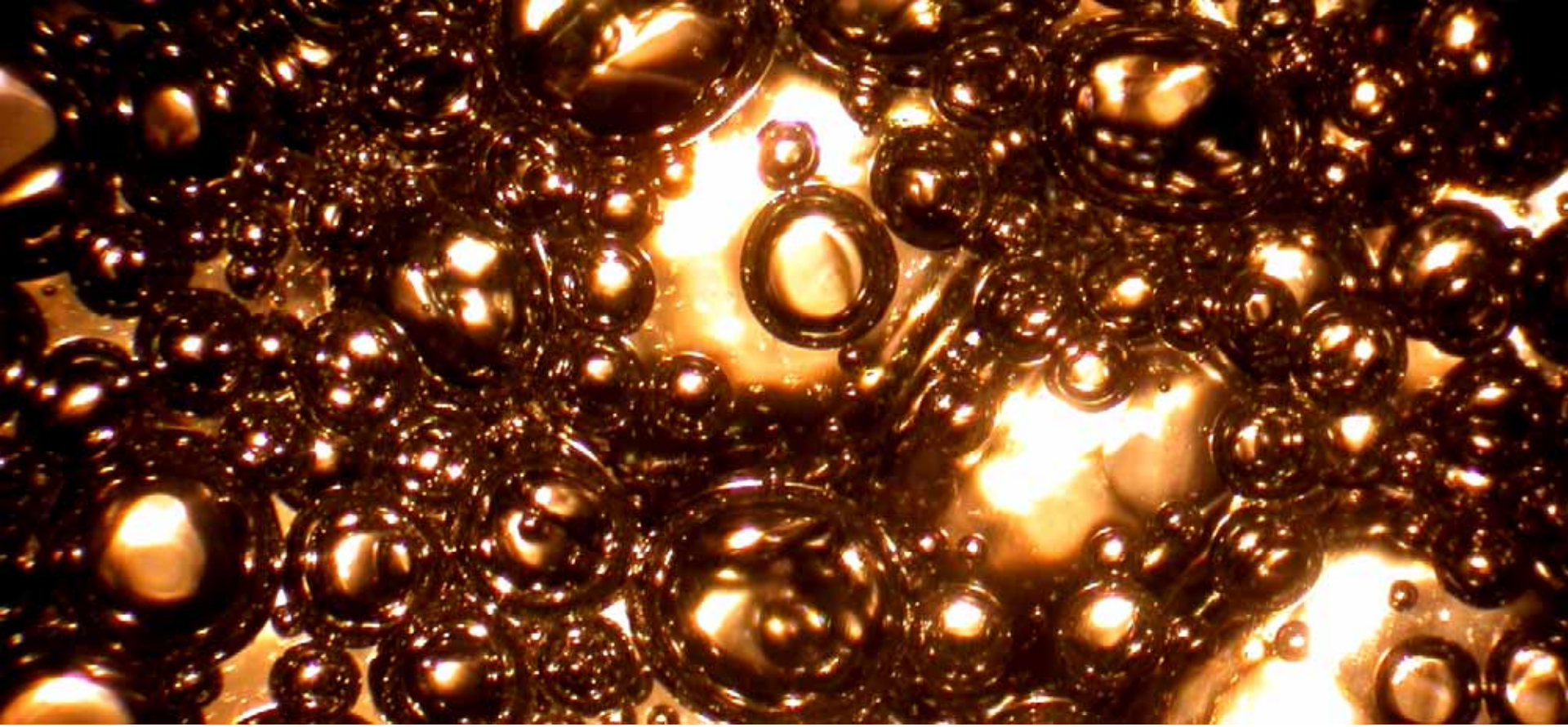
earth pressure
=
soil pressure
+
water pressure

What mother nature gave to us: geological profile



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

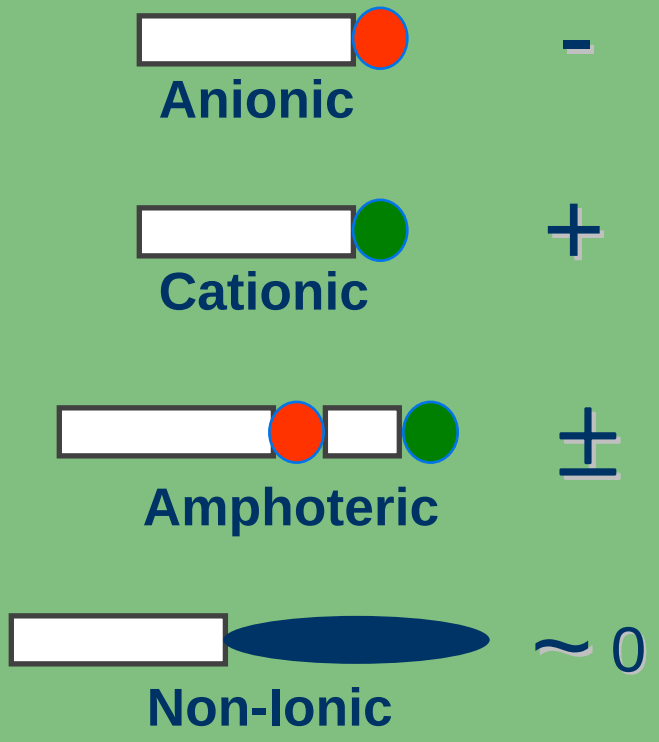


soil conditioning I

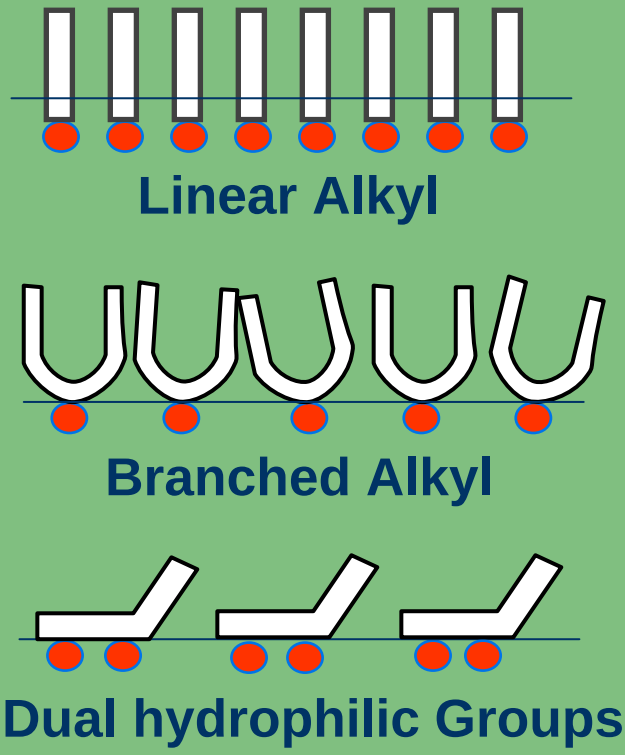
foam

Foam Types

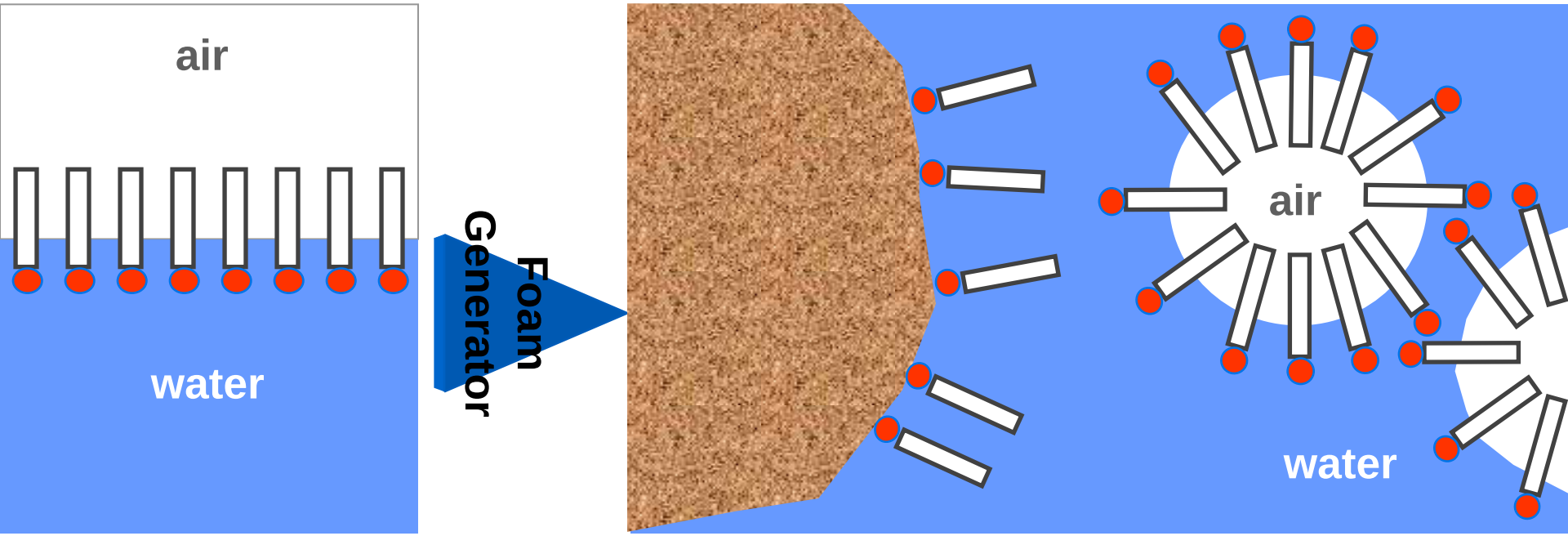
Ionic Classes



Structures

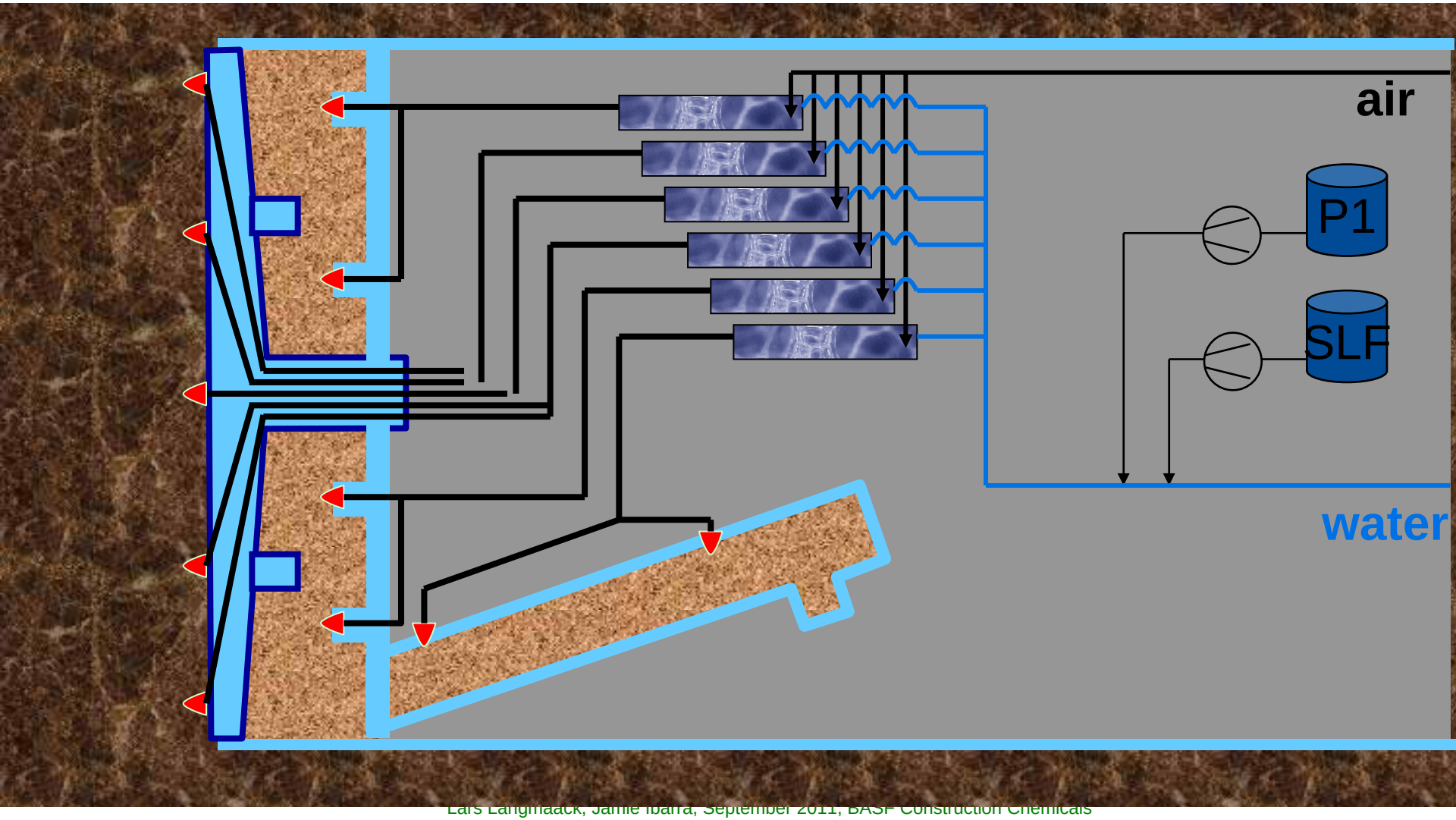


creation of tunnelfoam

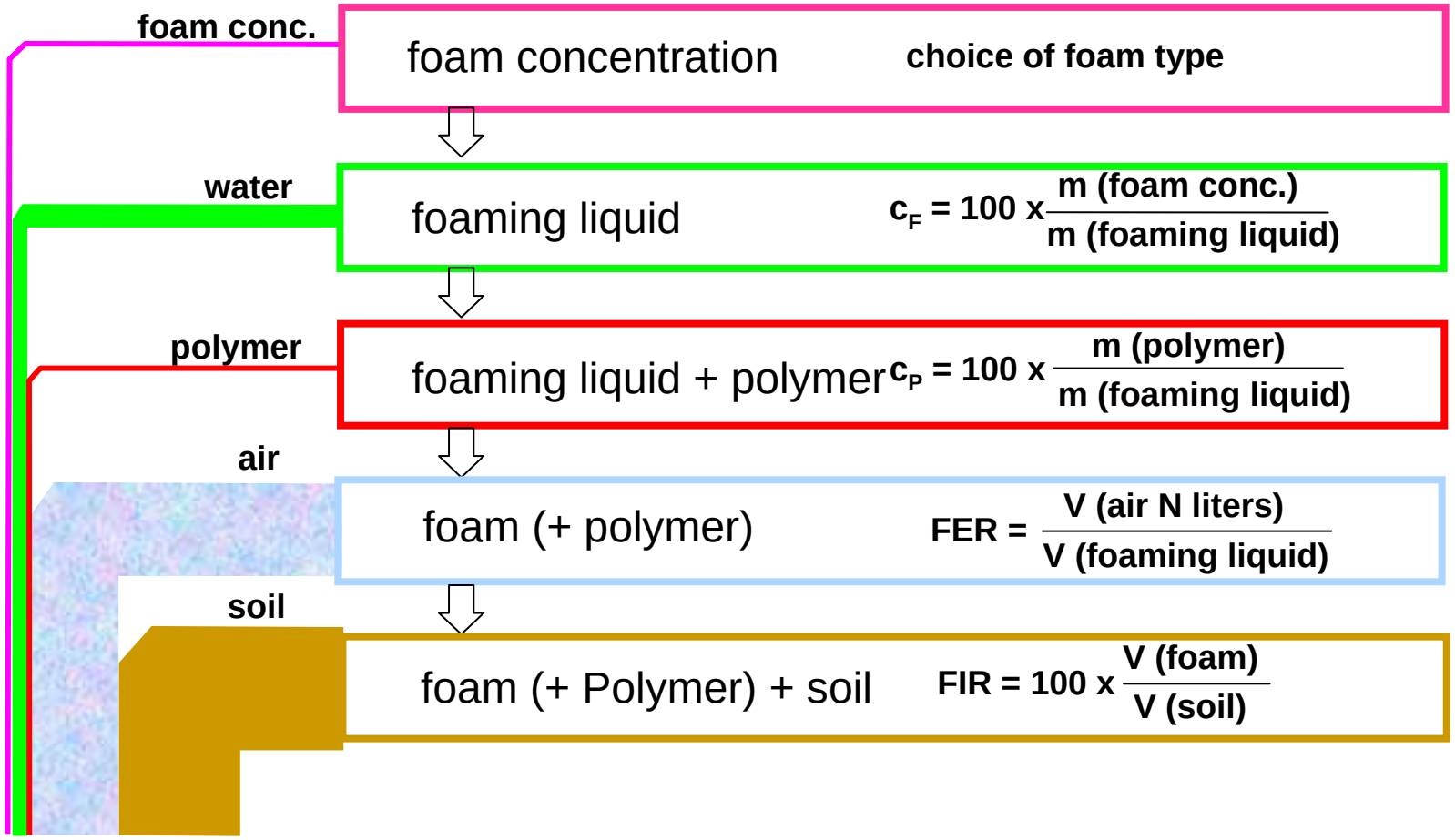


soil conditioning system on TBM

schematic view

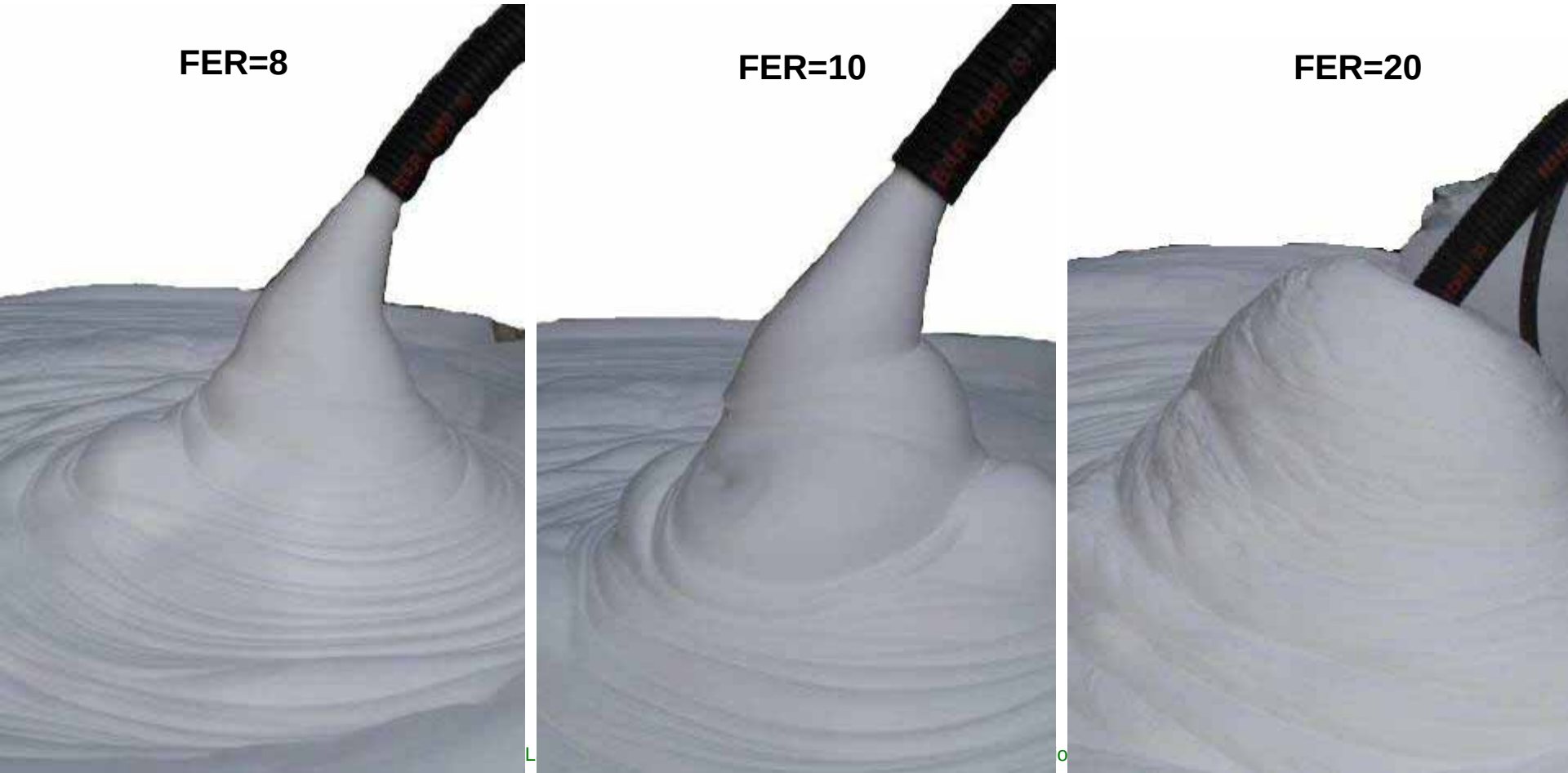


TBM Foam & Polymer parameters



Important: Foam Quality

over wide range of FER and output quantity



EPB Tunnelling in the Toronto Area

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

Madrid MetroLam project – belt view

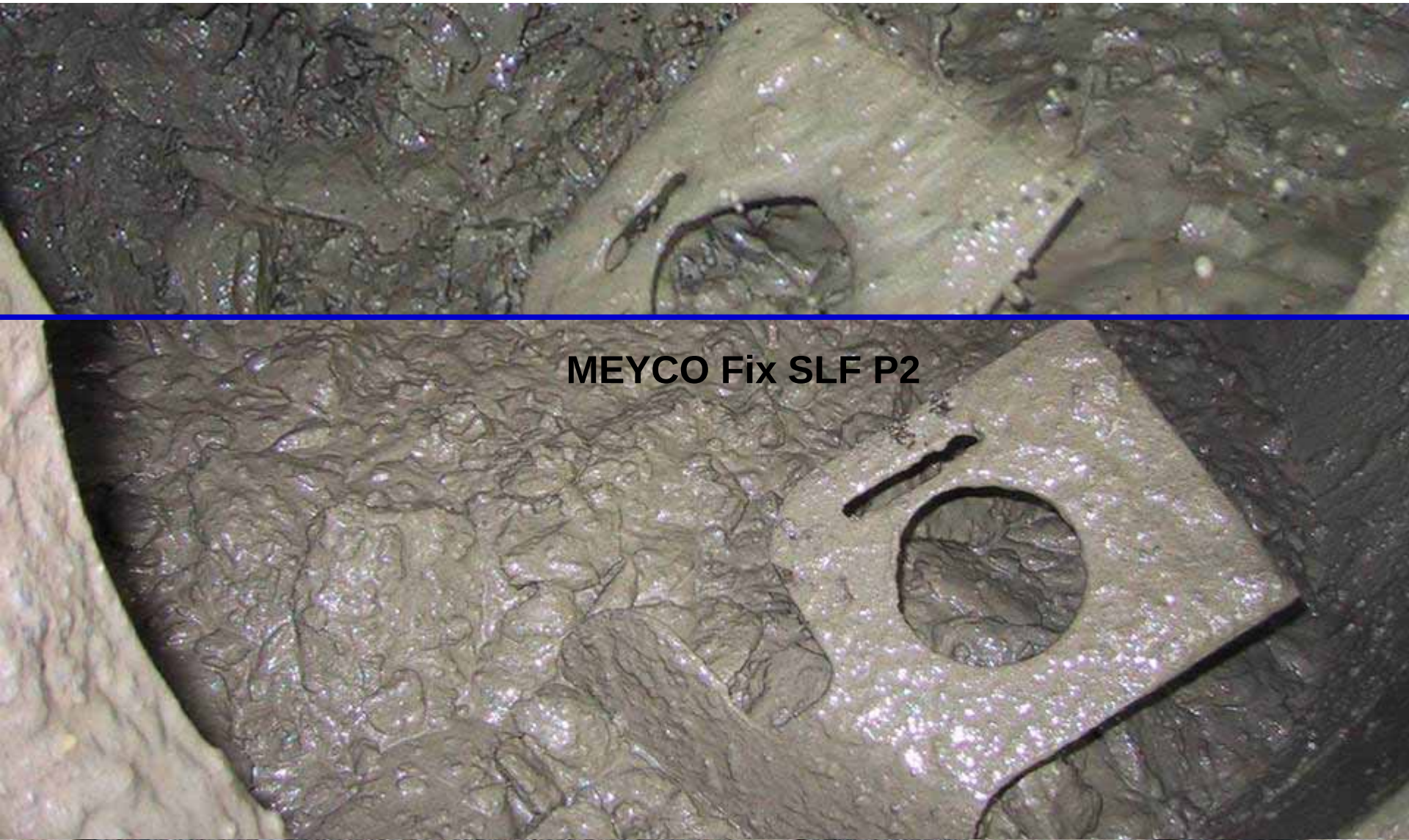
foam

foam + RHEOSOIL

soil conditioning III

long chain polymers

how do polymers work ?



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

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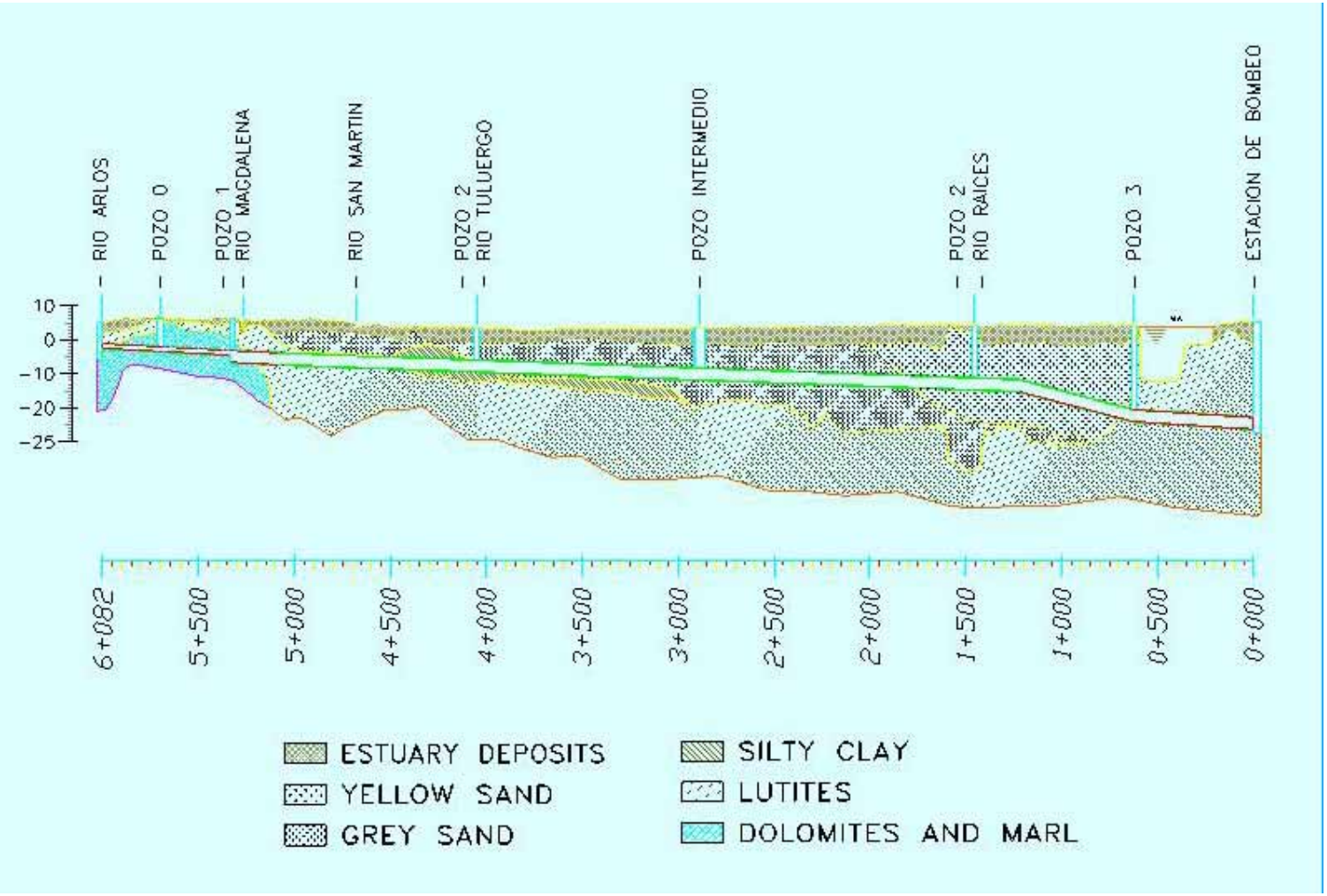
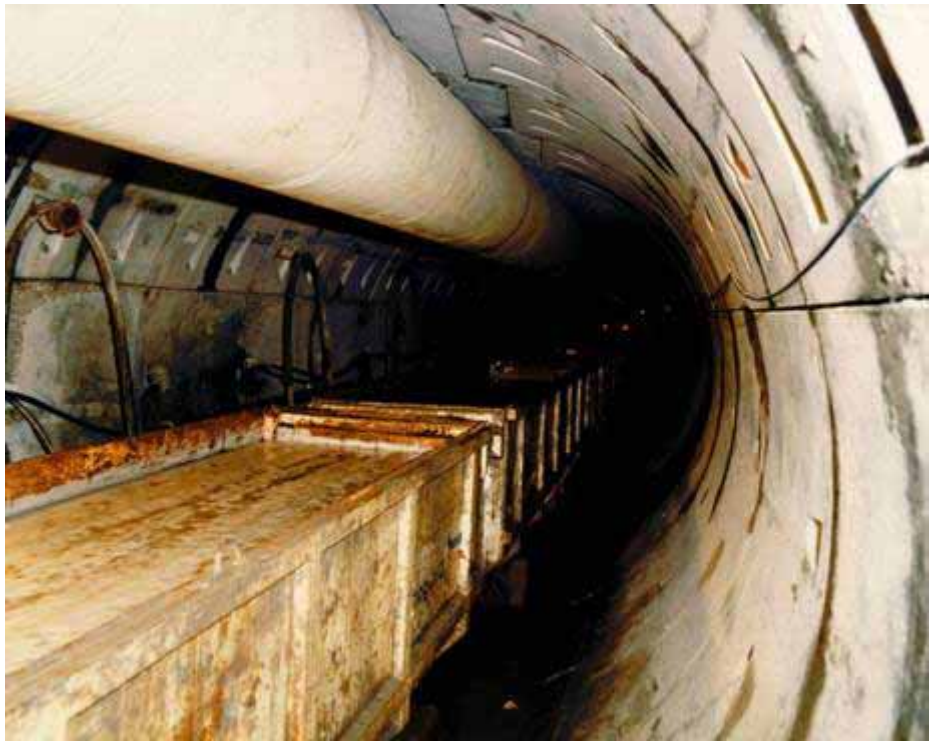
Aviles geology



effect of structurizing polymers



2,5 bar sea water pressure
use of foam

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

TBM parameters & advance rates

	LUTITES	SAND	SILTY CLAY	DOLOMITE	TOTAL TUNNEL
Average advance (m/day)	16,50	27,00	14,00	20,50	20,00
Max. Advance (m/day)	31,00	50,50	29,00	32,40	50,50
Average excav. time (min/ring)	46,00	16,00	35,00	40,00	24,00
Average installing time (min/ring)	21,00	18,00	15,00	15,00	16,00
Average thrust pressure (Ton)	200-300	600-800	300-500	800-900	
Average torque (Ton x m)	60	80	130	170	

Aviles Collector, Spain

successful breakthrough

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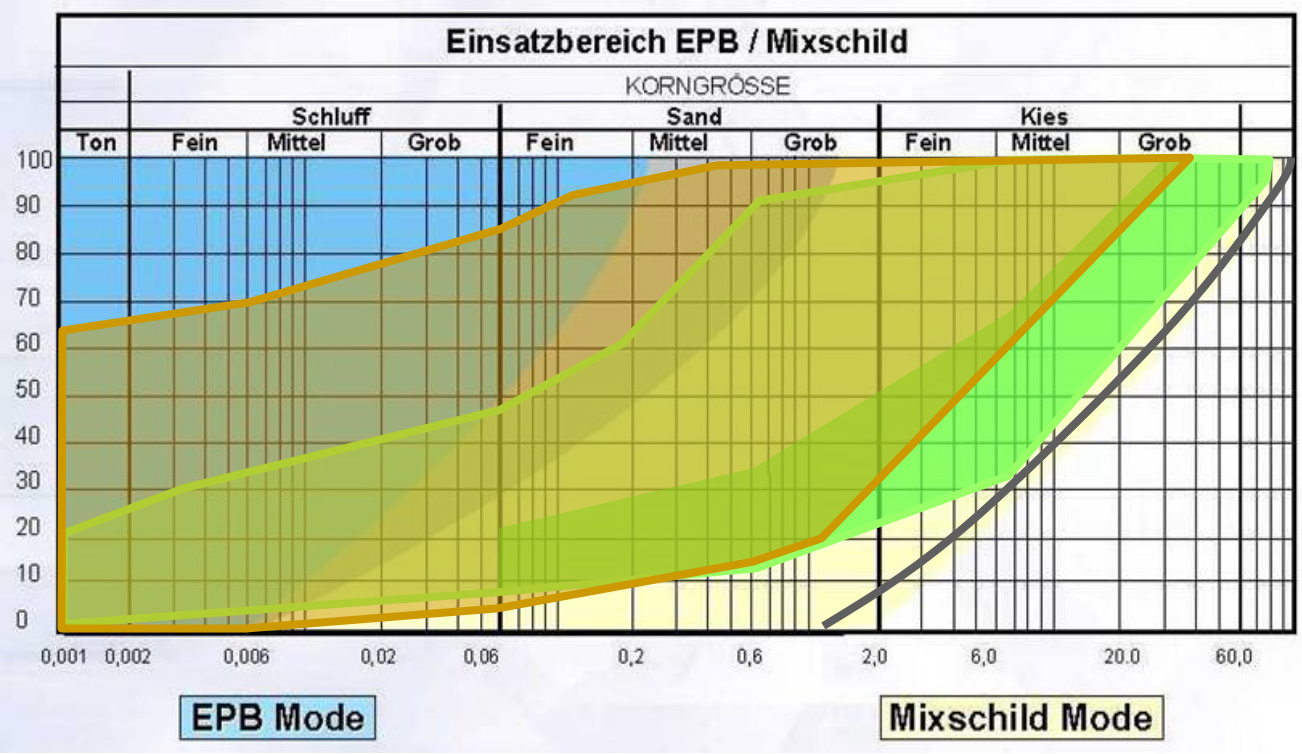
universal TBMs

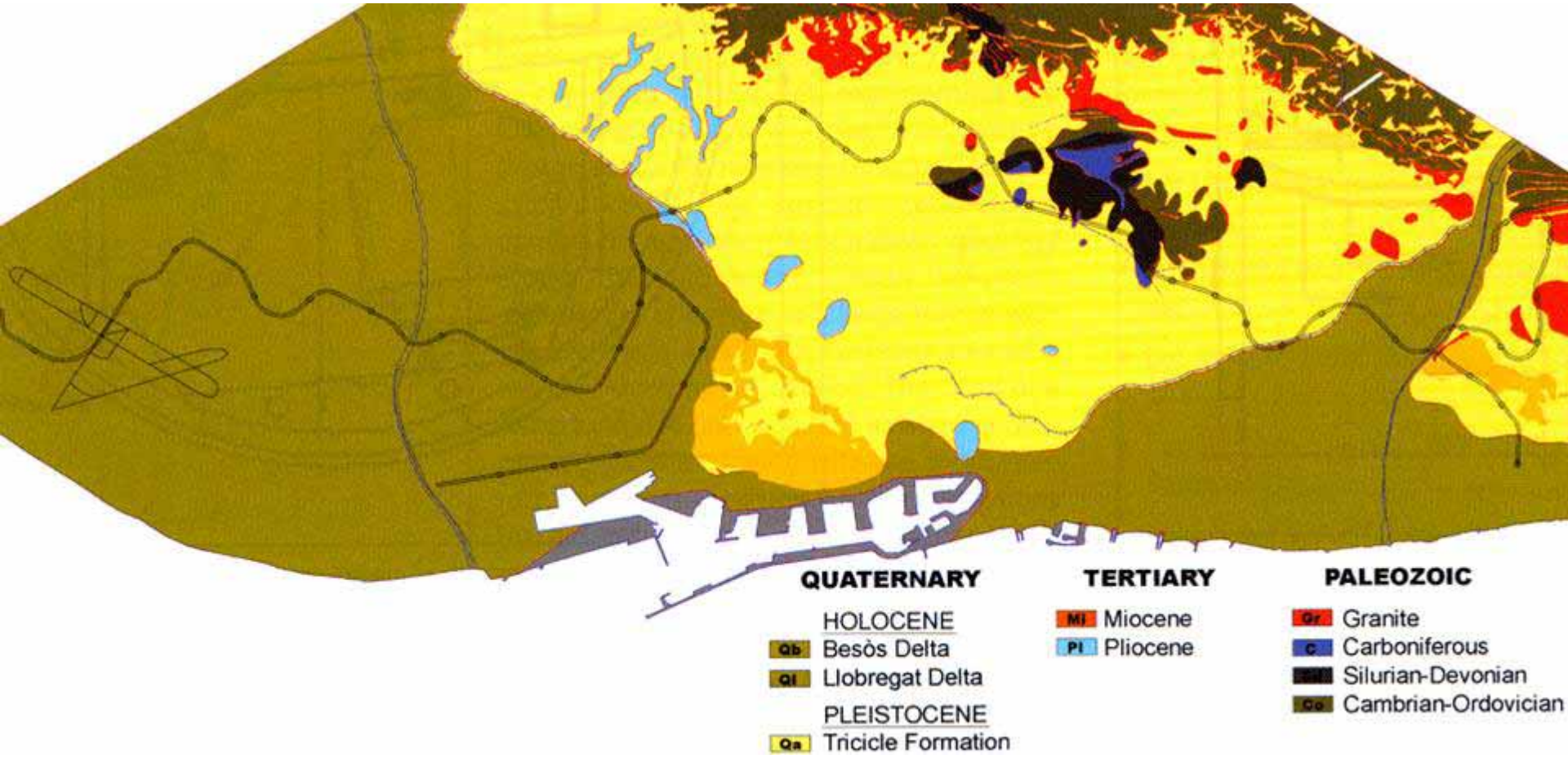
adoption to geology by soil conditioning



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 m

force = 110 MNm

torque = 37 MNm

power = 7,15 MW

26% open shield

Barcelona Metro L9, project UTE GORG

TBM-characteristics

d = 12,06 m

force = 110 MNm

torque = 38 MNm

power = 5,32 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:
Campenon Bernard TP & Eiffage TP

The TBM

EPB TBM S-208

shield length: 8,50m

- shield diameter: 7,750m
- cutterhead diameter: 7,785m
- TBM speed ≤ 80 mm/minute
- EPB pressure ≤ 3 bar.
- installed power: 2.000 kW,
- driving force: 55,75 kN
- jack force: 6.000 tons.

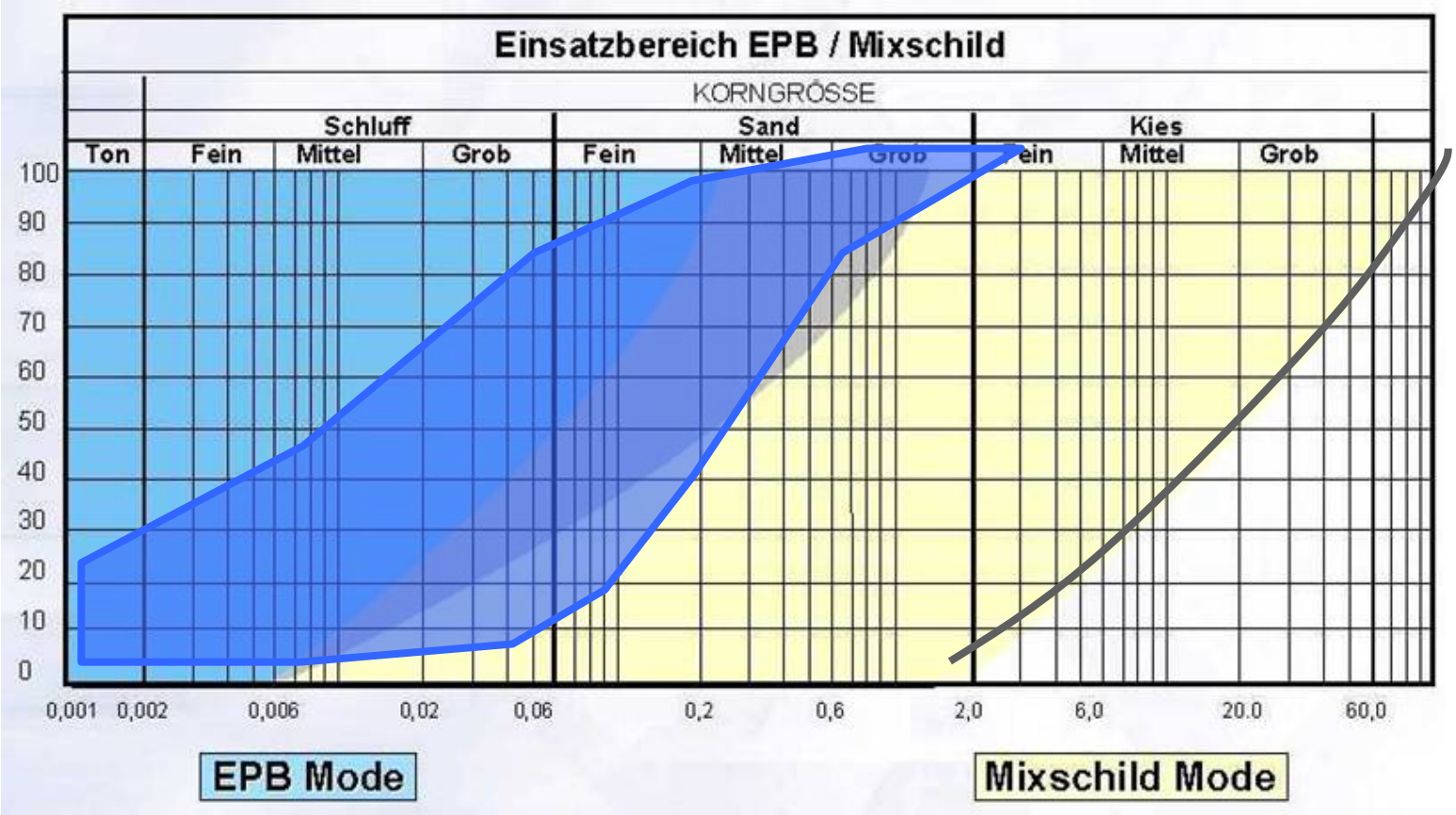
Segments

diameter: 6,80m (5+1)

- lenght: 1,40m
- thickness: 340mm.
- total segment number: 26.000
- total muck excavation: 225.000m³ or 517.000 tons

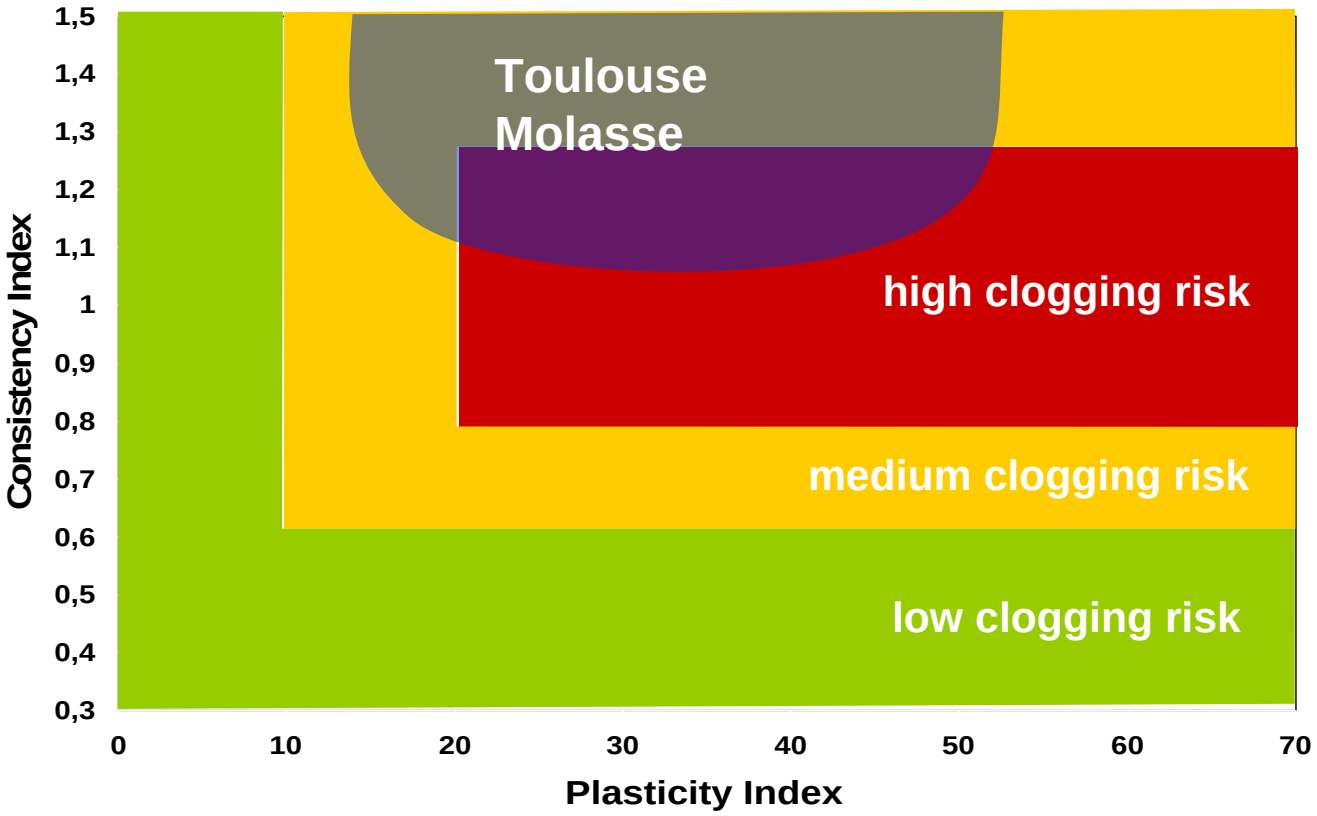
Toulouse Metro project

sieve curves



Toulouse (F) '2003
HK EPB, Ø=7.72m
mainly under water table
Foam + Anti Clay-Agent

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

Toulouse Metro Lot 2
cutterhead comparison

dry mode & empty chamber

plastic mode & full chamber
with RHEOSOIL®

EPB conditioned soil

Jamie Ibarra, September 2011, BASF Construction Chemicals

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

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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.*

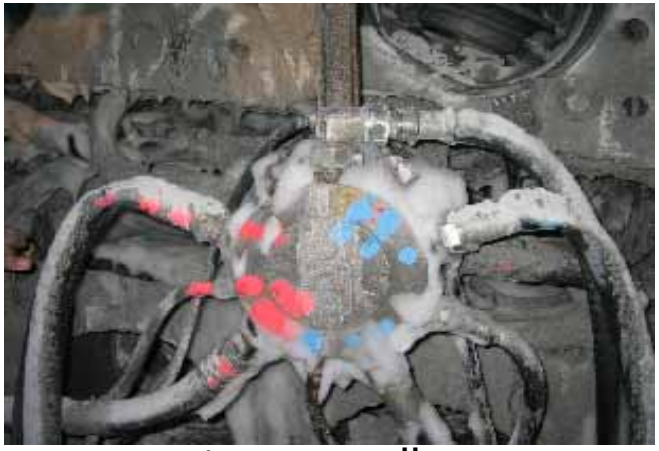
use of MEYCO® ABR5 makes the difference

- 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

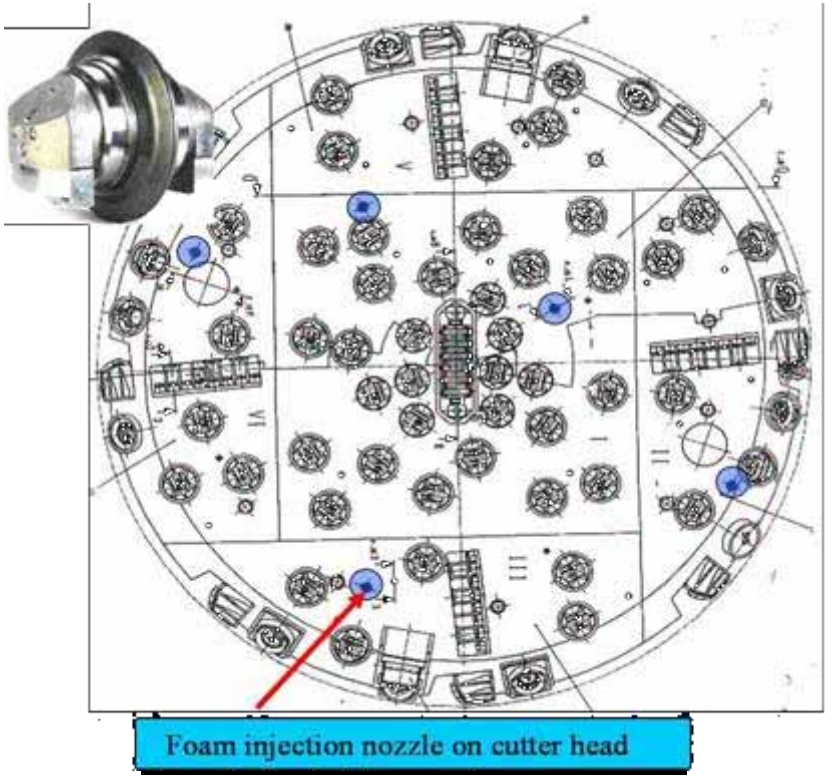
needs to use MEYCO® ABR5

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



rotary coupling



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 to10 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

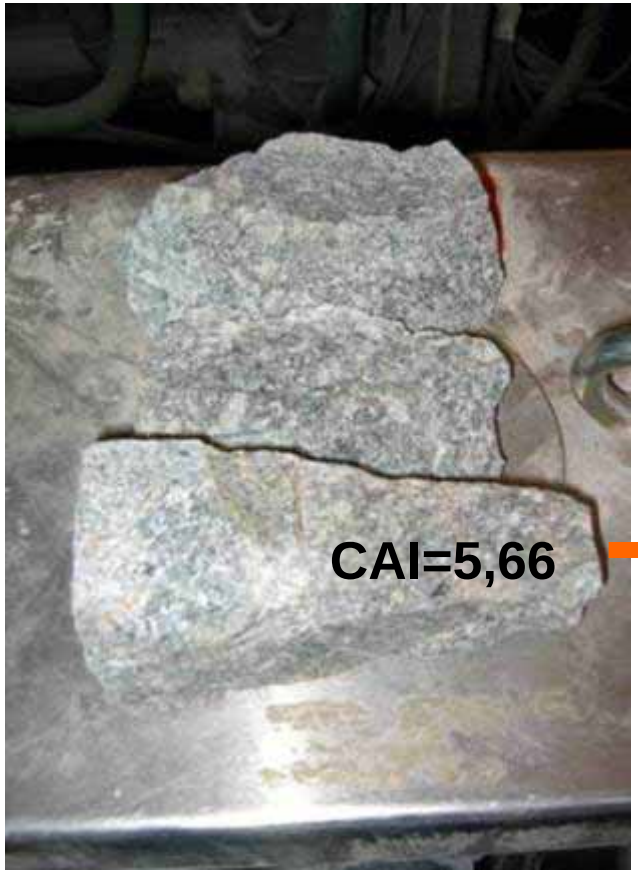
what expansion rate should be used?
- depending on the geological conditions, typical FER of 10-12

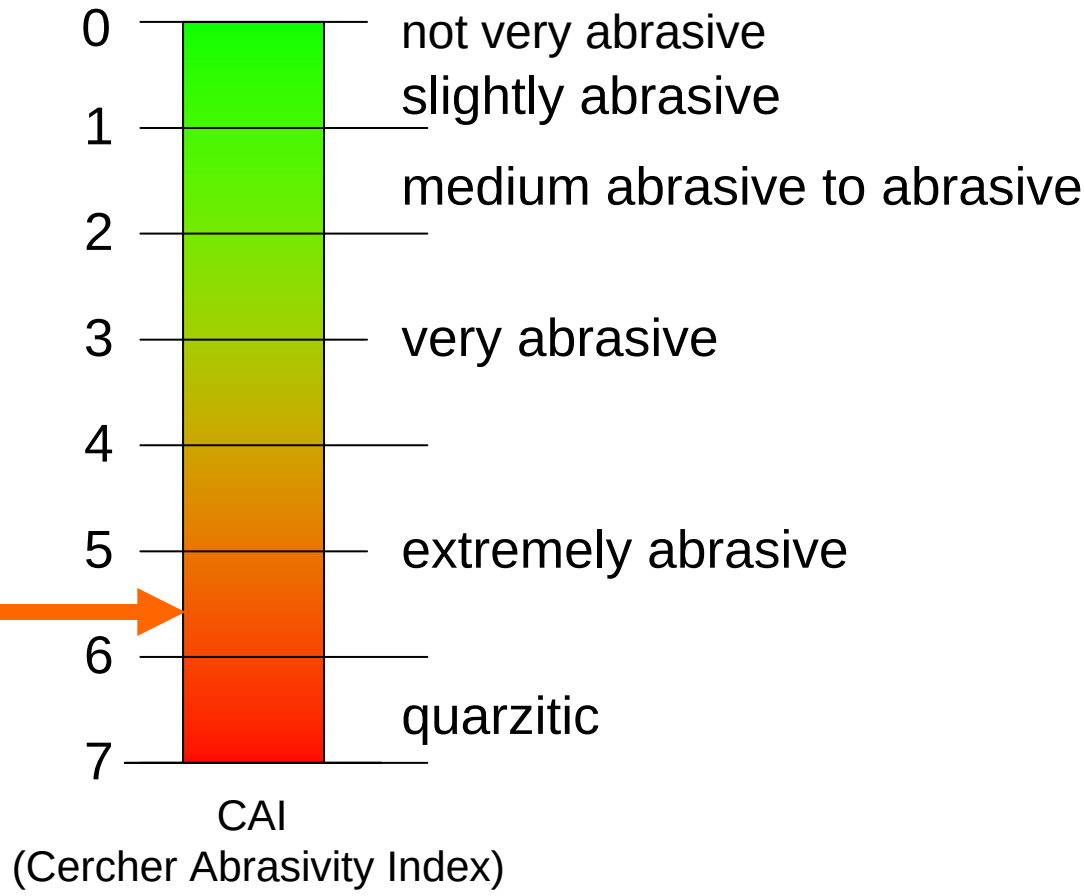
how much Foam should be injected?
- typically 250 to 300 litres per m³ rock (FIR=25-30%)

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





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


Guadarrama South

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

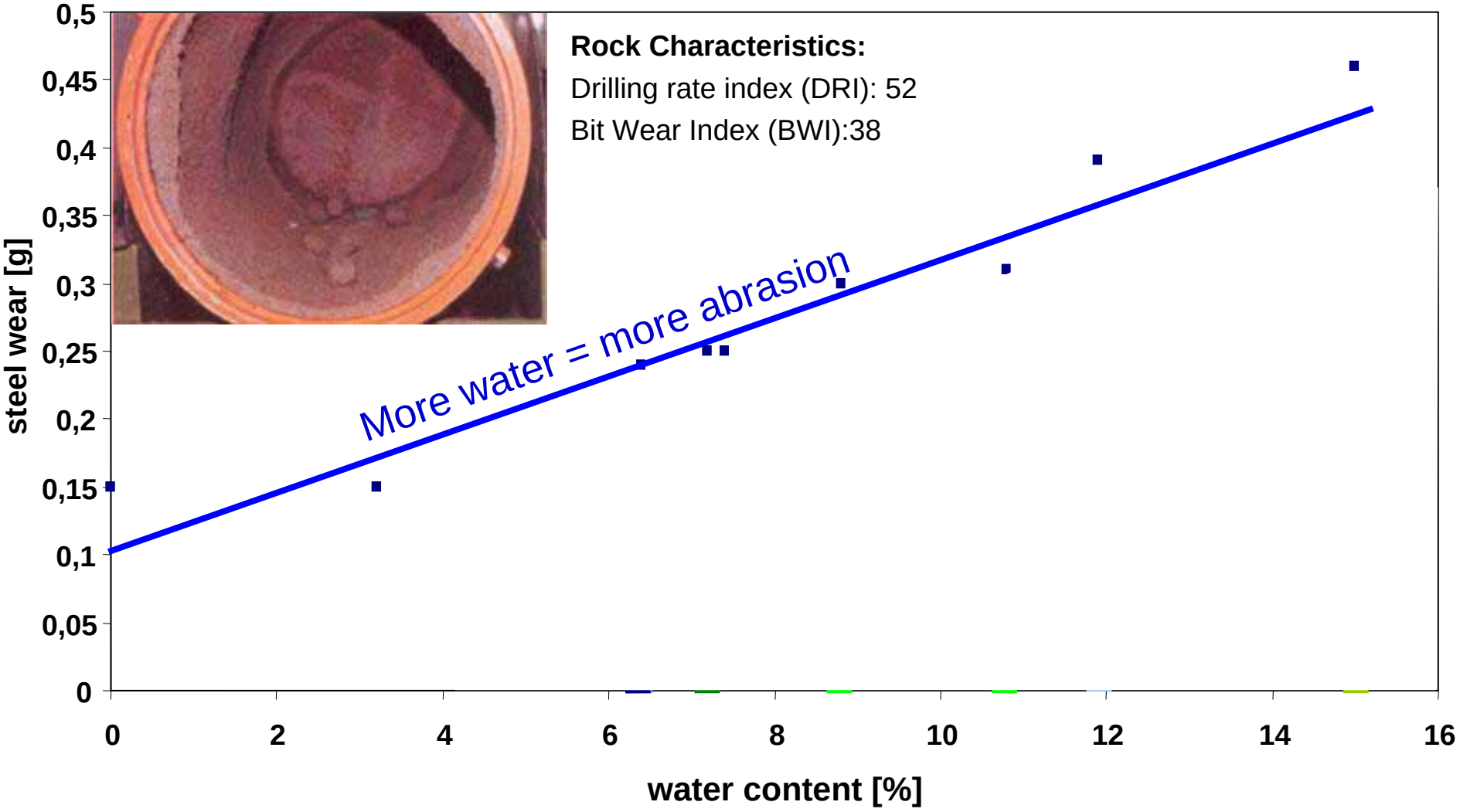
scientific research background

NTNU
Innovation and Creativity

Ball Mill Test Results, Trondheim University, N

TBM chips (crushed), Loetschberg, CH

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



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

Lars Langmaack, Jamie Ibarra, September 2011, BASF Construction Chemicals

ABR 5 Benefits

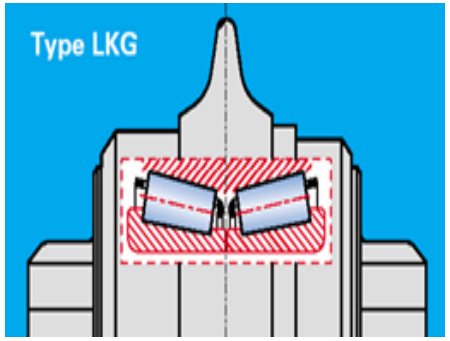
without ABR5

with 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

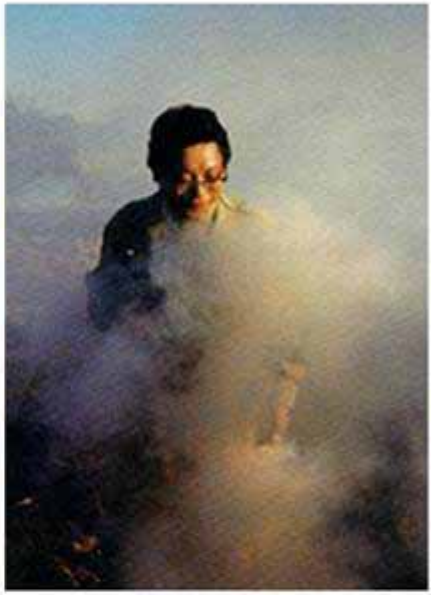


Environmental Studies

Emission possibilities

ground water

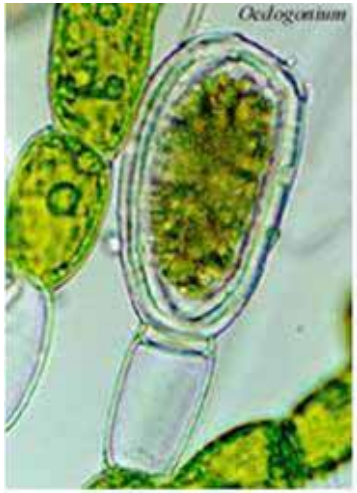
landfill



working environment

General background

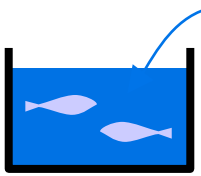
what do LC_{50}/EC_{50} data mean?



algues

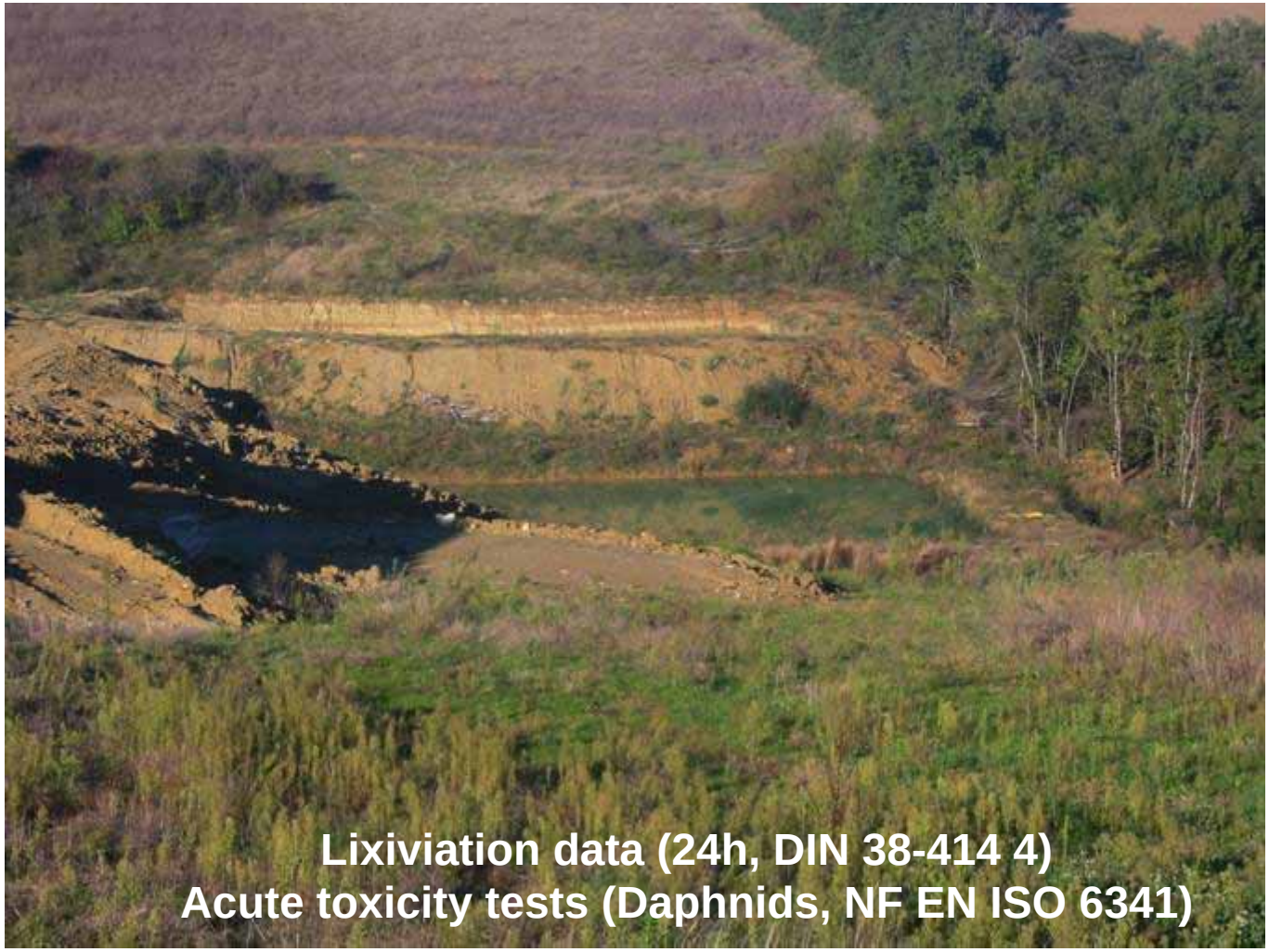
daphnia magna

rainbow trout



additives [mg/l water]

Landfill of excavated soil



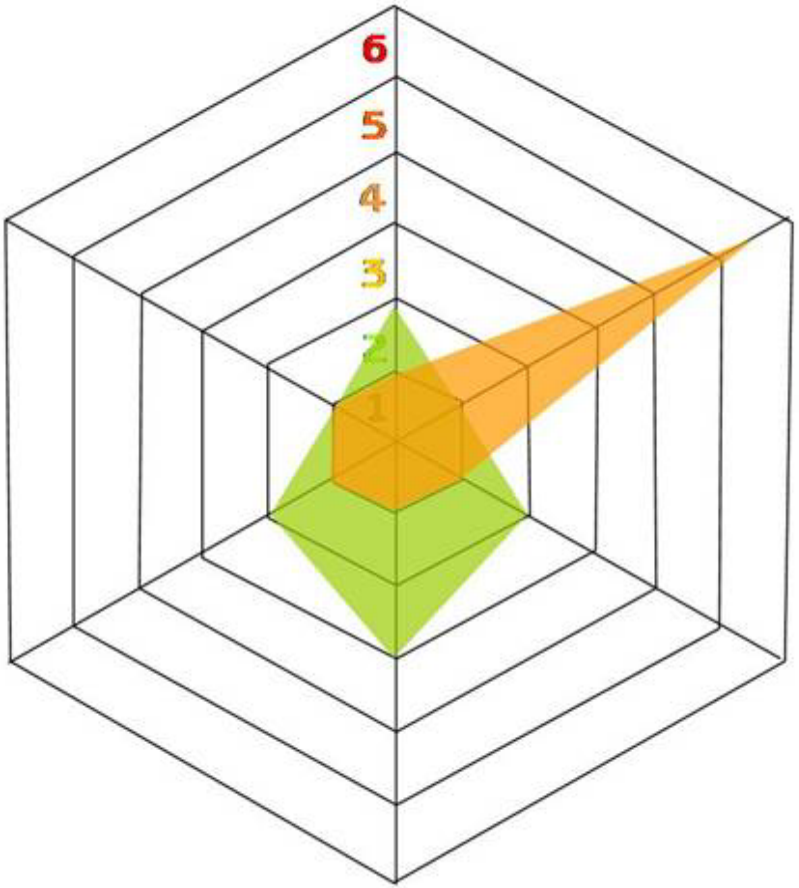
General Risk Characteristics

important factors of eco-compatibility

(mammal) toxicity

Risk to air

Persistence (biodegradation)

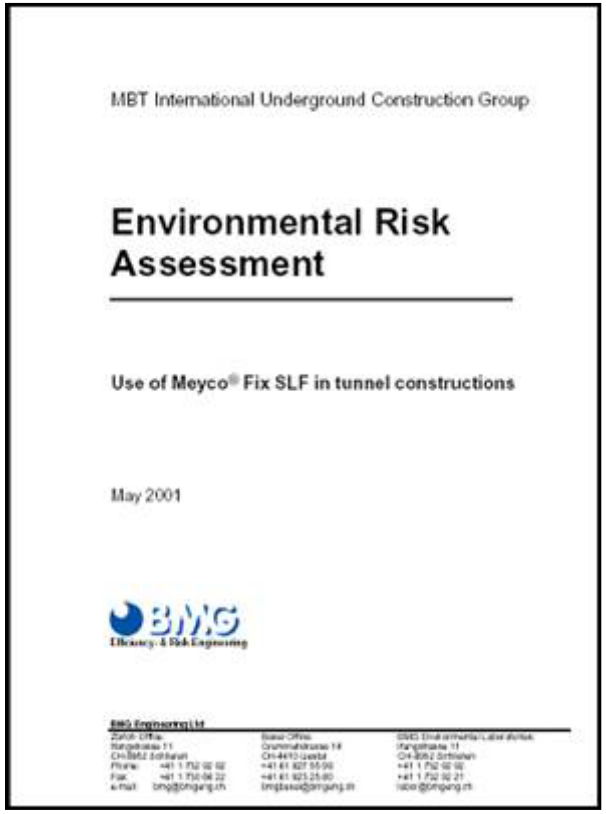


Risk to surface water

Bioaccumulation

Aquatic toxicity

Environmental Risk Assessments !


MBT International Underground Construction Group

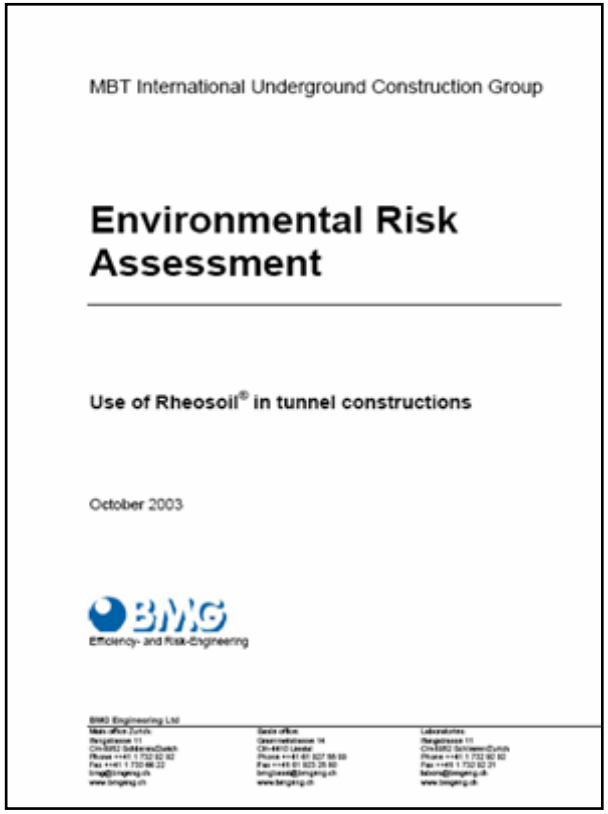
Environmental Risk Assessment

Use of Meyco® Fix SLF in tunnel constructions

May 2001

BMG Efficiency- & Risk-Engineering

Foams & Polymers


MBT International Underground Construction Group

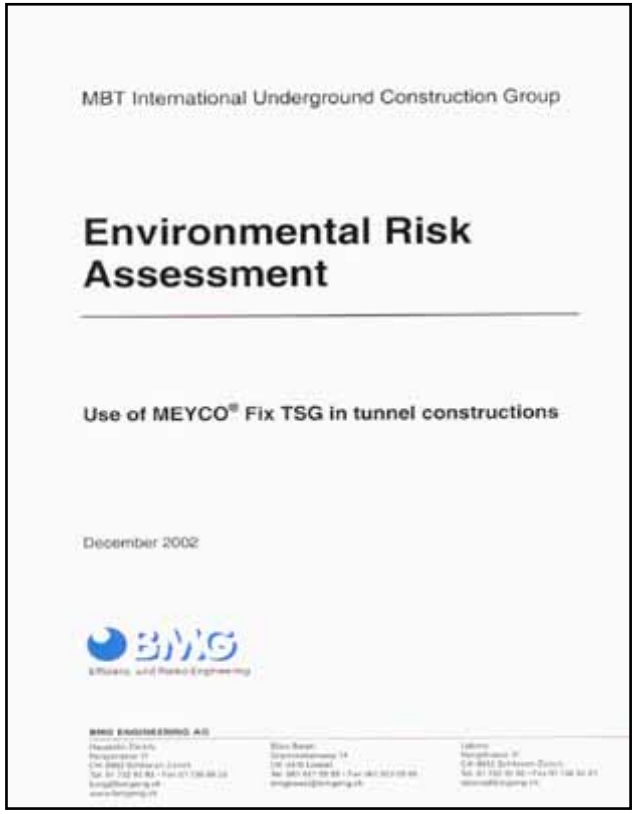
Environmental Risk Assessment

Use of Rheosoil® in tunnel constructions

October 2003

BMG Efficiency- and Risk-Engineering

Rheosoil®


MBT International Underground Construction Group

Environmental Risk Assessment

Use of MEYCO® Fix TSG in tunnel constructions

December 2002

BMG

TSG


Thank you for your
attetion