## Lake Mead Intake No 3 Tunnel

**Roberto Schuerch, ETH Zurich**

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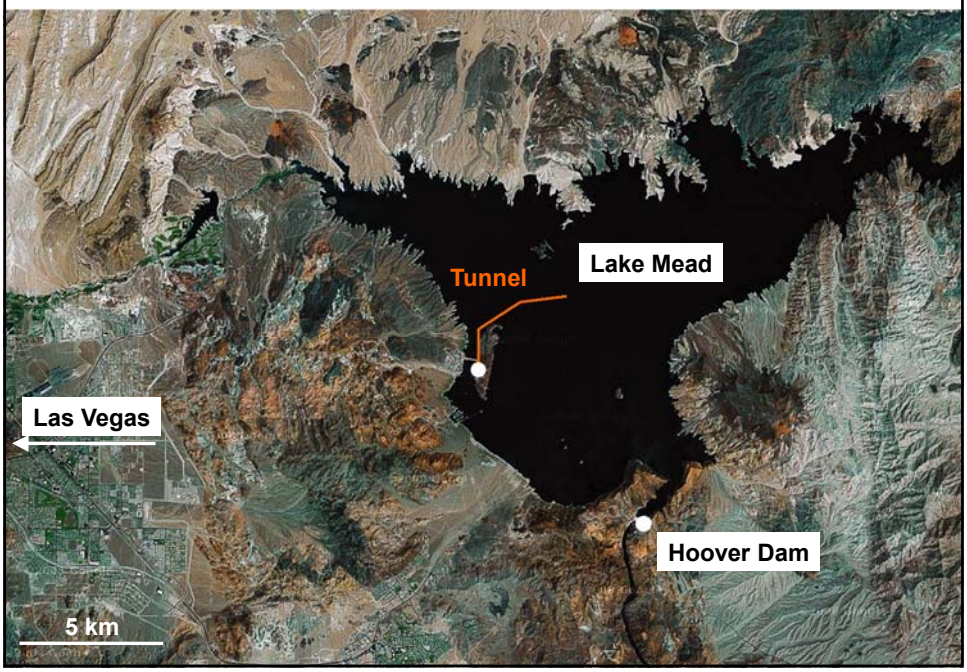
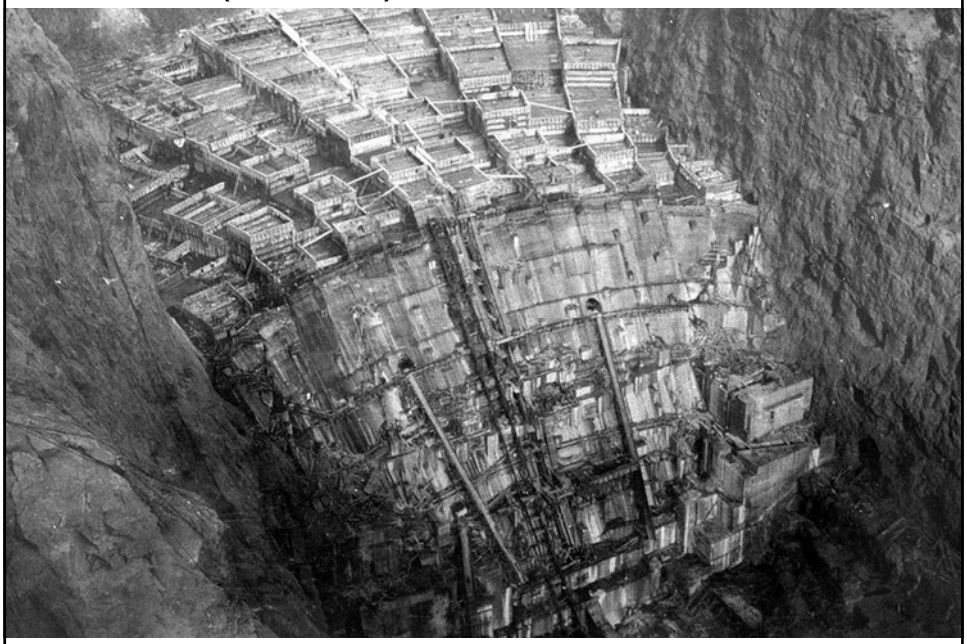


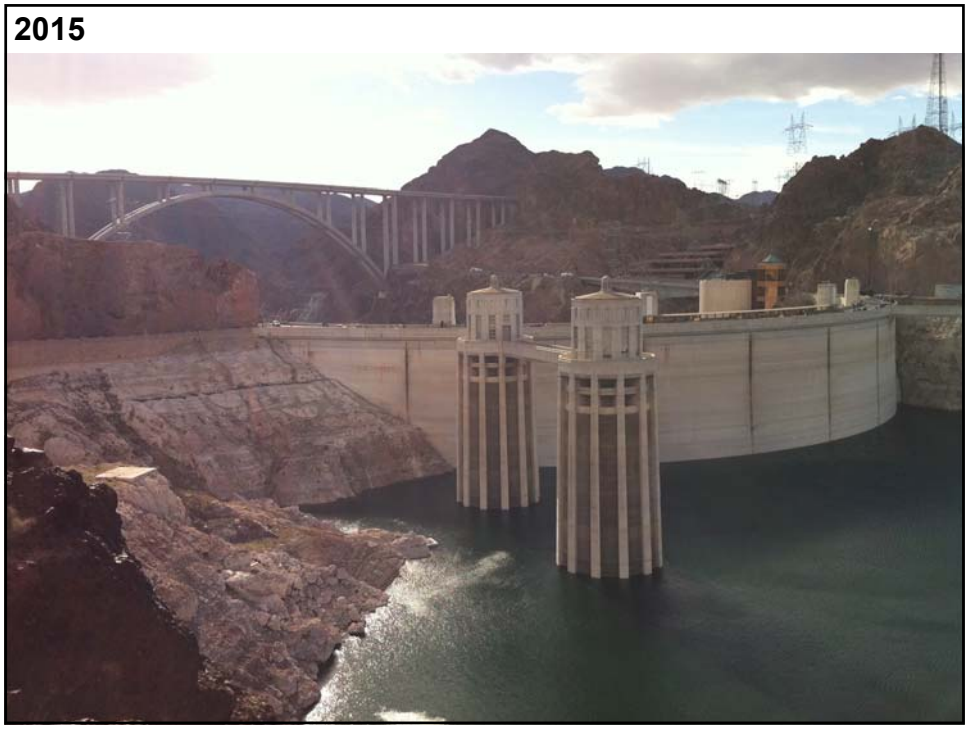

## Hoover Dam (1934-1936)

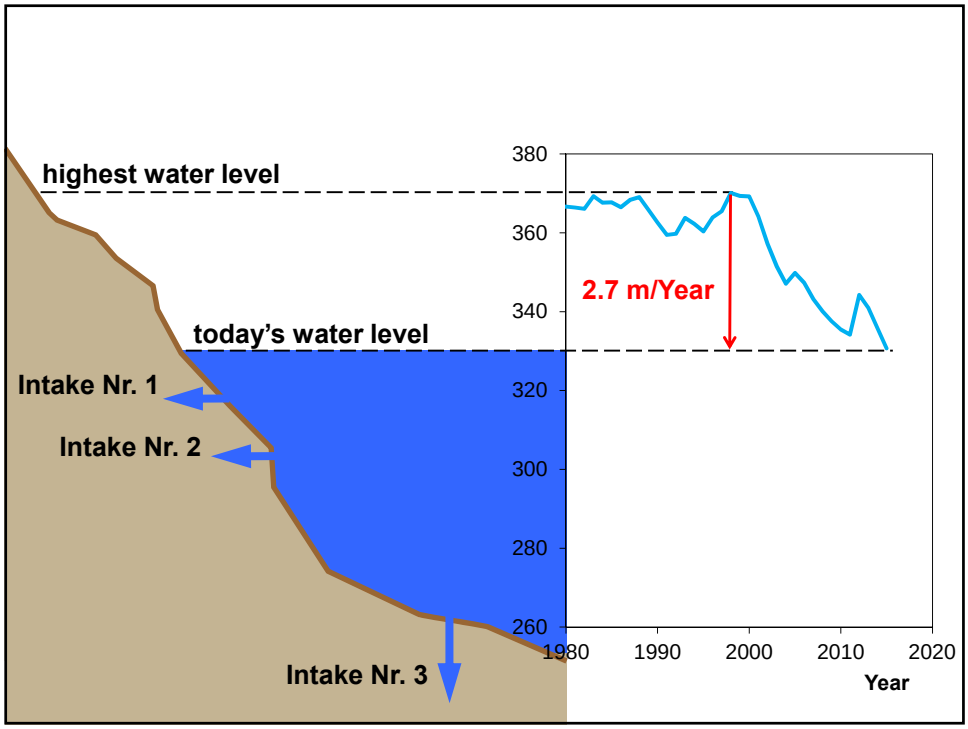


Power, flood control, water storage, regulation, recreation

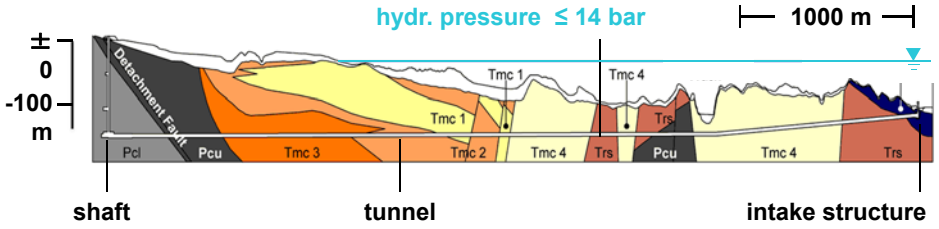
**1983**

**2015**


2015

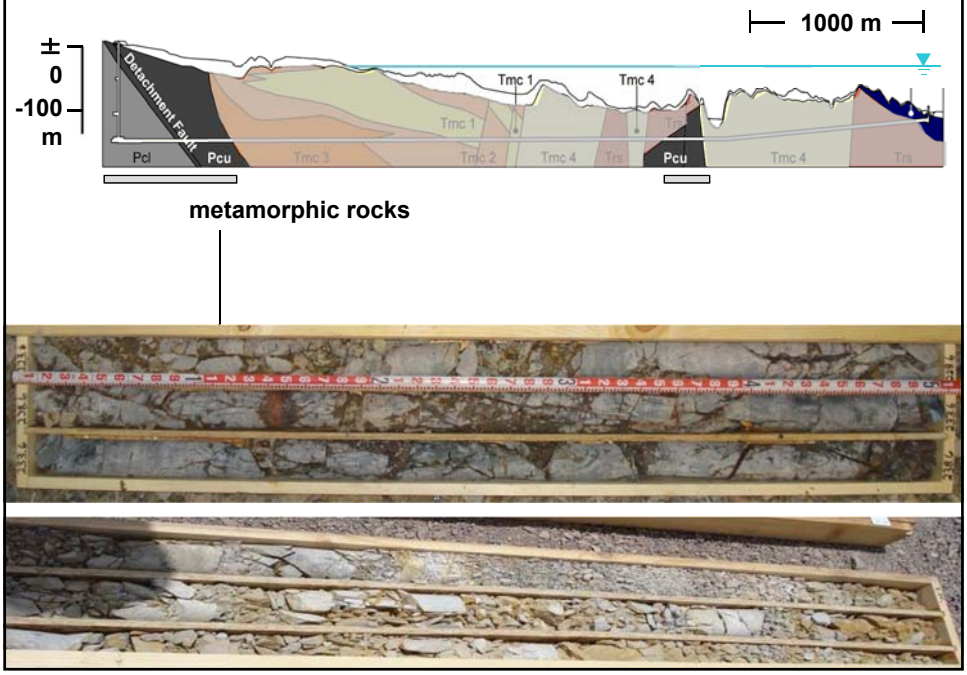

highest water level
today's water level
Intake Nr. 1
Intake Nr. 2
Intake Nr. 3
2.7 m/Year
380
360
340
320
300
280
260
1980
1990
2000
2010
2020
Year

## Lake Mead Intake No 3 Tunnel

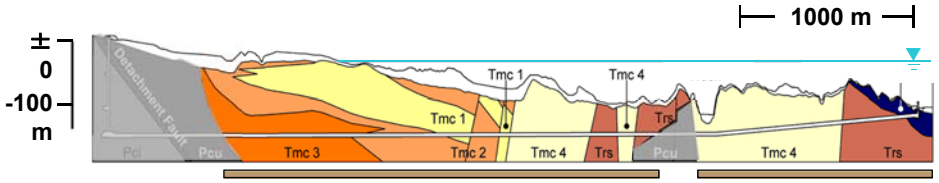



| | |
|---|---|
| **Length** | **4.75 km** |
| **Diameter** | **7.2 m** |

## Lake Mead Intake No 3 Tunnel



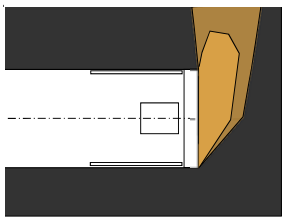
## Lake Mead Intake No 3 Tunnel

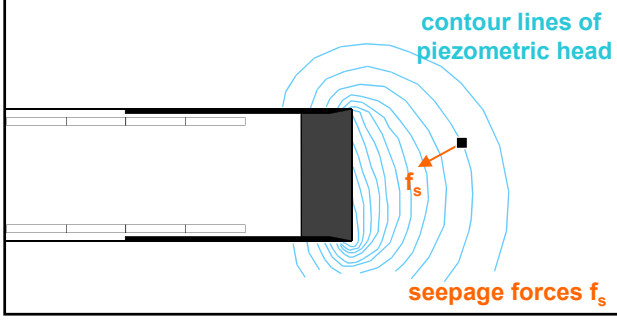



sedimentary rocks

## Major hazard scenarios

Face instability



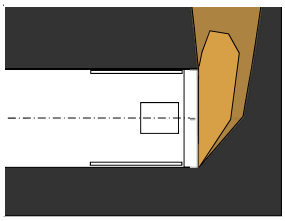


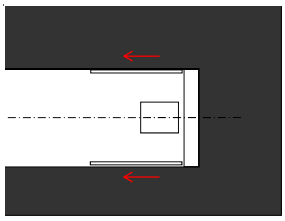
## Major hazard scenarios

**Face instability**

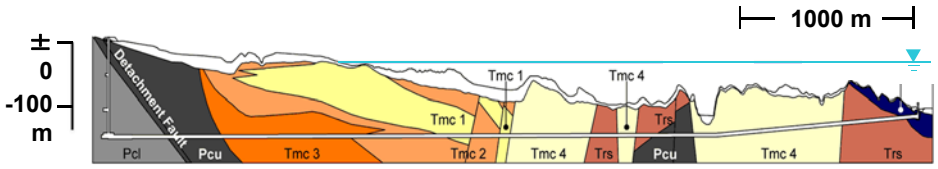
**Jamming of the shield**

**Unmanageable high water inflow**

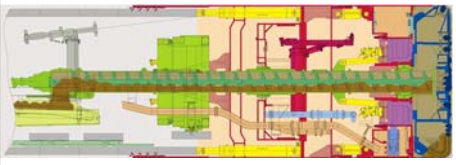




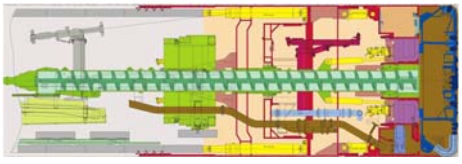
## Lake Mead Intake No 3 Tunnel




**hybrid TBM ø 7.22 m**

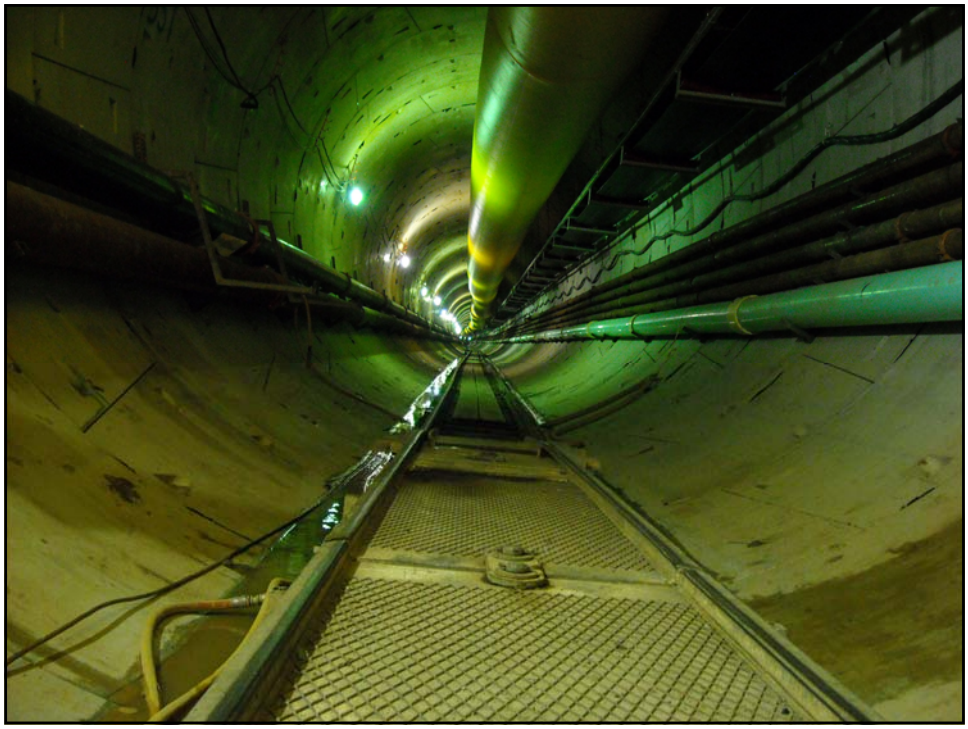


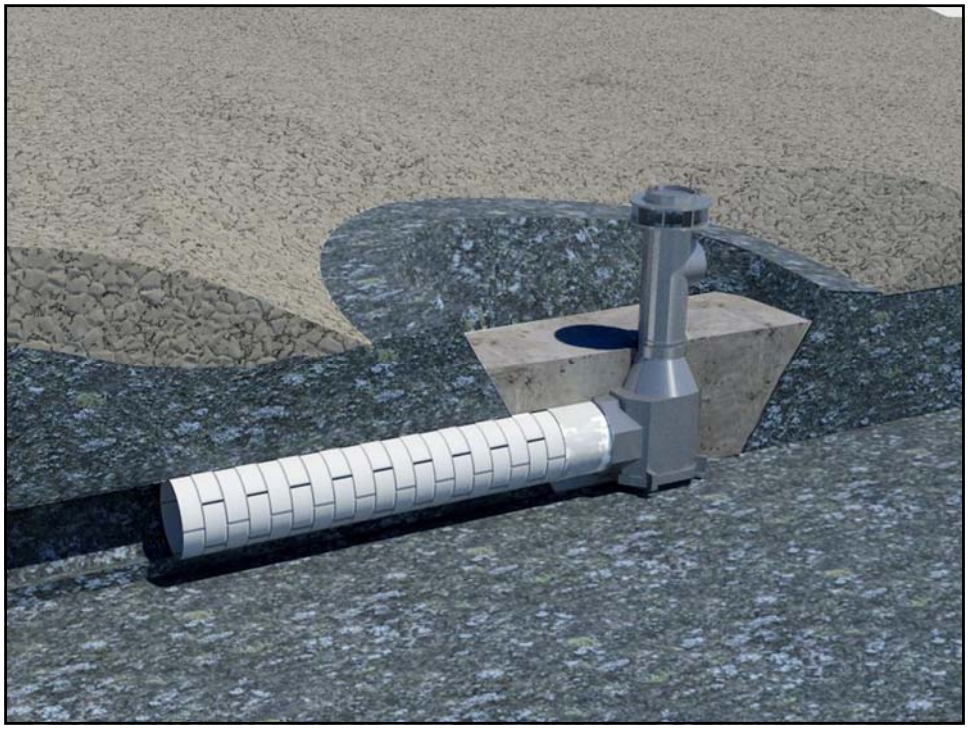
**Open mode:**
**Screw conveyor mounted**



**Closed mode:**
**Screw conveyor retracted**
**Mucking-out via hydraulic circuit**
**Face support by pressurized slurry**


DANGER
HIGH VOLTAGE
OVERHEAD





## Aid to decision making – consulting tasks

**Design phase (based upon excepted geological conditions):**
- **Tunneling operational plan (TOP)**
- **Tunneling condition assessment report (TCAR)**

**Excavation phase:**
- **Decision support during excavation**
- **Decision Tree (applies in case of deviations from the expected geological conditions)**
- **Analysis and interpretation of TBM data and of geological conditions**

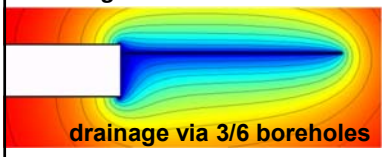
## TOP – operational modes

**Open mode (OM) excavation**

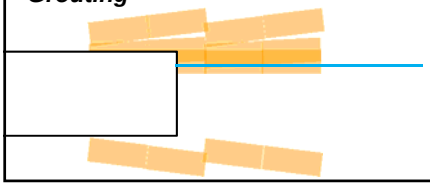
**Closed mode (CM) excavation at** **low (4.5 bar)**
**high (4.5-10 bar) and**
**very high support pressure (> 10 bar)**

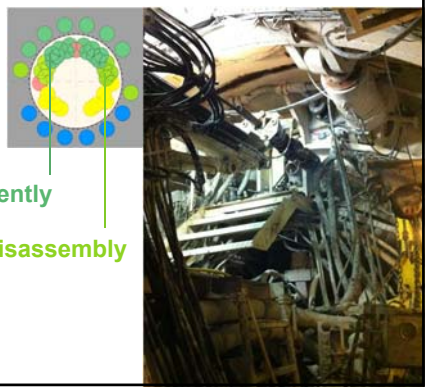
**Auxiliary measures:**

***- Drainage boreholes***

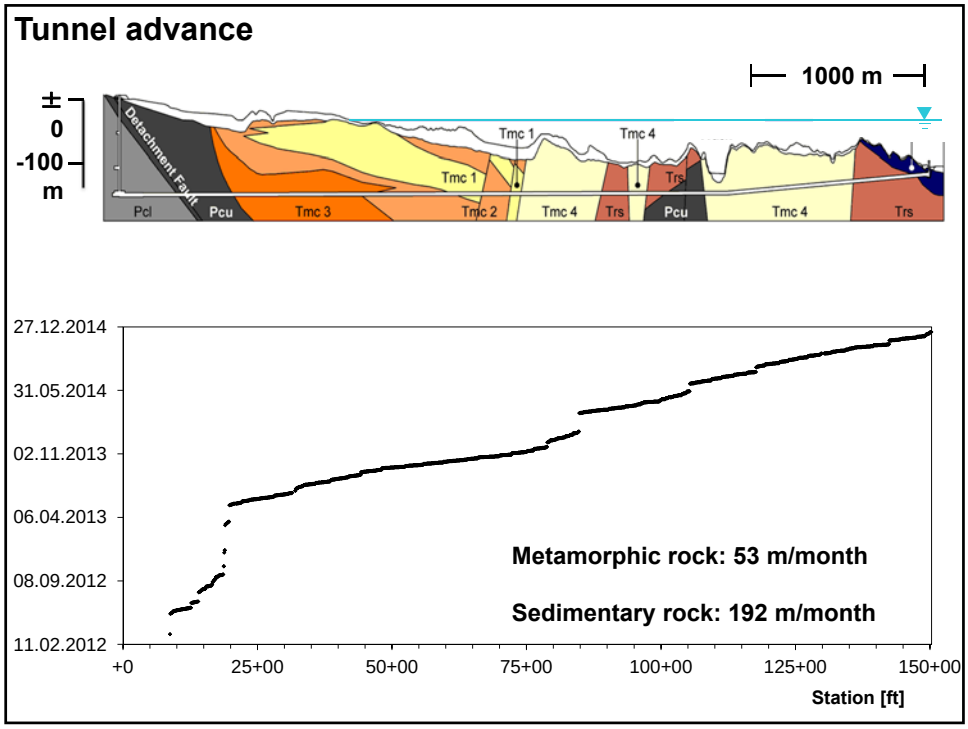


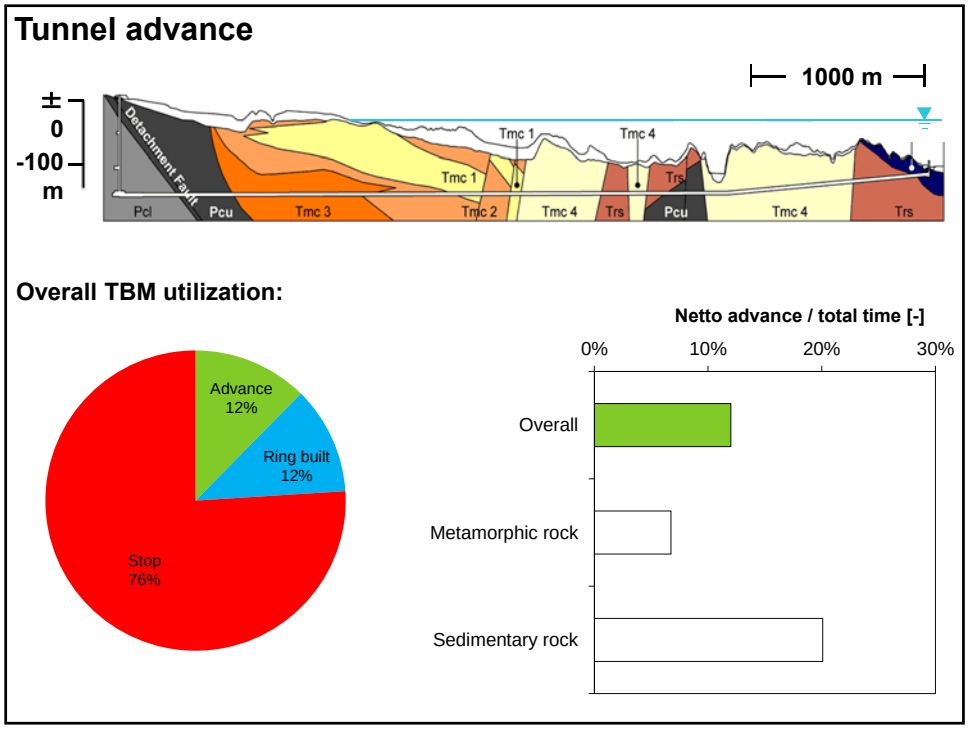

***- Grouting***

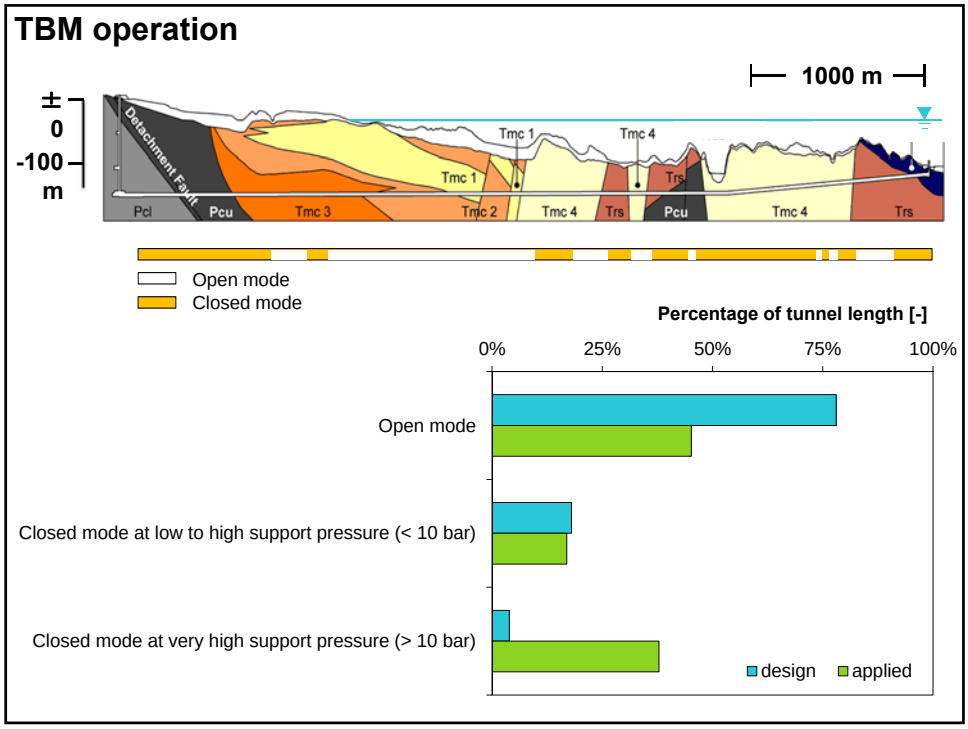


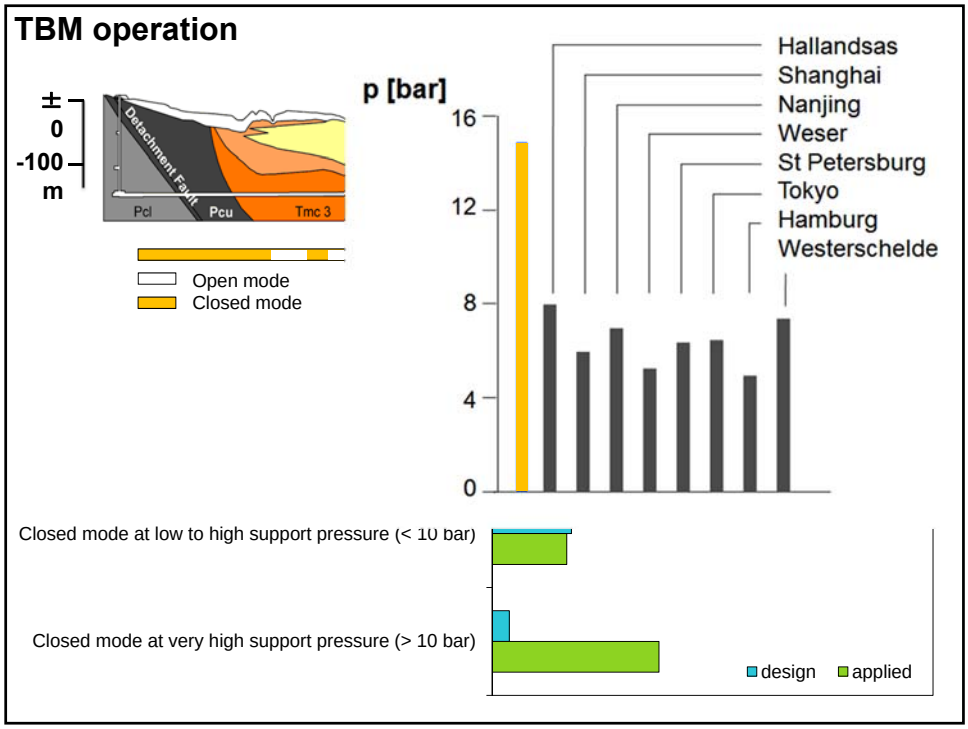


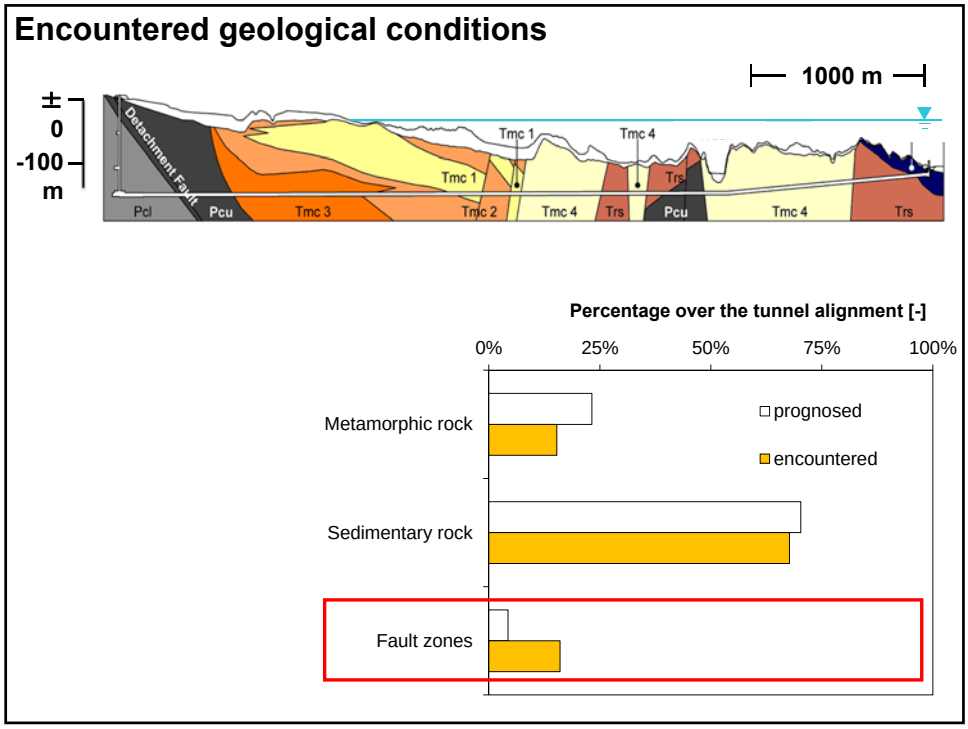

## Experience of TBM tunneling

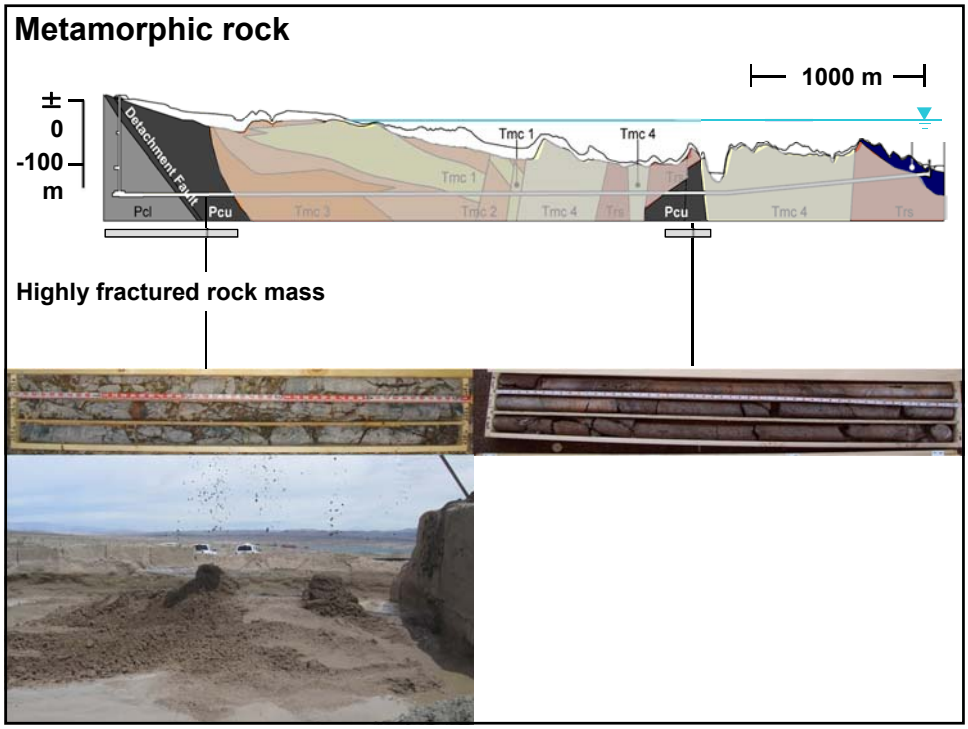

Tunnel advance
1000 m
± 0 -100 m
Detachment Fault
Pcl
Pcu
Tmc 3
Tmc 1
Tmc 2
Tmc 4
Trs
Pcu
Tmc 4
Trs
27.12.2014
31.05.2014
02.11.2013
06.04.2013
08.09.2012
11.02.2012
Metamorphic rock: 53 m/month
Sedimentary rock: 192 m/month
+0
25+00
50+00
75+00
100+00
125+00
150+00
Station [ft]


Tunnel advance
1000 m
± 0 -100 m
Detachment Fault
Pcl
Pcu
Tmc 3
Tmc 1
Tmc 2
Tmc 4
Trs
Pcu
Tmc 4
Trs
Overall TBM utilization:
Advance 12%
Ring built 12%
Stop 76%
Netto advance / total time [-]
0%
10%
20%
30%
Overall
Metamorphic rock
Sedimentary rock

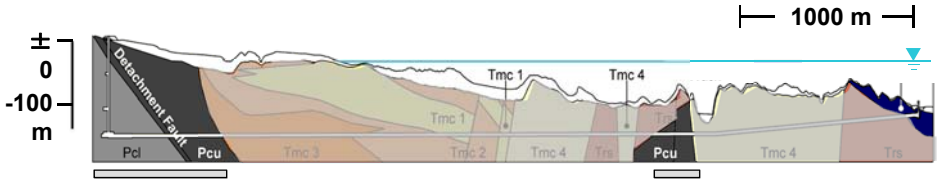

TBM operation
1000 m
± 0 -100 m
Detachment Fault
Pcl
Pcu
Tmc 3
Tmc 1
Tmc 2
Tmc 4
Trs
Open mode
Closed mode
Percentage of tunnel length [-]
0%
25%
50%
75%
100%
Open mode
Closed mode at low to high support pressure (< 10 bar)
Closed mode at very high support pressure (> 10 bar)
design
applied


TBM operation
± 0 -100 m
Detachment Fault
Pcl
Pcu
Tmc 3
Open mode
Closed mode
p [bar]
16
12
8
4
0
Hallandsas
Shanghai
Nanjing
Weser
St Petersburg
Tokyo
Hamburg
Westerschelde
Closed mode at low to high support pressure (< 10 bar)
Closed mode at very high support pressure (> 10 bar)
design
applied


Encountered geological conditions
1000 m
± 0 -100 m
Detachment Fault
Pcl
Pcu
Tmc 1
Tmc 3
Tmc 2
Tmc 4
Trs
Percentage over the tunnel alignment [-]
0%
25%
50%
75%
100%
Metamorphic rock
Sedimentary rock
Fault zones
prognosed
encountered

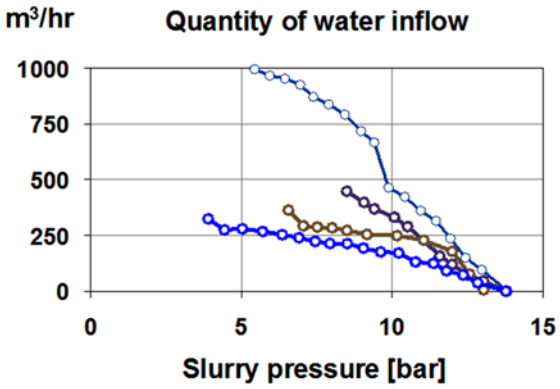

Metamorphic rock
1000 m
± 0 -100 m
Detachment Fault
Pcl
Pcu
Highly fractured rock mass

## Metamorphic rock

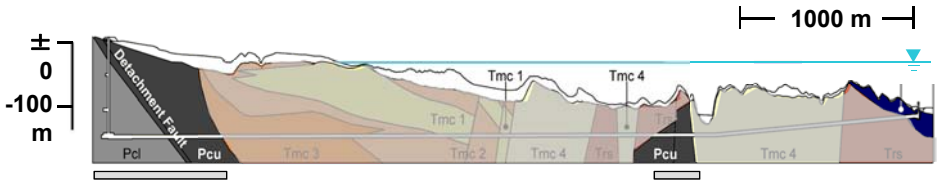



Highly fractured rock mass

**Extremely high water inflow when lowering the support pressure**




## Metamorphic rock

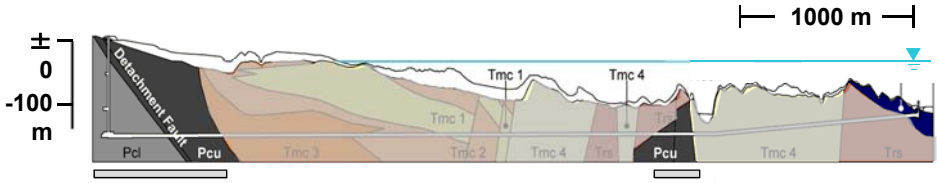



Highly fractured rock mass

Extremely high water inflow when lowering the support pressure

**Maintenance works not possible (unmanageable amount of water)**

## Metamorphic rock




Highly fractured rock mass

Extremely high water inflow when lowering the support pressure

Maintenance works not possible (unmanageable amount of water)

**Face inspection dangerous due to local instabilities (sudden rockfall)**


## Cutterhead repair in the metamorphic rock

**Metal pieces of the cutterhead at the separation plant**

**Drop of the TBM penetration**

**Inspection/maintenance required**

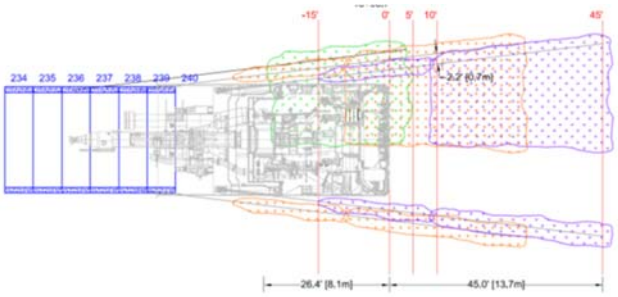
## Cutterhead repair in the metamorphic rock

Metal pieces of the cutterhead at the separation plant

Drop of the TBM penetration

Inspection/maintenance required

→ **3 campaign of grouting**



**400 Tons of grouted cement**

## Cutterhead repair in the metamorphic rock

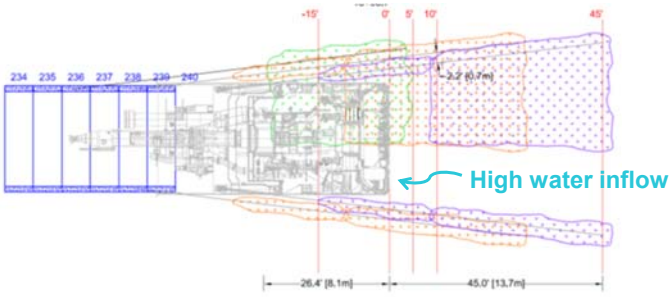
Metal pieces of the cutterhead at the separation plant

Drop of the TBM penetration

Inspection/maintenance required

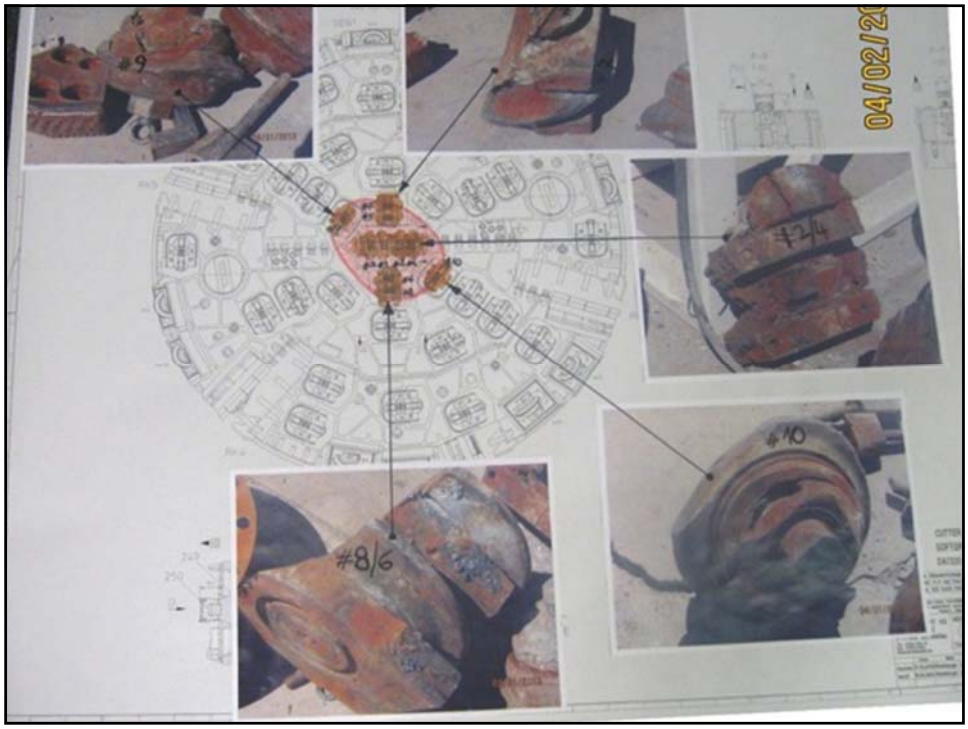
→ **3 campaign of grouting**

→ **unsuccessful due to geometrical limitation of the drilling pattern (but enough to carry-out maintenance at the slurry lines)**



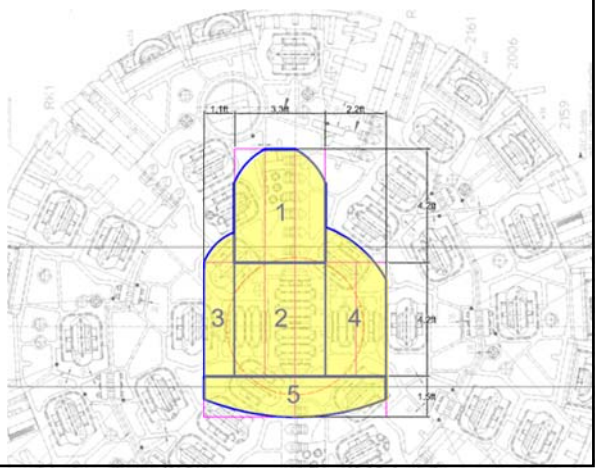
## Cutterhead repair in the metamorphic rock

**CH repair in a isolated pegmatite block of sound rock**



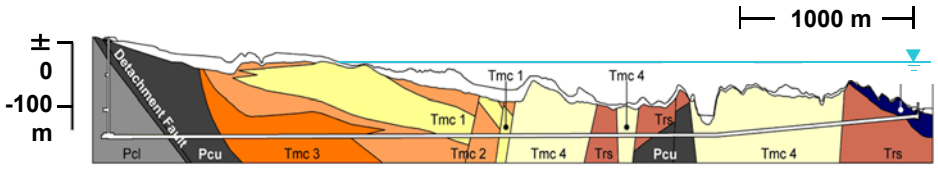
## Cutterhead repair in the metamorphic rock

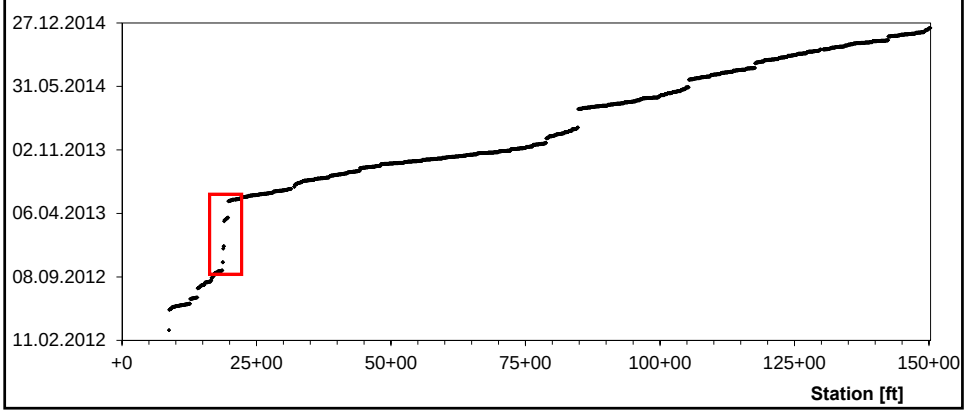
**Niche excavation in front of the cutterhead (April 1, 2013 to April 12, 2013)**



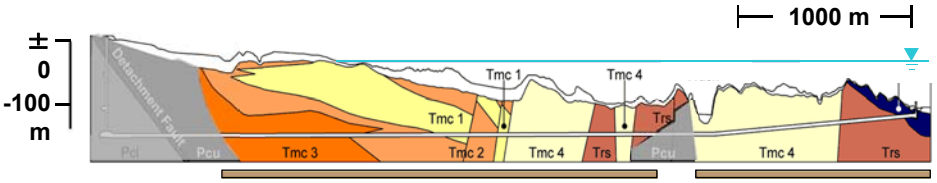

## Cutterhead repair in the metamorphic rock

## Cutterhead repair in the metamorphic rock

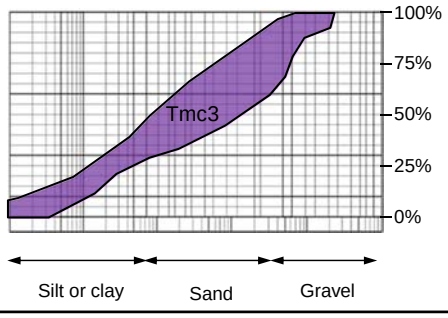


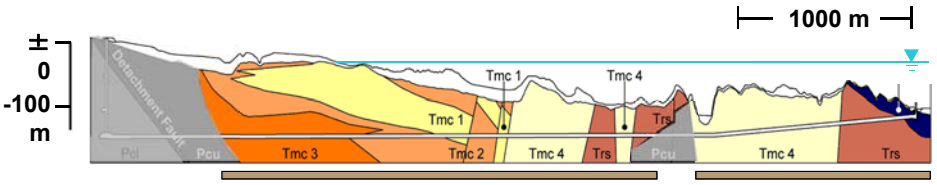
## Sedimentary rock



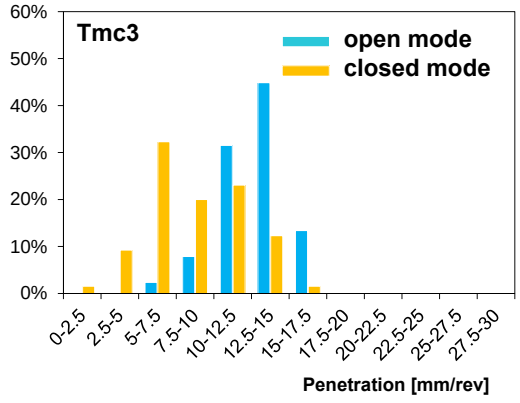

**Clogging**




## Sedimentary rock



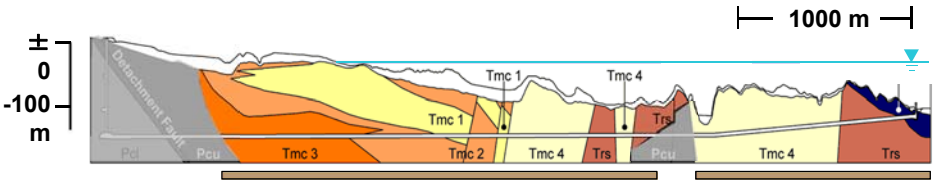

**Clogging**




06/28/2013


06/28/2013

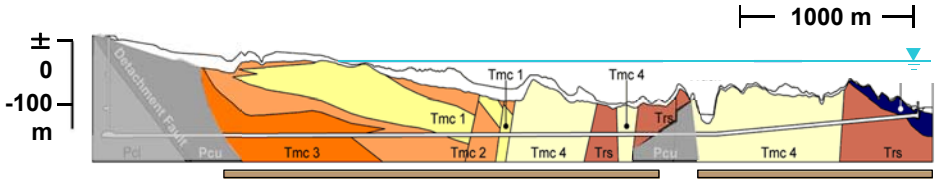
## Sedimentary rock




**Clogging**

**Soil-like muck**

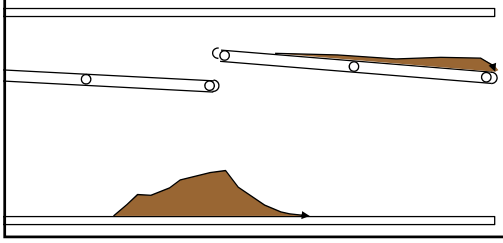
## Sedimentary rock




Clogging

Soil-like muck

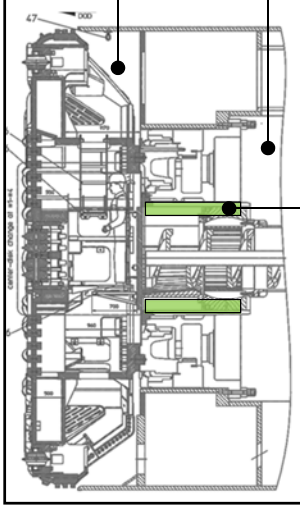
**Mucking-out difficulties in open mode (for Q > 25 m³/h)**



## Repair of the cascade sealing system

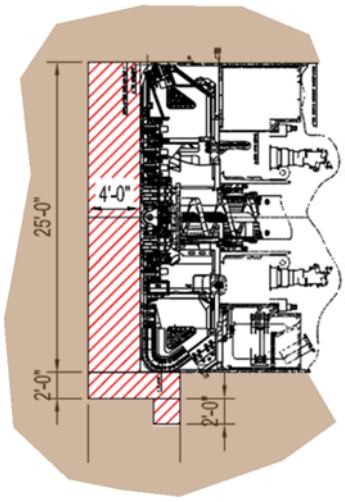
**Working chamber ($p = p_{support}$)**

**Drilling chamber ($p = p_{atm}$)**

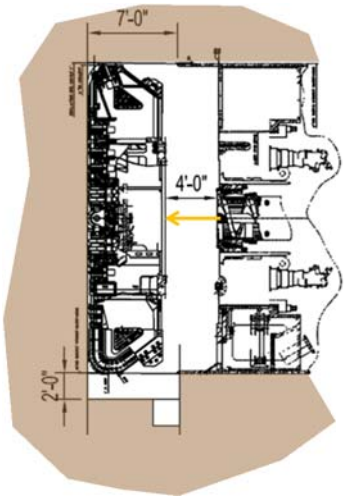



**Damage of the cascade sealing system (leakage between pressurized chambers) due to the unexpected length over which the TBM had to be operated at extremely high support pressure**

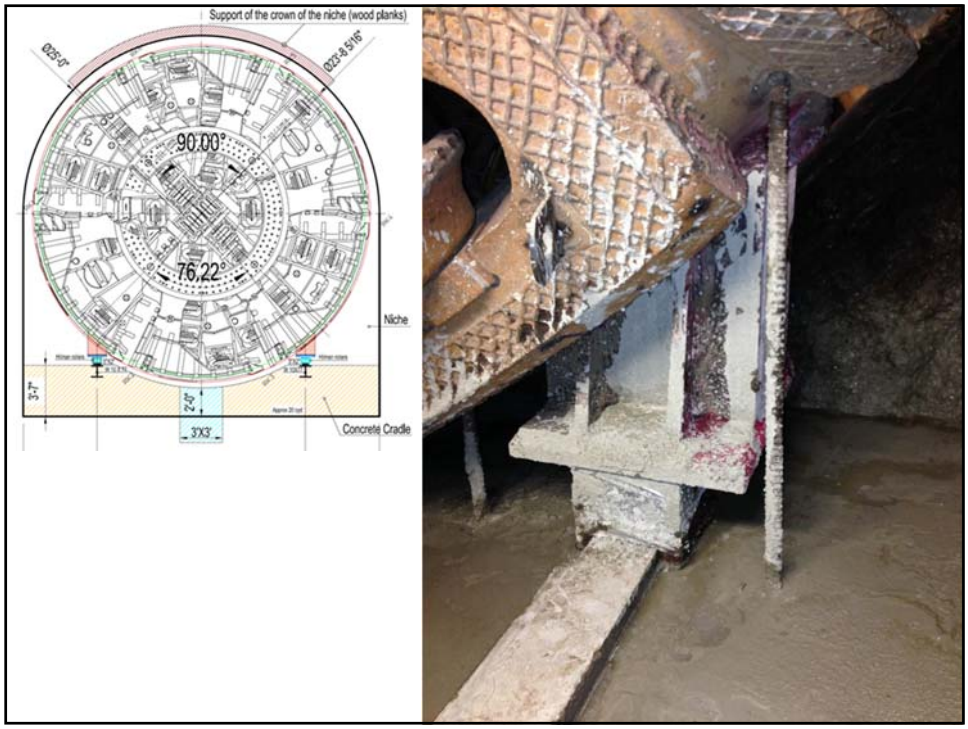
## Repair of the cascade sealing system

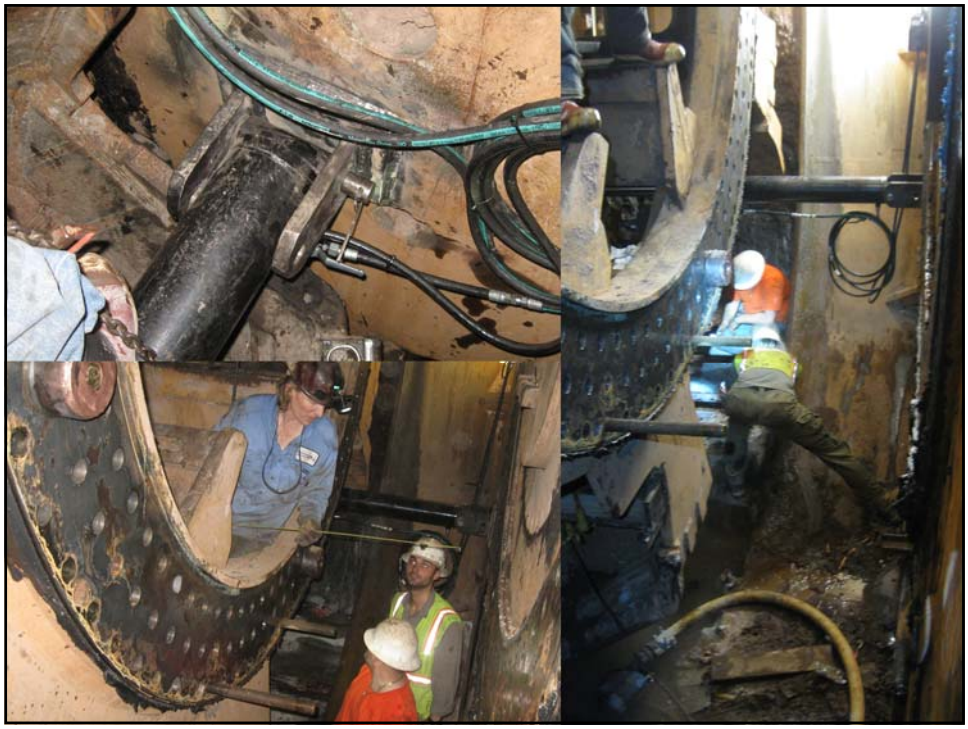



Niche excavation in front of the CH



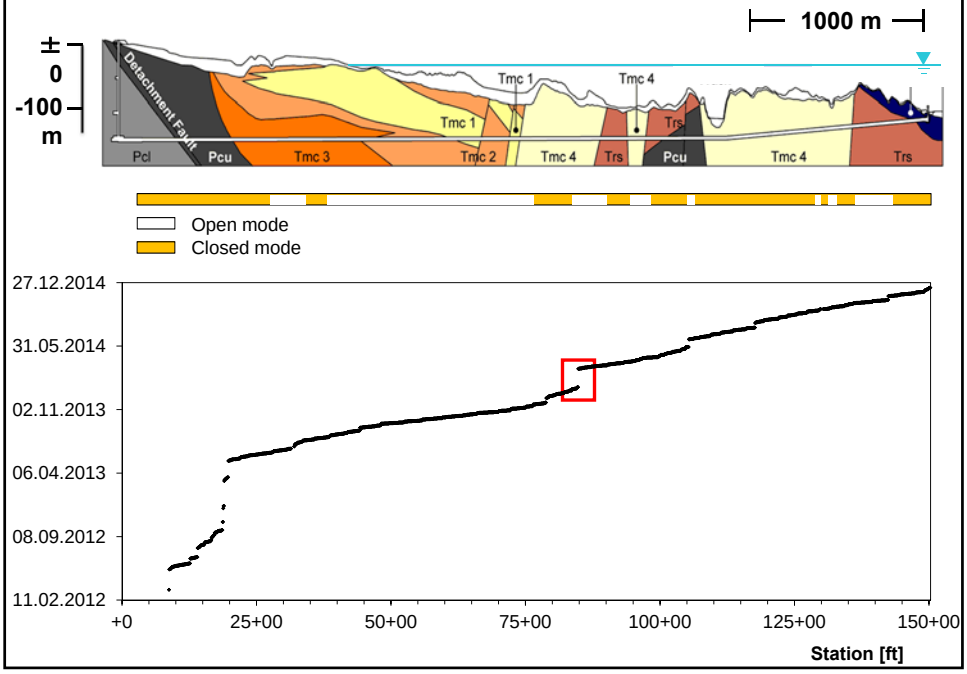

Forward push of the cutterhead for sealing substitution


Support of the crown of the niche (wood planks)
90.00°
76.22°
Niche
Concrete Cradle

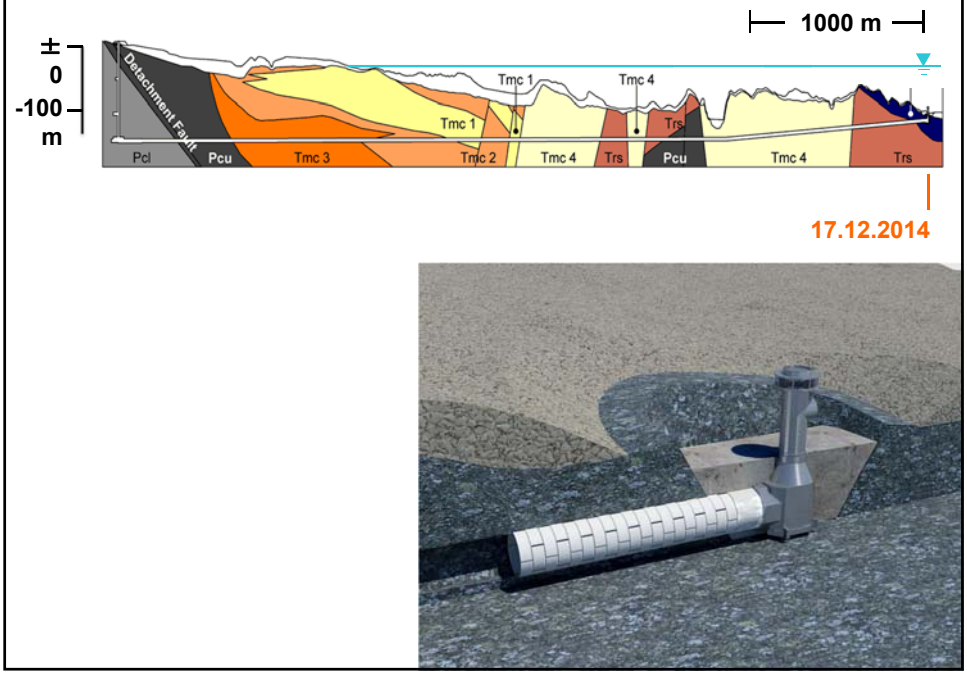



2014

## Repair of the cascade sealing system

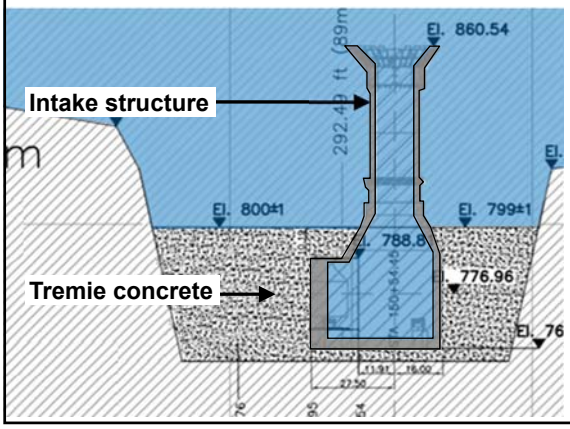



## TBM-docking



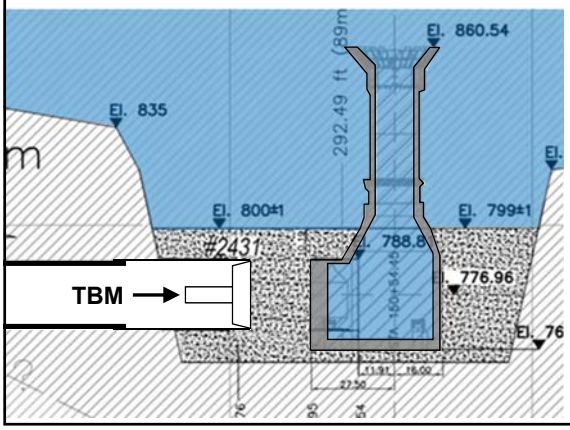
## TBM-docking

**Construction of the intake structure**




## TBM-docking

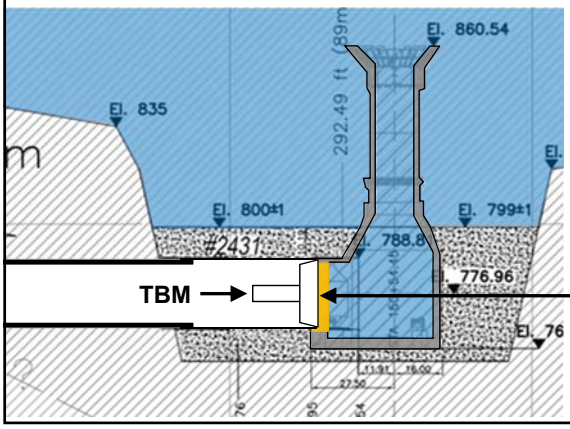
**Final TBM approach to the intake structure:**
**- Closed mode with full compensation of the hydrostatic pressure during breakthrough ("flooded shaft" principle)**
**- No advance exploration or grouting (risk of concrete cracking and/or blow-out)**



## TBM-docking

**Excavation of the "soft-eye" (breakthrough)**

**Intake structure**




**"Soft-eye"**
**(0.5 m fiberglass-reinforced concrete wall)**

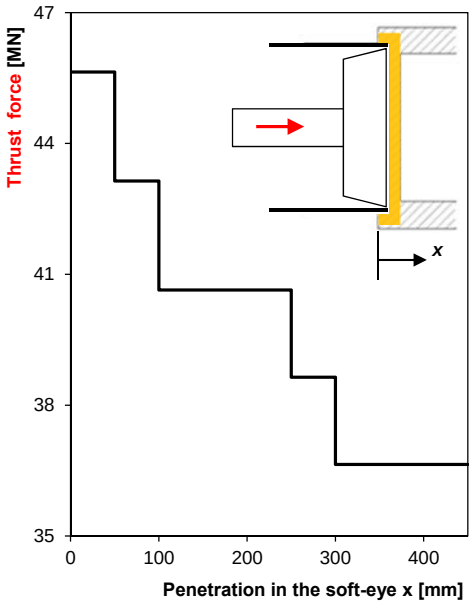
## TBM-docking

**TBM-parameters for breakthrough:**

**- Thrust force dependent on the advance in the soft-eye**

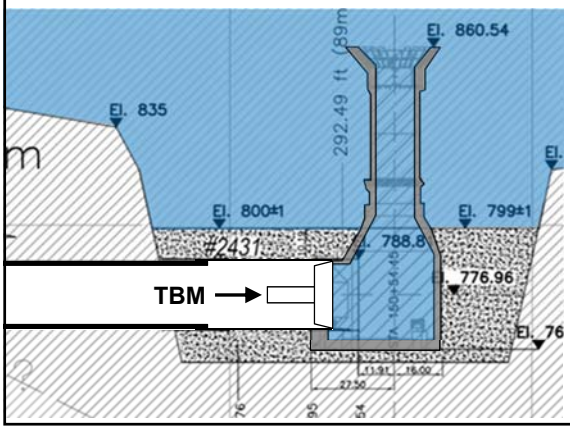
**- Small penetration (about 1.5 mm/rev)**

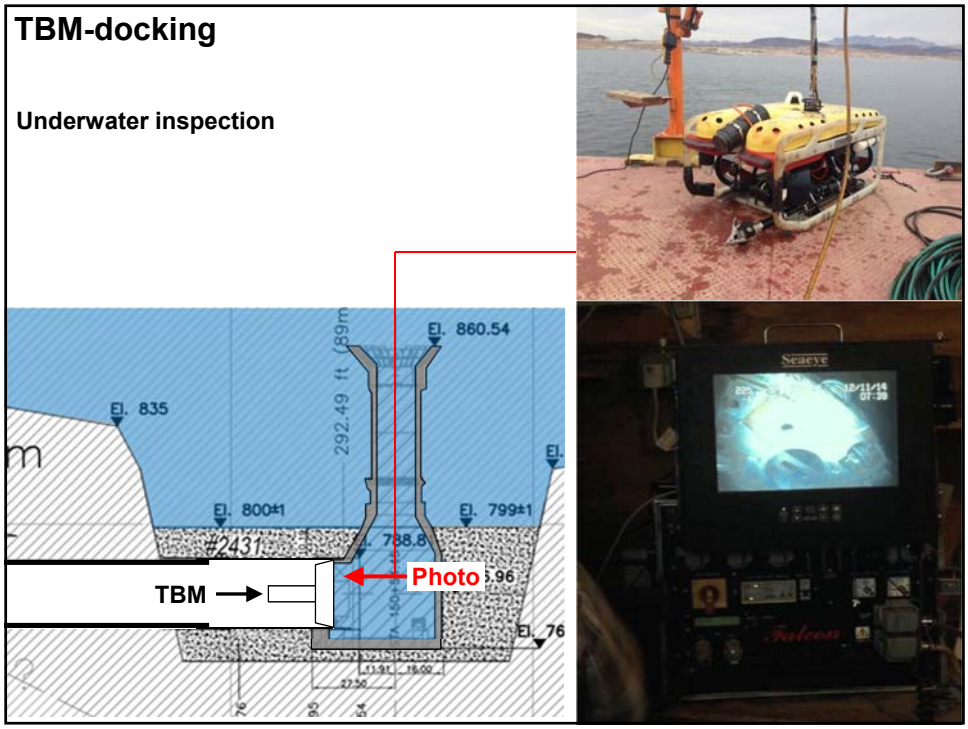
**- High rotational speed (3.5-4.5 rpm)**



## TBM-docking

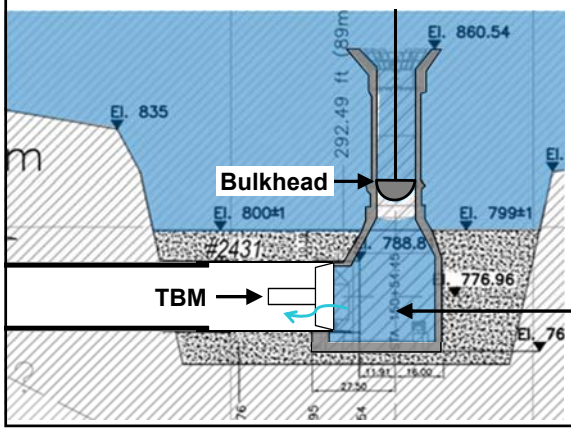
**Final position of the TBM**

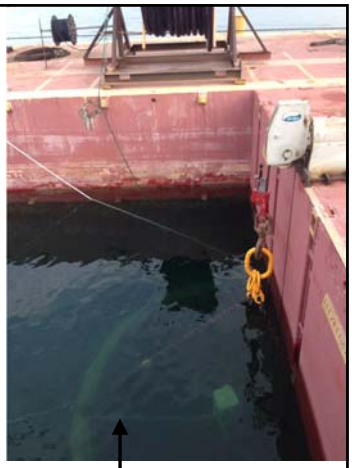



TBM-docking
Underwater inspection
El. 860.54
El. 835
292.49 ft /89m
El. 800±1
El. 799±1
#2431
El. 788.8
Photo
TBM
El. 76
Seaeye
Falcon

## TBM-docking

**Lowering of the bulkhead and emptying of the intake chamber**

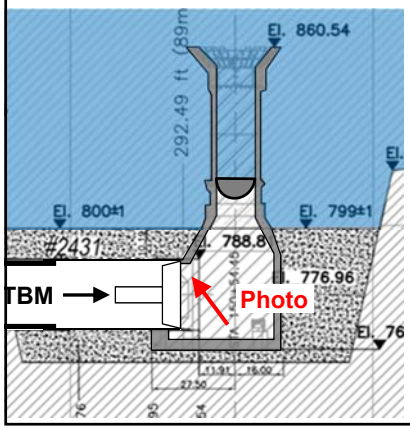


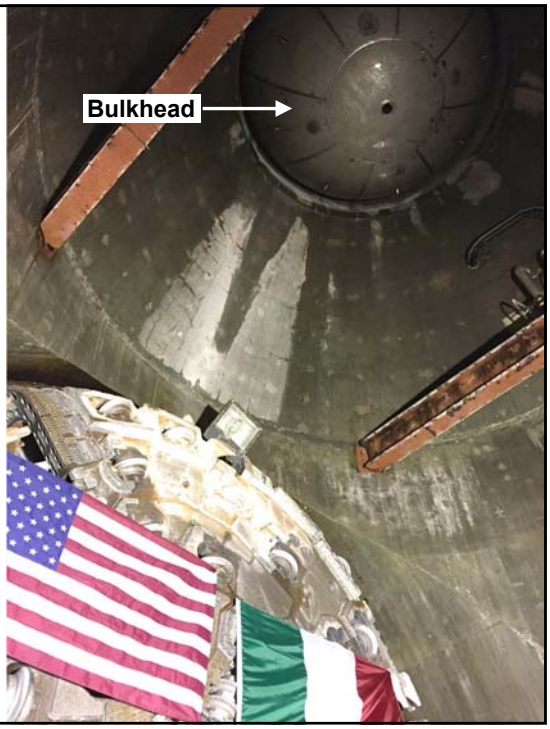



Bulkhead

Intake chamber

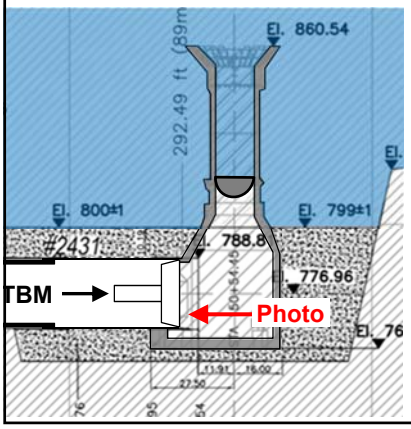
## TBM-docking



## TBM-docking

**Thickness of the collapsed soft-eye 12 cm only!**

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Nicola, A., Nickerson, J., Bono, R., Donadoni, N., Anagnostou, G., Schürch, R., Zingg S. (2014) Lake Mead Intake Tunnel No. 3 – A step beyond the limits. *Swiss Tunnel Congress*, Lucerne, 166-173.