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*Challenges and Innovations in Tunnelling*

## Multi Mode TBMs

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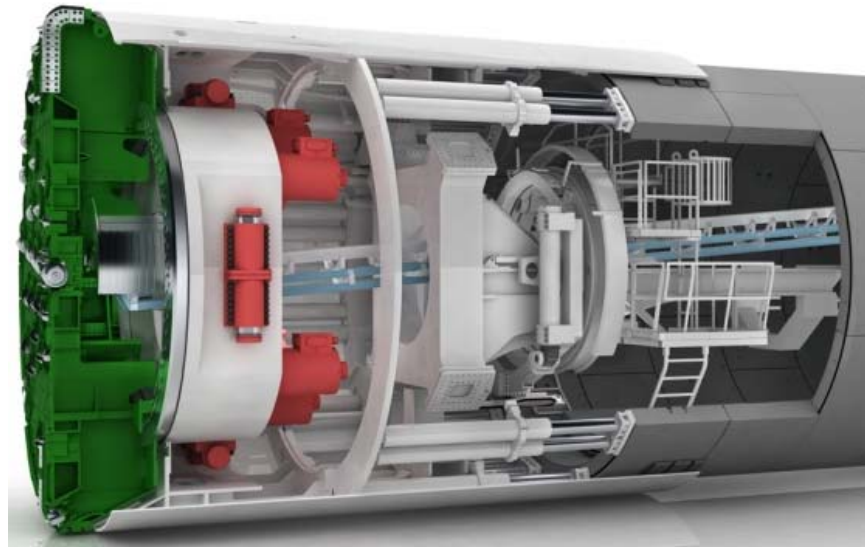
Tunnelling Association of Canada  
Association Canadienne Des Tunnels



# Multi Mode TBMs

- ▶ **Basic Open and Closed mode TBM principals**
- ▶ **Motivation for Multi – Mode TBMs**
- ▶ **Change between EBP and Open single shield**
- ▶ **Change between Slurry and Open single shield**
- ▶ **Change between Earth Pressure Balanced shield and Slurry shield**
- ▶ **The Next Step: Herrenknecht “Variable Density” ® TBM**
- ▶ **Case Histories**

## Open Mode TBM principal

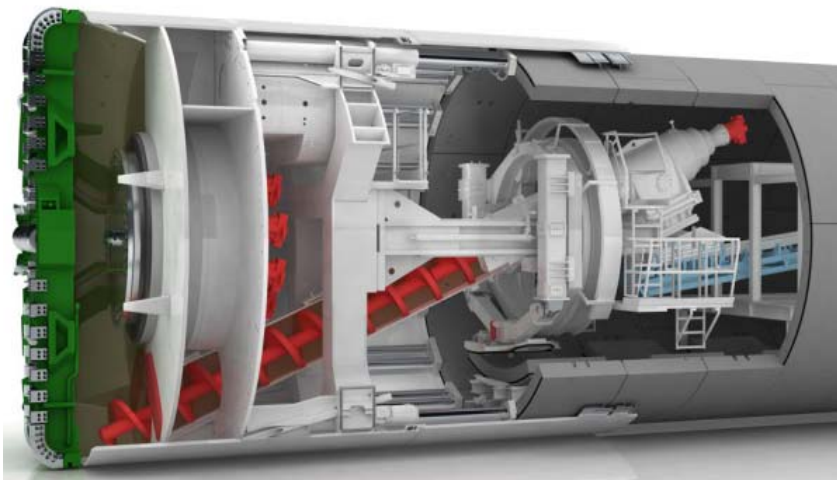


### Open Single Shield

- Stable, usually non-water bearing ground conditions
- Atmospheric pressure
- Usual dry muck removal with belt conveyor

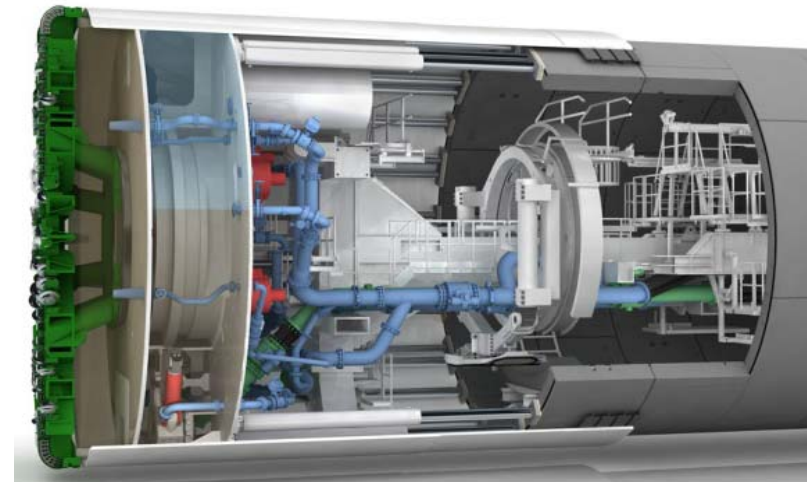
# Earth Pressure Balance Shield and Slurry Shield Principal

## Modes Of Operation



### Closed Earth Pressure Balanced Shield (EPBM)

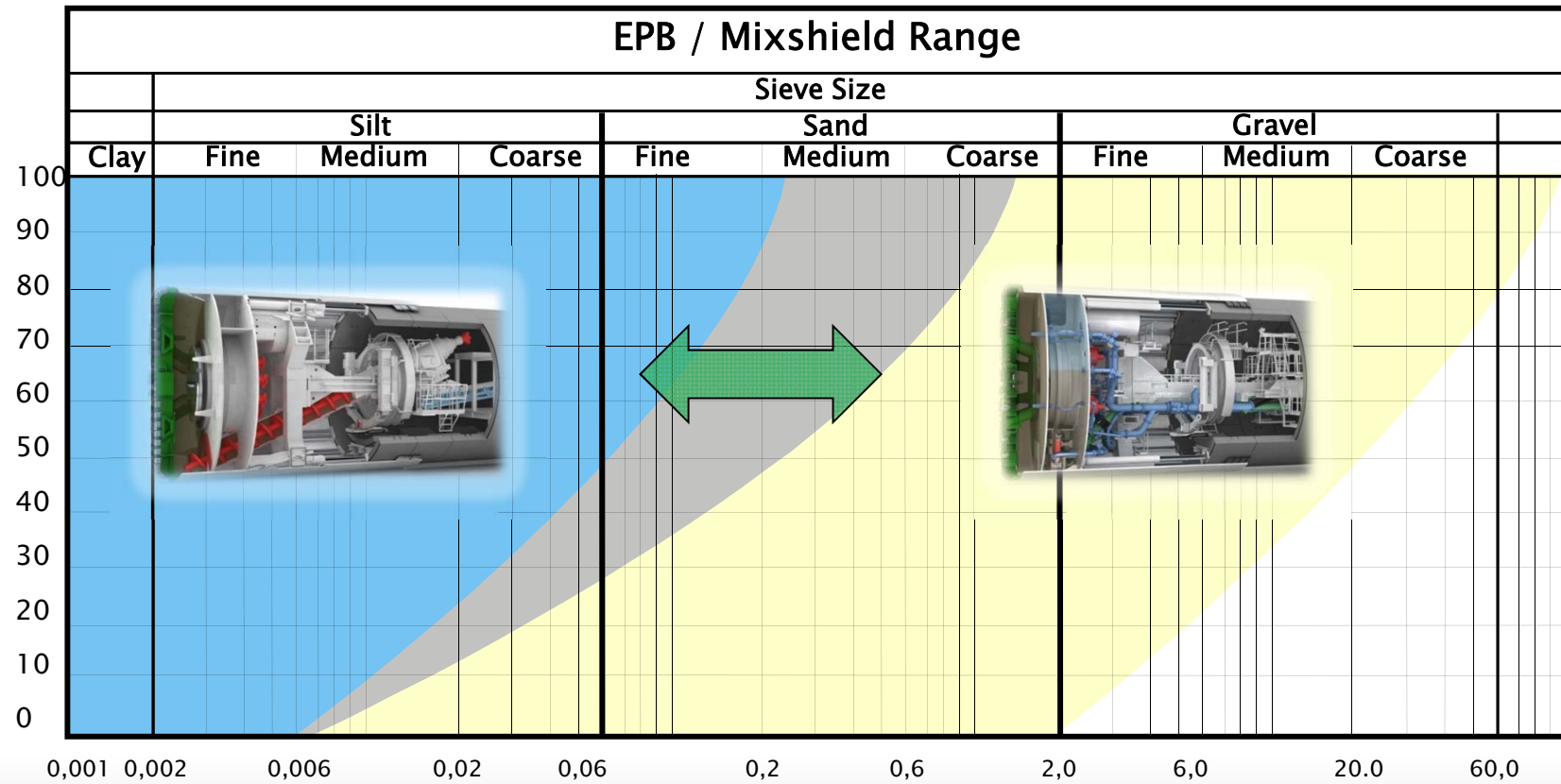
- Fine grained, unstable water-bearing soils
- Controlled pressure (screw and thrust)
- Thick-matter-type via screw conveyor



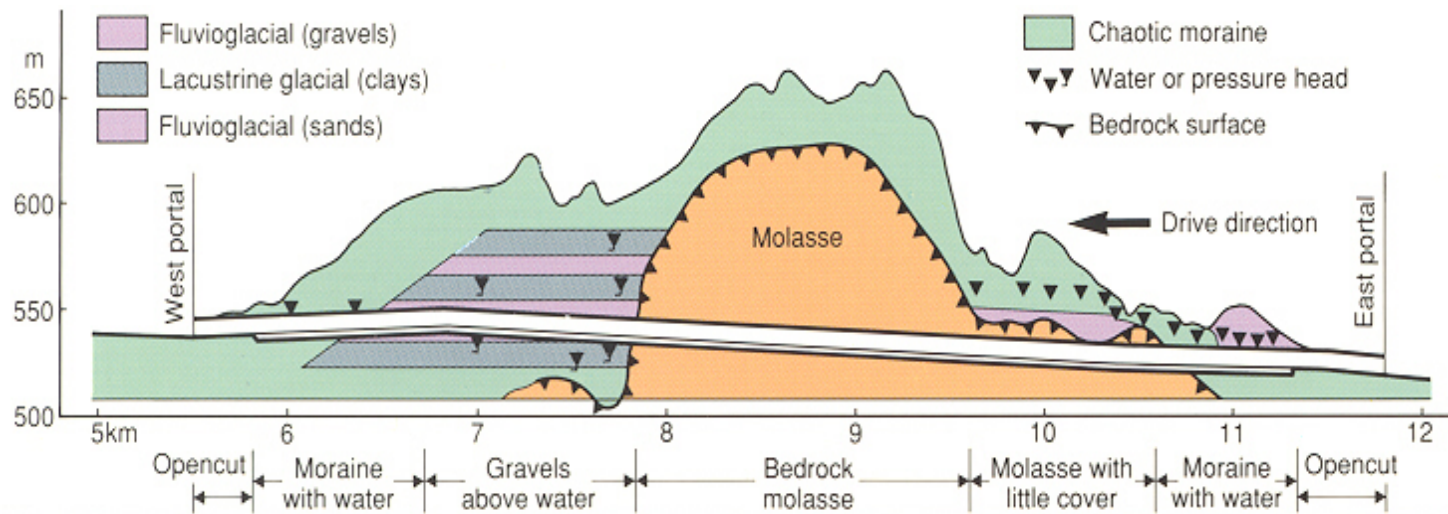
### Closed Slurry Machine (STBM)

- Course grained, unstable water-bearing soils
- Controlled pressure (air bubble)
- Slurry circuit and above ground slurry treatment plant

# Multi – Mode / Convertible TBMs



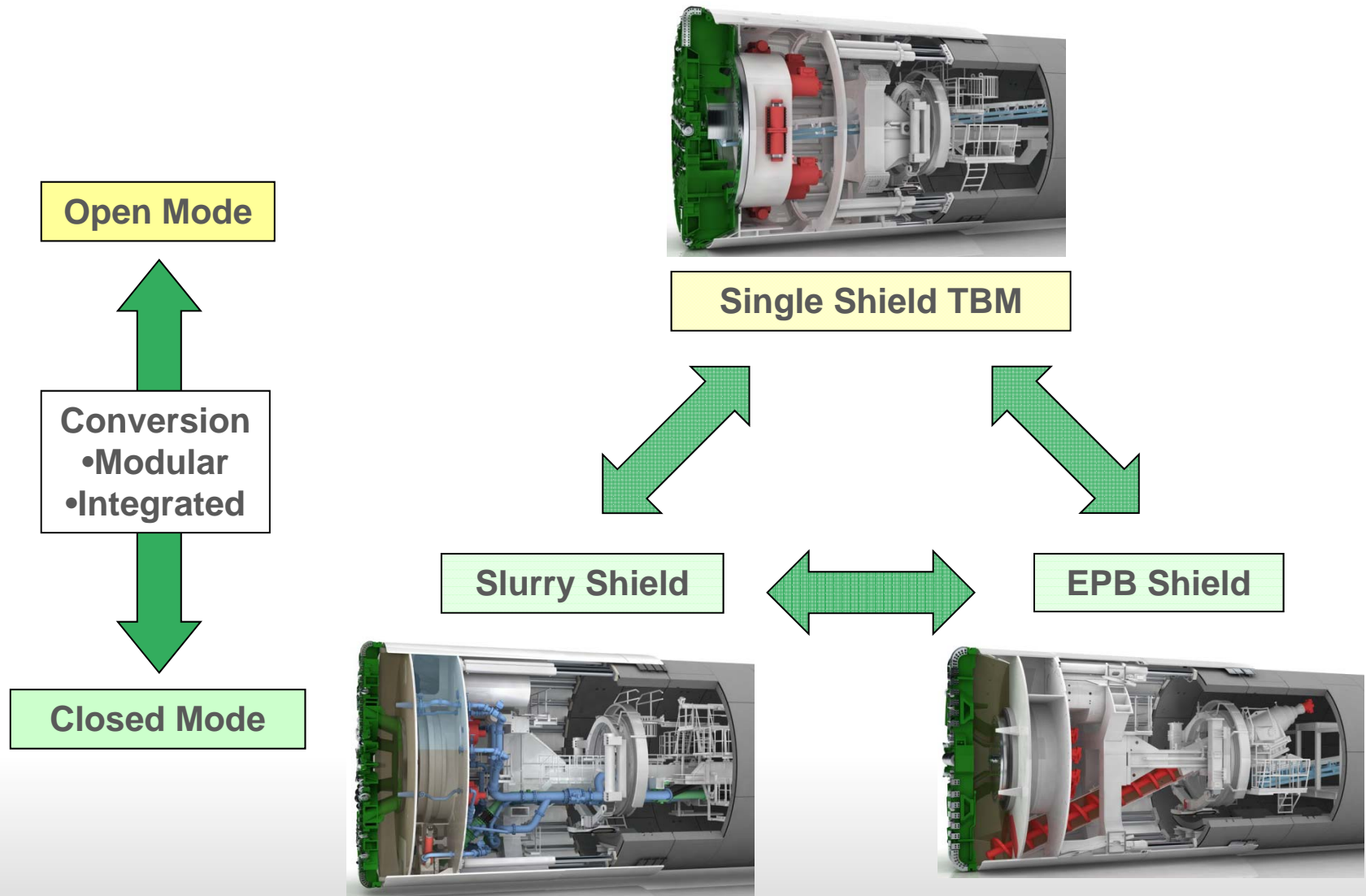
## Motivation for Multi - Mode TBMs.



- ▶ Long sections of different ground conditions along the alignment
- ▶ Best suitable mode of operation for each single section
- ▶ Best suitable mode of operation → optimized economy
- ▶ Best suitable mode of operation → increased safety



# Convertible Machines

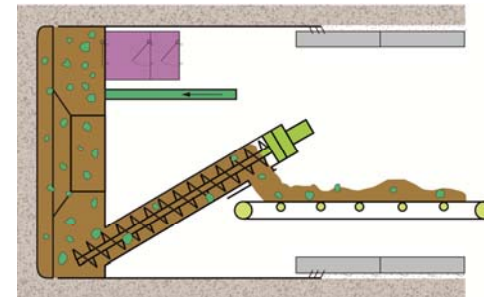


# Change between EPB and Open single shield

## Modes Of Operation

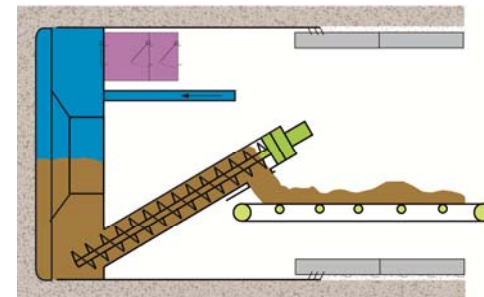
### Closed Mode - Earth Pressure Balance

- regular mode of operation
- positive face support
- max. 6-8 bar depending on soil condition(ing)



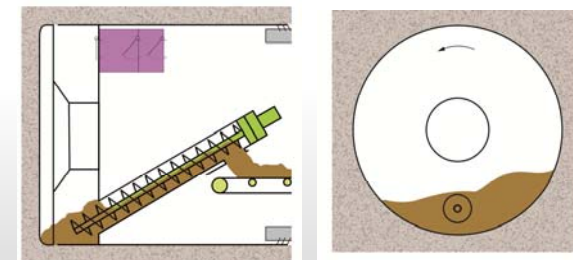
### Closed Mode - Compressed Air

- exceptional mode of operation
- control of water inflow
- max. 2,5 bar depending on soil condition(ing)



### Open Mode

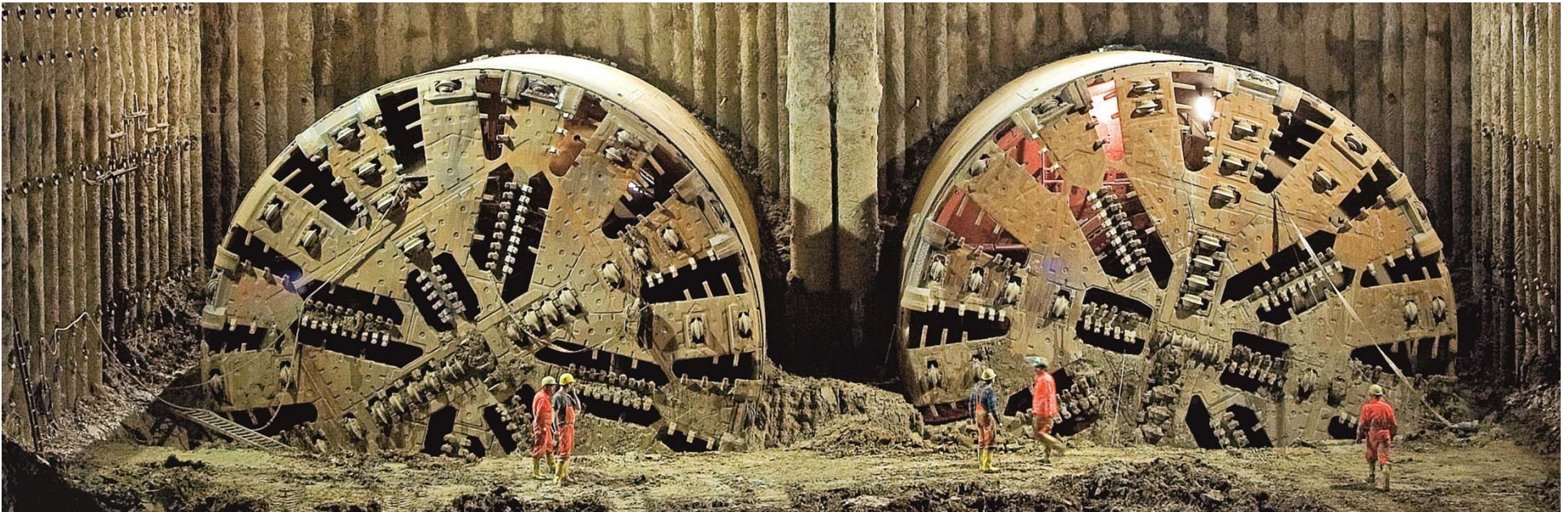
- stable face conditions
- atmospheric excavation chamber
- rapid chamber isolation possible (discharge gate)
- muck pile in chamber required (cutterhead wear)





# Change between EPB and Open single shield

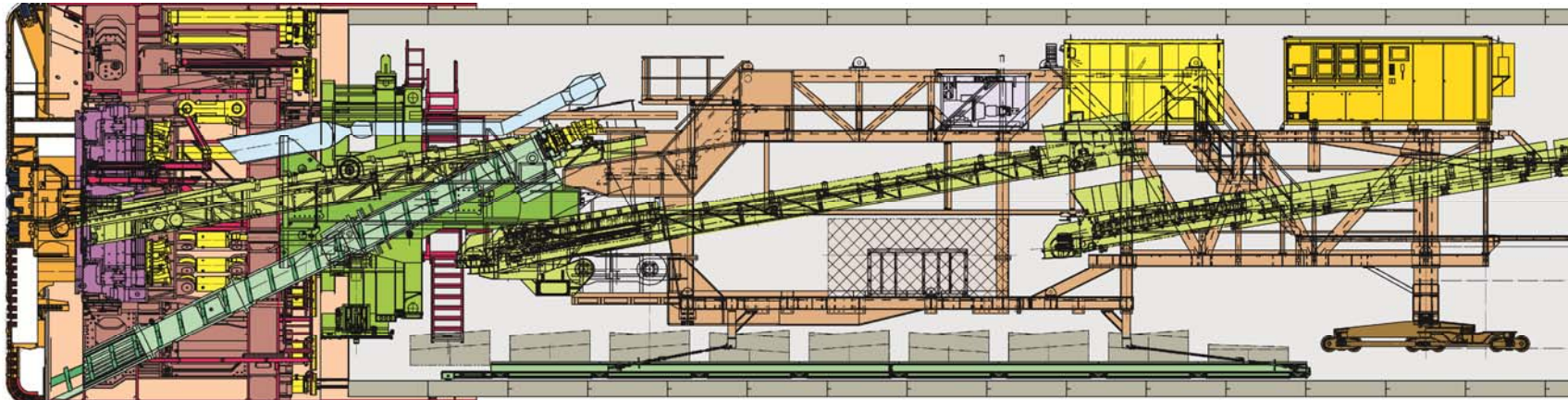
## Katzenberg Tunnel, Germany



- ▶ Screw conveyor for primary mucking system
- ▶ No modification for open – closed mode change
- ▶ Short individual closed mode sections along the alignment (approx. 10%) – 8.9km
- ▶ Moderate soil abrasivity

## Change between EPB and Open single shield

### Center Belt Conveyor And Screw Conveyor As Primary Mucking System



#### Closed Mode - Earth Pressure Balance

- Screw conveyor in forward position for full capacity
- Center belt and muck hopper retracted, rotary installed
- Cutterhead muck transport channels partially removed

#### Open Mode

- Screw conveyor in retracted position (limited capacity)
- Center belt and muck hopper in forward position, rotary removed
- Cutterhead muck transport channels installed



# Change between EPB and Open single shield

## Saverne Tunnel, France

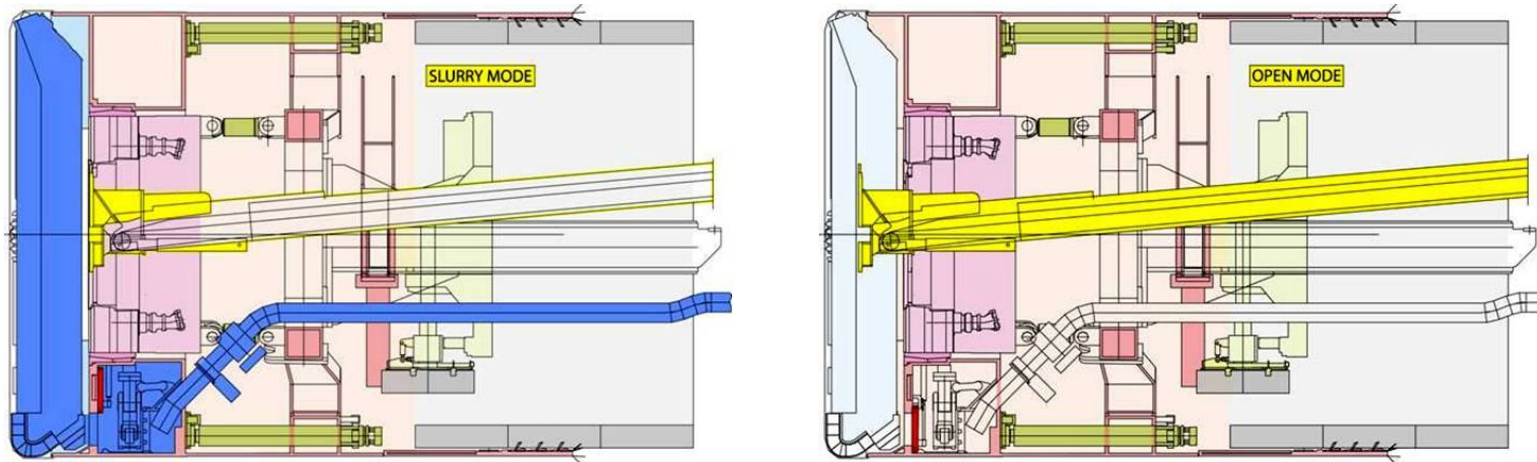


- ▶ Screw conveyor and center belt / muck hopper for primary mucking system
- ▶ Approx. four days required for open – closed mode change
- ▶ Two short closed mode sections along the alignment (approx. 5%)
- ▶ Very high rock/soil abrasivity

11

## Change between Slurry and Open single shield

### Slurry Circuit and Center Belt Conveyor As Primary Mucking System



#### Closed Mode – Slurry machine

- Submerged wall gate open
- Center belt and muck hopper retracted and sealed
- Slurry circuit and treatment plant in operation

#### Open Mode

- Submerged wall gate closed
- Center belt and muck hopper in forward position
- Closing / Mode change within 2 - 4 hours

# Change between Slurry and Open single shield

## Weinberg Tunnel, Switzerland



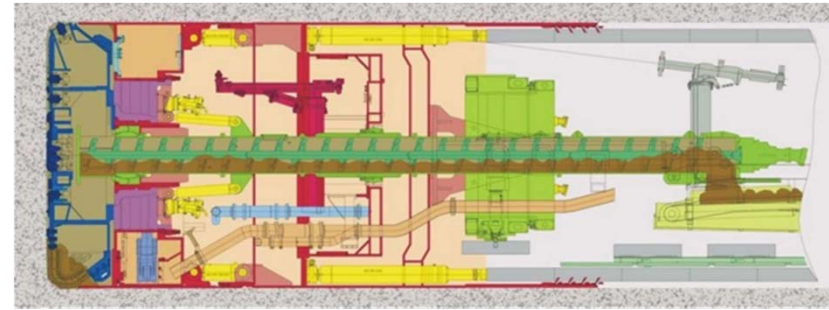
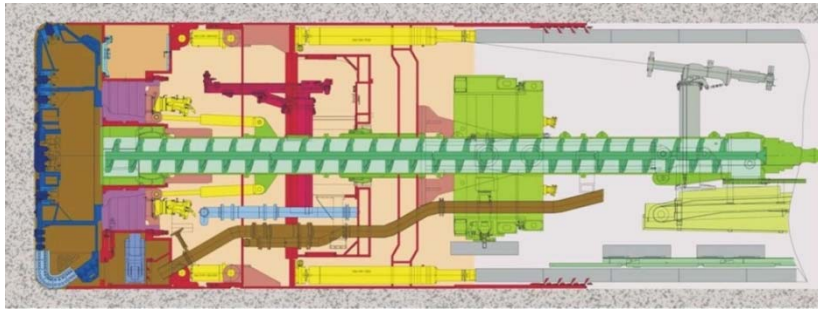
- ▶ Slurry circuit and center belt / muck hopper for primary mucking system
- ▶ Approx. one week required for open – closed mode change
- ▶ 10% of the tunnel length in closed slurry mode at the end of the drive for Limmat river crossing (transition from molasse rock in gravelly material)

13



## Change between Slurry and Open single shield

Center Screw Conveyor and Slurry Circuit as Primary Mucking System  
(Special Version for Lake Mead Intake No. 3 Tunnel)



### Closed Mode – Slurry machine

- Submerged wall gate open
- Center screw and muck hopper casing retracted and sealed
- Slurry circuit and treatment plant in operation

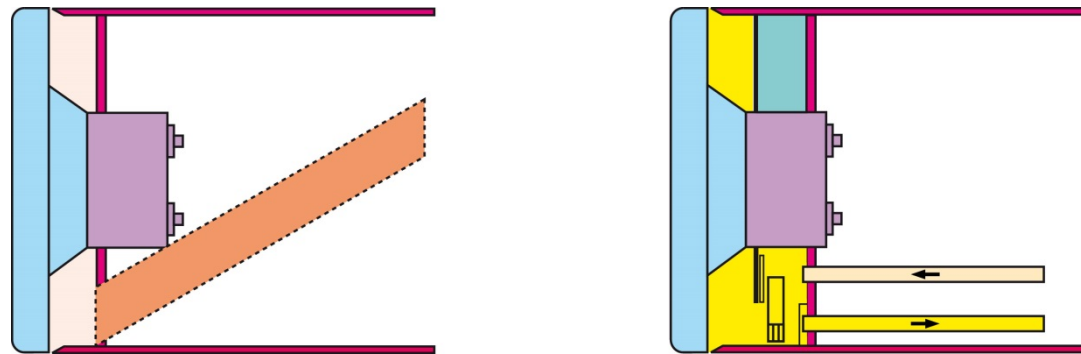
### Open Mode

- Submerged wall gate closed
- Center conveyor and muck hopper casing in forward position
- Closing in less than 20 seconds (screw discharge gate)



## Change between Earth Pressure Balance Shield and Slurry Shield

Slurry Circuit or Screw Conveyor as Primary Mucking System, Different Method of Face Pressure Control



### Closed Mode – EPB Machine

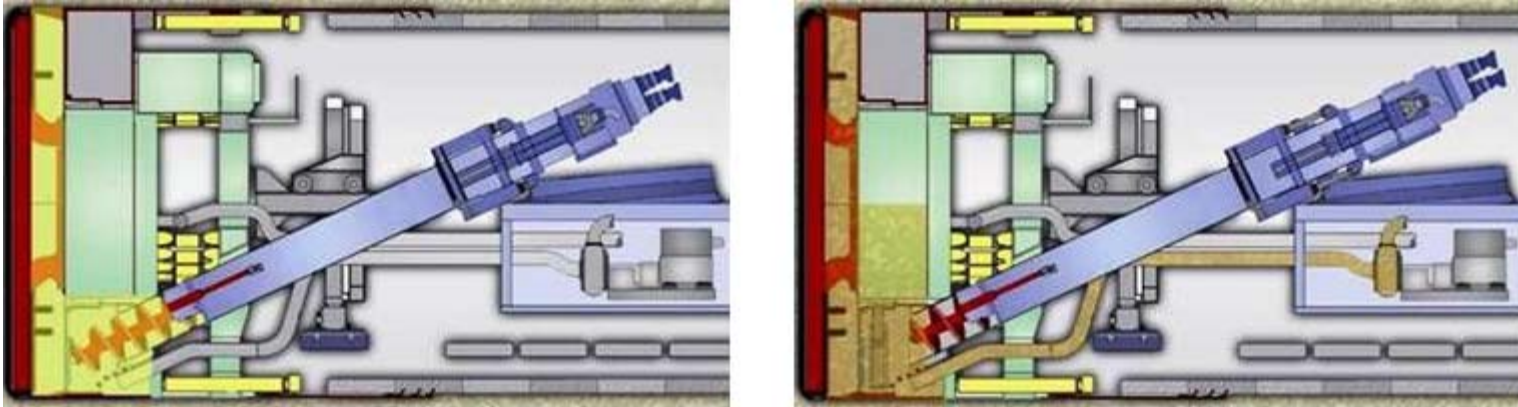
- Screw conveyor for primary muck discharge
- Advance speed and / or discharge volume regulation for face pressure control → muck volume based face pressure control

### Closed Mode – Slurry Machine (Mixshield)

- Slurry circuit for primary muck discharge
- Air bubble for face pressure control → independent face pressure control

# Change between Earth Pressure Balance Shield and Slurry Shield

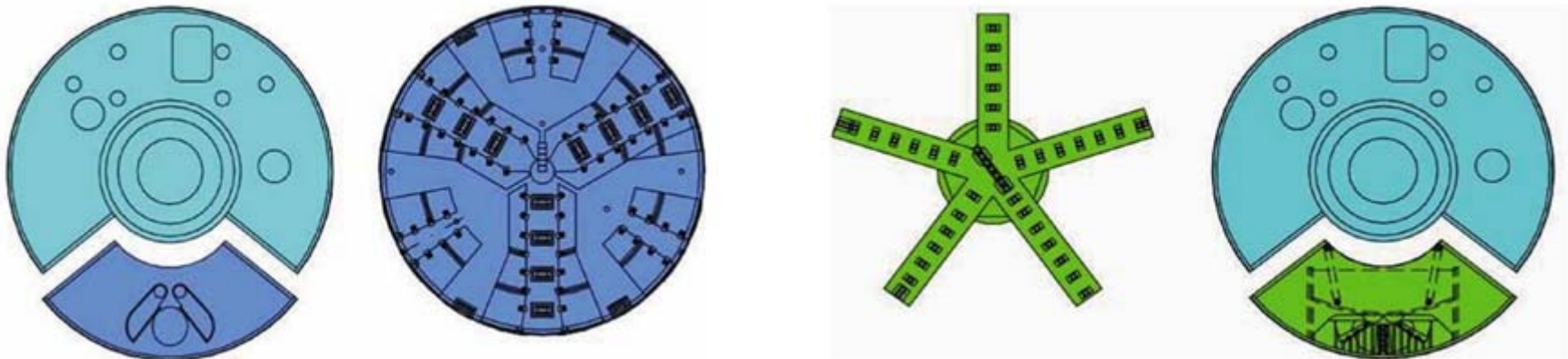
## Integrated Concept for Change of Operation Mode



- ▶ EPB and Slurry specific modules or subassemblies permanently installed
- ▶ Change of operation mode in the tunnel
- ▶ Chamber interventions for “activation” of mode specific equipment required

# Change between Earth Pressure Balance Shield and Slurry Shield

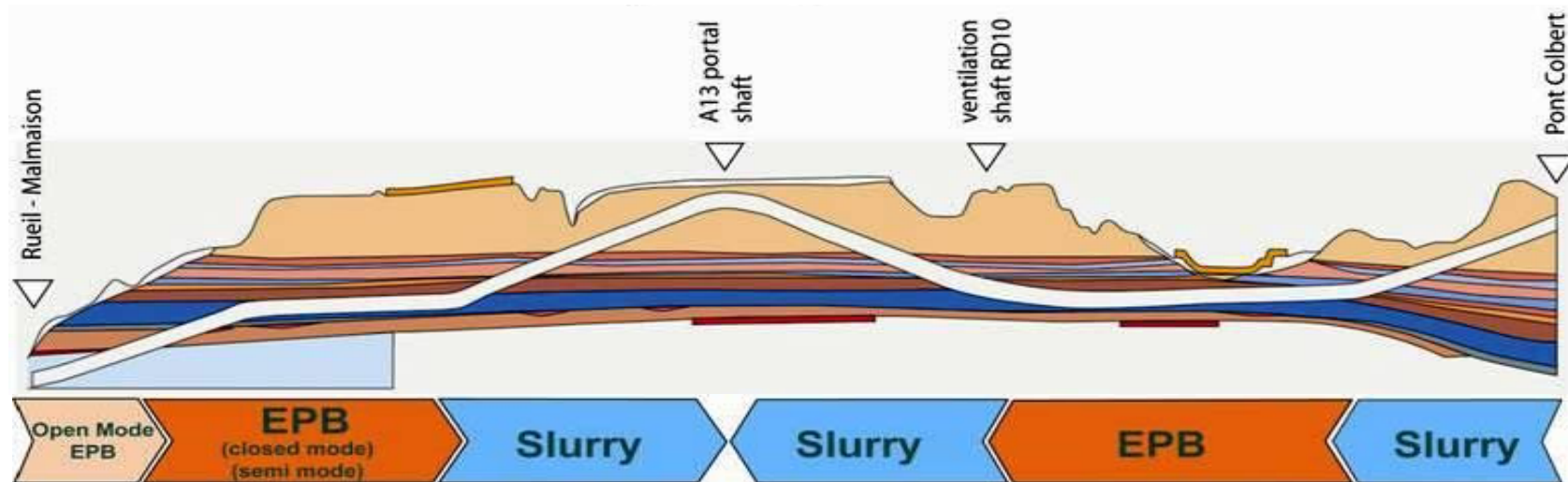
## Modular Concept for Change of Operation Mode



- ▶ Exchange / installation of system specific modules or subassemblies in intermediate shaft (e.g. slurry circuit – screw conveyor, air bubble regulation system...)
- ▶ Common modules for not system specific functions (e.g. ring erection, cutterhead drive, air lock systems...)

# Change between Slurry Shield and Earth Pressure Balance Shield

## SOCATOP Tunnel, France

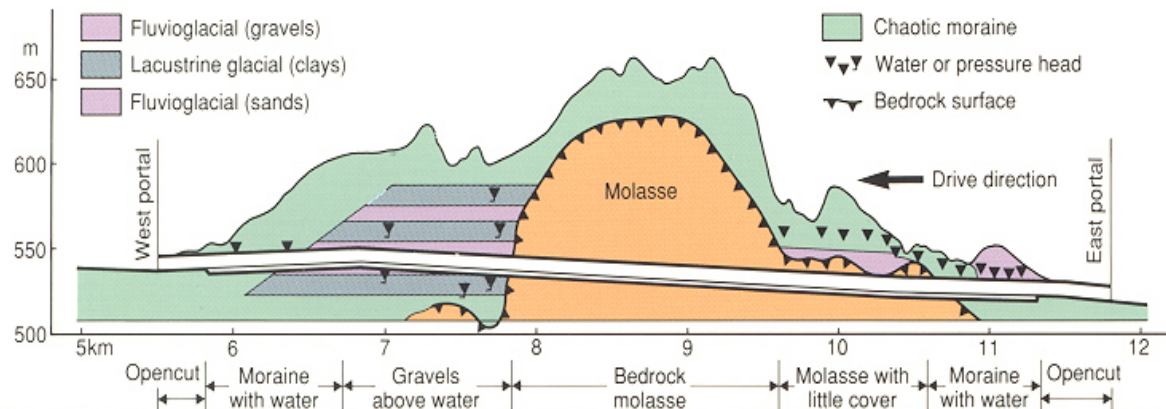


- ▶ Long tunnel (10km)
- ▶ Long single stretches within the alignment with clear preference for operation mode
- ▶ TBM size of 11.6m sufficient to install parallel systems

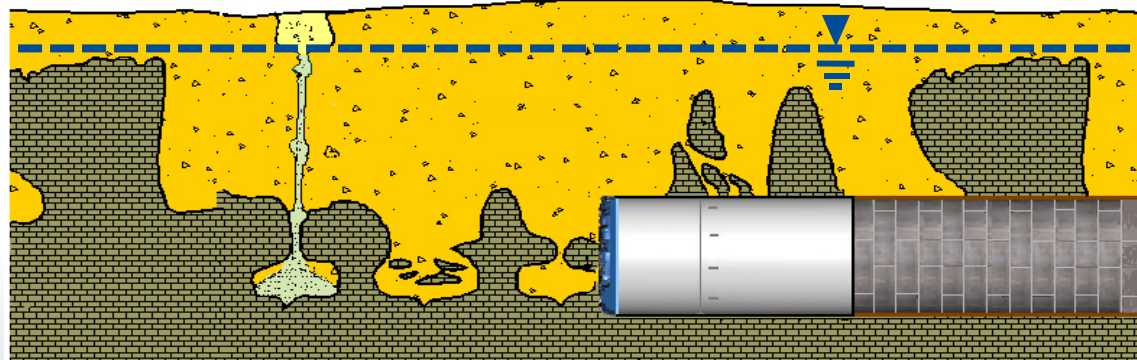
## The Next Step – Frequent Changes.

### Seamless Transition – Switching Between Modes of Operation

- ▶ Long sections of different ground conditions along the alignment



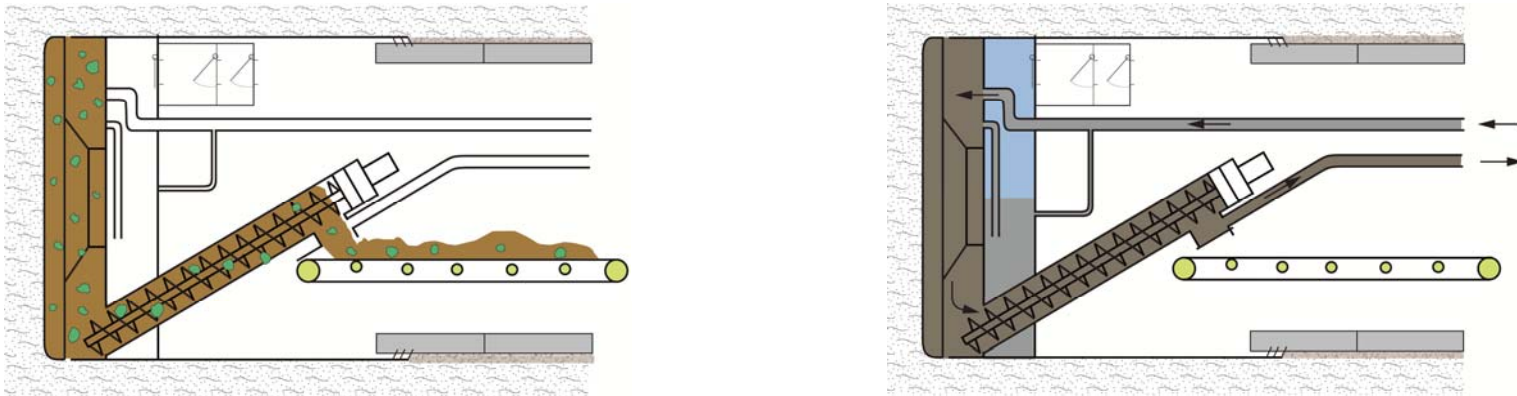
- ▶ High frequent changes of ground conditions along the alignment





# Change Between Slurry Shield and Earth Pressure Balance Shield

## The Herrenknecht “Variable Density” ® Concept



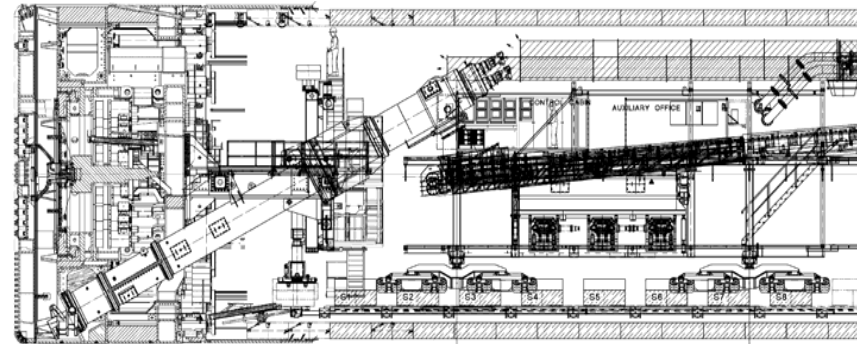
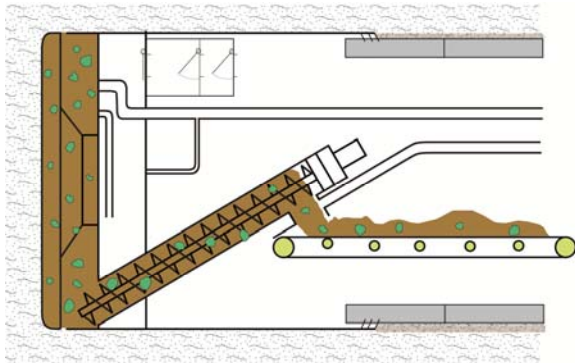
- ▶ Transformation between EPB face support and slurry face support in the tunnel without the need of modification or chamber intervention
- ▶ Full size and quality face support systems for EPB and slurry operation
- ▶ Safe and fully controlled conditions for face support during mode change



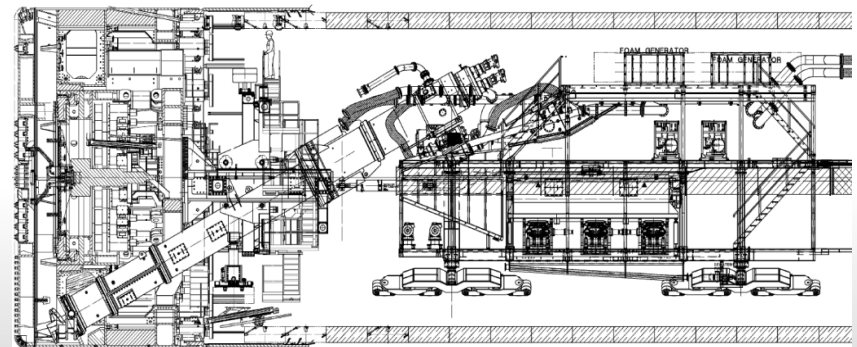
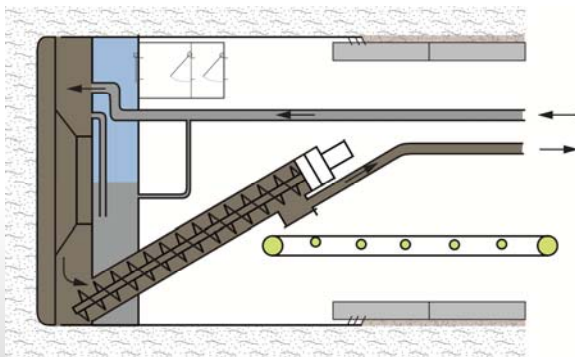
# The Herrenknecht “Variable Density”<sup>®</sup> TBM

Some of the Functional Principles Used for The “WCP – Mode” on the Port of Miami TBM

EPB Mode

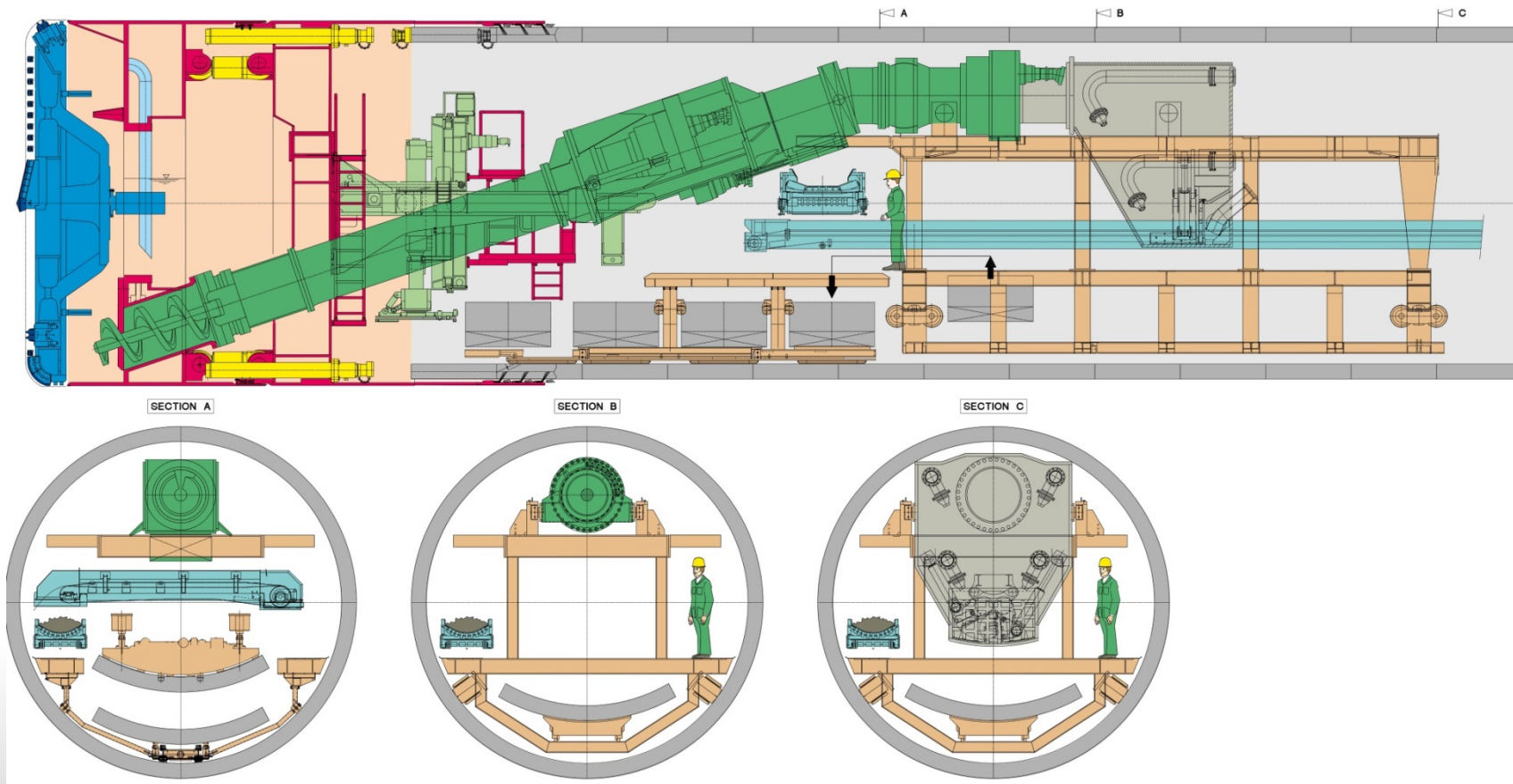


WCP Mode



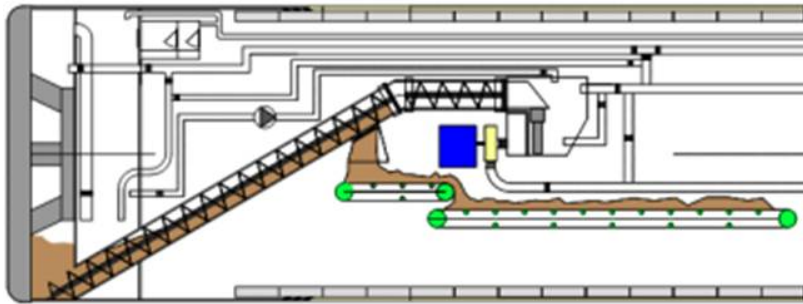
# The Herrenknecht “Variable Density”<sup>®</sup> TBM

## Typical Layout for a Mid-Size TBM in Full Multi Mode Configuration

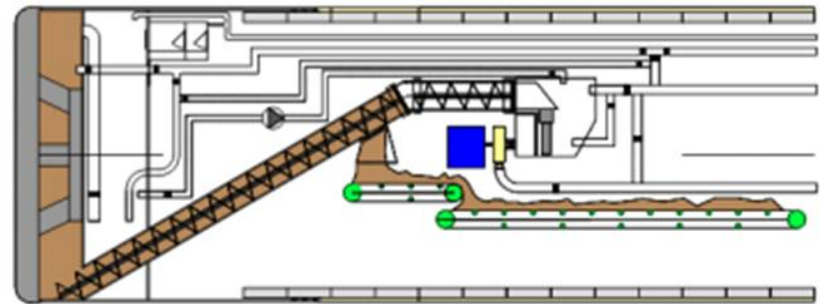


# The Herrenknecht “Variable Density”<sup>®</sup> TBM

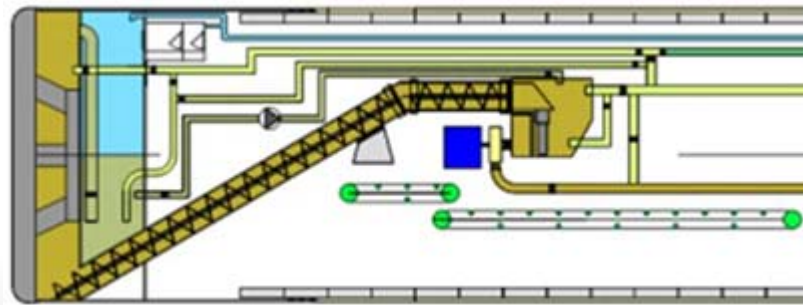
## Modes of Operation



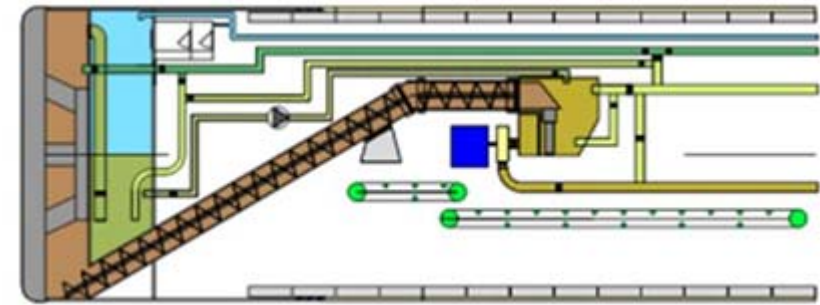
Open Mode



EPB Mode



Slurry Mode



High Density Slurry Mode



# The Herrenknecht “Variable Density” ® TBM Successful Completion at Kuala Lumpur



- ▶ Supplied a total of six Variable Density TBMs and two EPB TBMs for the project
- ▶ Greatly varying geology: Hard Granite Rock, mixed soft ground “Kenny Hill Formation” and extreme karstified limestone
- ▶ The highly flexible Variable Density TBM concept proved to be the perfect solution for the difficult ground conditions in Kuala Lumpur
- ▶ ITA Technical Innovation of the Year Award (2014)



THANK YOU FOR YOUR ATTENTION.

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