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TBM Tunnelling in Rock

The main function of rock TBM is to excavate the rocks. The excavation is by disc cutters. Stability usually is not a problem, and often no shield is needed. The main engineering issues are the penetration and cutter wear, which are governed by the interaction of the rock and the TBM.

Gripper Type Rock TBM
Interaction between cutters and rock

(a) Ridge formation: disc space too large or cutter force too small.

(b) Excessive crushing: disc space too small or cutter force too large.

(c) Optimum cutting with optimum crack length and direction.
TBM Tunnelling in Soil

The main function of soil TBM (shield) is to support the soft ground while removing the soil.

Soft ground is prevented from movement by the shield and face pressure generated by fluid pressure (slurry machine) or earth pressure (EPB machine).

Excavation of soil usually is not a problem.

The main engineering issues are the stability control at face and overall deformation control.

Slurry and Earth Pressure Balance Shields
Face Pressure Control Mechanism of slurry and EPB machines

Classification of Mixed Ground

A mixed ground is usually defined as simultaneous occurrence at excavation face of two or more sufficient areas of grounds with significantly different properties that affect TBM operation. They can be:

(a) Layered or banded ground formed by rock beddings, dykes, faults or shear zones.

(b) Interface ground of soil and rock, typically weathered materials above bedrock.

(c) Mixed ground with locked corestones mixed with soil materials.
Classification of Mixed Ground

Problems of TBM in Mixed Ground

**Effective rock excavation, minimum cutter wear.**
- Cutterhead design, TBM operation, and mucking system.

**Stability of soil, minimum settlement.**
- TBM selection, operation, and mucking.

Groundwater at interface.
- Transport of excavated materials.
Problems of TBM in Mixed Ground

Excavation
Uneven/unbalanced cutter force distribution at excavation face. Cutters on rock attract more applied thrust than that on soil.

Sudden impact loading and intense hammering effect on cutters and bearings.

High cutter wear/damage. Low cutting efficiency. Low advance rate.

Penetration is controlled by rock.

Problems of TBM in Mixed Ground

Face Support

In EPB machine, due to high modulus (stiffness) of rock, face support pressure is primarily on rock. Little pressure is on soil.

Excessive over-cutting of soil may occur, leading to large displacement.

\[ E_{\text{rock}} >> E_{\text{soil}} \]
\[ P_{\text{rock}} >> P_{\text{soil}} \]
\[ P_{\text{soil}} \approx 0 \]
Problems of TBM in Mixed Ground

Combining Excavation and Face Support

High damage/wear of cutters.
Jam of roller cutter bearing.
Compromise of cutter number (spacing) and opening size.
Over excavation of soil.
Large displacement of soil and settlement.
High water seepage at interface.
Handling of muck of mixed materials.

Some Existing Solutions

Mixed Slurry Shield with Stone Crusher for Gravel Ground
Some Existing Solutions

Ground conditioning is often used to make the ground to ‘suit’ the machine.

TBM manufacture yet to find solutions for TBM ‘suit’ the ground. Convertible TBM?

Convertible TBM for varying geology
Some Existing Solutions

Slurry mode  
EPB mode

Convertible TBM for varying geology

Case Study – Tunnel in Weathered Granite

Background

A tunnel of 4.9 m bored diameter, at depth up to 50 m. 
Granite, bedrock level undulating, sharp transition from residual soil to fresh granite.

Tunnel frequently cutting through soil/rock interface.
EPB machine with roller cutters.
High groundwater pressure and high permeability.
Case Study – Tunnel in Weathered Granite

Example of Ground Profile
Chainage 55+334 – 54+900 m (434 m length of tunnelling)

Expected face condition: Grade I/II (fresh to slightly weather granite)

Reported face condition:
Grade V/VI material (55+334 – 55+297),
Mixed face condition (55+297 – 55+290),
Grade I/II material (55+290 – 55+227),
Mixed face condition (55+227 – 55+210),
Grade V/VI material (55+210 – 55+190),
Mixed face condition (55+190 – 55+150),
Grade I/II material (55+150 – 55+122),
Mixed face condition (55+122 – 55+110),
Grade V/VI material (55+110 – 55+102),
Mixed face condition (55+102 – 55+090),
Grade I/II material (55+090 – 55+073),
Mixed face condition (55+073 – 55+002),
Grade I/II material (55+002 – 54+955),
Mixed face condition (54+955 – 54+935),
Grade I/II material (54+935 – 54+900).
Case Study – Tunnel in Weathered Granite

Example of Ground Profile
Chainage 55+334 – 54+900 m (434 m length of tunnelling)

7 times in and out soil/rock.

Problems Encountered

High damage/wear of cutters due to impact and excessive loading.

High damage of roller cutter bearing due to jamming.

Over excavation of soil leading to large settlement.

High water seepage at interface.

Not able to maintain face pressure.

Difficult to handling of muck in the screw conveyer.
Case Study – Tunnel in Weathered Granite

Suggestions for Solutions

Select a tunnelling method (e.g., type of TBM, design of TBM) to suit the given ground – Modifications to the TBM.

Conditioning the ground to suit the given (available) tunnelling method – Conditioning of the ground.

Match the tunnelling method (TBM) with the ground – Better Operation of TBM.

Case Study – Tunnel in Weathered Granite

Suggestions for Solutions - Modifications to the TBM

Change the cutterhead to improve the flow of material to the plenum:
- increase the area of the cutterhead openings;
- decrease the number of cutting discs;
- increase the number of scraper teeths.

Modify the screw conveyor:
- adding a second screw conveyor behind the existing one; or,
- replacing the existing one by a single, longer screw conveyor.

Modify the conveyor belt, making it slightly less inclined.

Possibly change TBM from a EPB to a slurry machine to better counteract the excess water ingress.
Case Study – Tunnel in Weathered Granite

Suggestions for Solutions – Conditioning of the Ground

Conditioning of the grades III/IV and V materials, to make the grade III/IV less permeable and the grade V more stable. Jet grouting in grade V materials and permeation grouting in grades III/IV materials.

Temporarily lowering down groundwater table to reduce water pressure and water inflow.

Case Study – Tunnel in Weathered Granite

Adopted Solutions

Replacing the cutterhead with larger area of openings and less number of cutters.

Replacing the screw conveyor by a longer smaller screw conveyor. Conveyor belt is made less inclined.

Temporarily lower down of groundwater table at face by dewatering from surface boreholes.

Operating TBM at lower rpm at mixed face.
R&D in Searching for Solutions

What are the Needs (in term of geomechanics)

Characterisation of mixed ground (type, ratio)
Methods to explore mixed ground
Behaviour and deformation of mixed face (stability)
Behaviour of mixed ground with groundwater (coupled effects)
Interaction between mixed ground with TBM (cutter/ground interaction)
Effectiveness of ground treatment
R&D in Searching for Solutions

What are the Challenges

Characterisation by engineering geology, weathering, soil mechanics, or rock mechanics?

Exploration by geophysical methods? Intensity of boreholes? Interpretation of profile?

How to measure and model mixed face behaviour?

How to model the interaction between ground and cutter?

How to transport the excavated materials?
R&D in Searching for Solutions

Researches at EPFL -- TBM in Difficult Ground Conditions

1. At great depth: squeezing, spalling, high water pressure, risks and decisions

2. In faulted zones: highly fractured rock mass, blocky rock, fault and bedding interface

3. In mixed ground: rock-soil matrix, rock-soil interface, mixed rock types