TBM Tunneling in Mixed Grounds

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Why in mixed ground?
- Tunnel diameters are increasing
- Tunnel drives are getting longer
- The better places are taken
  - Deep metro tunnels - in rock or firm soil
  - Shallow utility tunnels – in soft soil
  - New tunnels can be built between them
    - Not ideal environment
    - Interface of different material
    - Sensitive surrounding structures

Contents
- Definition of mixed ground
- Mixed ground classifications
- Problems in different mixed ground compositions
- Solutions and Recent developments
- Case study
Definition of mixed ground

What do we call mixed ground?
“From a geological viewpoint, the mixed face ground can be defined as simultaneous occurrence of two or more geological formations, or the same geological formation with conspicuously different weathering grades.”... “On the other hand, from TBM tunneling viewpoint, the mixed face ground defined on the geological basis may not influence the TBM operation and performance parameters.” (Zhao, 2009)

Definition of mixed ground

What do we call mixed ground?
- Two ore more material present in THE SAME cross section with SIGNIFICANT differences in mechanical properties
  - Uniaxial Compressive Strength
  - Elasticity
  - Permeability
  - Stability

Definition of mixed ground

The ‘Hard’ material
- Usually hard rock
- High UCS
- High Elasticity
- STABLE face
- Low permeability
**Definition of mixed ground**

- The ‘Hard’ material
  - In rock tunneling face is stable, no -or limited- need of shielded machine
  - No need of segmental lining
  - In rock tunneling high UCS means low penetration rate, high thrust forces and torque are needed
  - Disk cutters are used to excavate material
  - Depending on abrasivity, cutter wear might be an issue

**Definition of mixed ground**

- Schematics of a gripper TBM

**Definition of mixed ground**

- Typical hard rock cutter head
Definition of mixed ground

- The ‘Soft’ material
  - Material might vary from soft rock – stiff clay - soil
  - LOW UCS
  - Low Elasticity
  - Possible UNSTABLE face
  - Might be problem with groundwater

Definition of mixed ground

- In rock tunneling face might not be stable, shielded machine is needed to excavate the tunnel
- Need of using segmental lining
- Low UCS result high advance rates, lower thrust force and torque
- Scrapers, teeth and buckets are used to excavate
- Keeping face stable and avoid surface movements is the biggest issue

Definition of mixed ground

- Schematics of a soft rock TBM
Definition of mixed ground

- Typical soft rock cutter head

Definition of mixed ground

- Mixed ground
  - Two or more material present on face
  
  No clear definition yet!!!
  
  - Literature uses UCS as differentiate the different materials

  \[ \text{UCS}_{\text{HARD}} : \text{UCS}_{\text{SOFT}} \geq 10 : 1 \rightarrow \text{Mixed ground} \]

  - Others say 8 : 1 (6 : 1) already should be considered as mixed ground

Definition of mixed ground

- Mixed ground Condition or changing ground condition?
  
  - Mixed ground: two significantly different material present in the same cross section
  
  - Changing Ground: material change along the axis of tunnel, but sections can be determined, where there is only one material present on the tunnel face
Definition of mixed ground

- Issues with mixed ground
  - Sum of negative properties of the different materials:
    - Hard part: high UCS → low penetration, high thrust force
disc cutters needed
    - Soft part: stability issues → face stabilization is needed
groundwater problems
  - segmental lining is necessary

Mixed ground classifications

- Three different categories
  - Class 1: Layered, Banked, Interfaced Mixed Ground
  - Class 2: Two or Three portion Mixed Ground
  - Class 3: Blocky Mixed ground

Mixed ground classifications

- Class 1: Layered, banked Mixed Ground
  - Face is composed of stable materials
  - Intrusion can be harder or softer than surrounding material
  - Difference in permeability can cause groundwater issues
  - Even relative small amount of harder material can slow down excavation
  - Direction of the interface (angle, dipping) can influence performance
  - Around shear zones, dykes, discontinuities, volcanic areas
Mixed ground classifications

- **Class 2: Two/Three Portion Mixed Ground**
  - Usually face is composed of hard material covered with softer ground.
  - Tropical weathering cause such face compositions.
  - Bedrock covered with weathered rock, soil or artificial fills.

- **Class 3: Blocky Mixed ground**
  - Cobbles, boulders embed in soft, clayey or sandy material.
  - River or Glacier deposits, landfills, landslides.

Problems

- Overview of different issues:
  - Excavation
  - Face stability
  - Material transport
  - Groundwater problems
Problems

- Problems with excavation:
  - When cutters moving from a soft material, there is an impact load on cutter
  - This is causing vibration in cutter head
  - Thrust force is not evenly distributed on the face
  - Driving TBM is more difficult
  - Extensive wear of cutters due to broken bearing, stuck cutters, break/chipping of cutting ring, not enough resistance in soft material

Problems

- Problems with excavation:
  - Reduced penetration, as thrust force and rotation speed has to be reduced
  - Mere frequent working chamber interventions needed reducing advance speed further
  - Specially in blocky mixed ground freely moving boulders rotating with cutterhead cause extensive wear on tools

Problems

- Problems with face stability:
  - EPB/Slurry mode needed, reducing performance and increasing cost
  - Difficult to get the right consistency of soil mixture in working chamber
  - Face support pressure is not evenly distributed
  - High risk of overcutting, face collapse, development of sinkholes
  - Risk of large surface movements
  - Hard to break boulders embed in weak ground
Problems

- Problems with material transport:
  - Difficult to transport blocky/bouldery material with screw conveyor/conveyor belts
  - Difficult to keep the pressure in the screw conveyor \(\rightarrow\) blow out
  - Blocky ground can plug/damage slurry lines, specially in curves

- Problems with groundwater:
  - There is high risk of groundwater flowing in at rock/soil interface
  - Flowing water in tunnel face increase the probability of face collapse

- Particular problems in Class 1 Mixed Ground:
  - Vibration caused by cutters moving from one material to other
  - Extensive wear on moving parts in cutterhead working chamber
  - High cutter consumption due to dynamical loading
    - Damage of cutter bearing
    - Breaking, Chipping of cutting ring
Problems

- Particular problems in Class 1 Mixed Ground:
  - Normal wear
  - Blocked disc
  - Crack, brittle fracture
  - Chipping
  - Mushrooming
  - Wear at housing

Problems

- Particular problems in Class 1 Mixed Ground:
  - Same problems as in Class 1 Mixed Ground
  - Pre-stressed disk cutters do not rotate in soft material
  - Small particles can clog cutter bearing causing flat, multi-flat wear on disk cutters
  - Increased face pressure leads to increased abrasion and temperature
Problems

- Particular problems in Class 3 Mixed Ground:
  - Same problems as in Class 1 and Class 2 Mixed Ground
  - In low strength soil matrix cobbles/boulders dislocate
  - Dramatically decreased advance rate
  - High risk of over-excavation
  - Moving blocks damage tools and cutter head
  - Working chamber interventions to clear face from moving blocks of rock

Solutions and Recent developments

- In not real mixed ground case
  - Slurry machines can be capable of excavate material, should be equipped with stone crusher for boulders entering the working chamber

- Ground improvement can be applied to make the face more uniform
Solutions and Recent developments

- In not real mixed ground case
  - Ground improvement can be applied to make the face more uniform

Solutions and Recent developments

- Convertible TBM

Solutions and Recent developments

- Convertible TBM

Open mode

Slurry mode
Solutions and Recent developments

- Convertible TBM

Solutions and Recent developments

- Radars mounted on cutterhead to detect boulders and cavities

Solutions and Recent developments

- Radars mounted on cutterhead to detect boulders and cavities
Solutions and Recent developments

- Sensors installed with cutting tools to detect extensive wear and blocked disks

Solutions and Recent developments

- Extensive muck and pressure control to reduce settlements and over-excavation

Solutions and Recent developments

- Extensive muck and pressure control to reduce settlements and over-excavation
Case study

- Singapore DTSS

Case study

- Singapore DTSS

T-05 TBM  T-06 TBM

Case study

- Singapore DTSS
Case study

- Singapore DTSS

Old cutterhead  Modified cutterhead

Case study

- Singapore DTSS

Case study

- Singapore Circle Line, C855 project
Case study

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Case study

- Metro Line 9, Barcelona

Case study

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Discussion

- Challenges for TBMs in Mixed Grounds
  - Characterization of mixed ground
  - Effective exploration methods
  - Solving face stability problems
  - Mechanical problems involving groundwater
  - Cutter-ground interaction
  - Ground treatment