HARD ROCK TBMs

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HARD ROCK TBM TYPES

- Main-Beam (open, gripper)
- Single Shield
- Double Shield
MAIN-BEAM HARD ROCK TBM
MAIN-BEAM HARD ROCK TBM
DOUBLE-SHIELD CROSS-SECTION
DOUBLE-SHIELD TBM
### COMPARISON BETWEEN HARD ROCK TBM TYPES

<table>
<thead>
<tr>
<th></th>
<th>Single shield</th>
<th>Double shield</th>
<th>Open type</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Single shield</strong></td>
<td></td>
<td></td>
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</tr>
<tr>
<td></td>
<td>• For the poorest ground condition</td>
<td>• For poor to medium quality rock</td>
<td>• For medium to high quality rock, gripper reaction needed to advance machine</td>
</tr>
<tr>
<td></td>
<td>• Used with pre-cast segments (required for thrust reaction)</td>
<td>• May be used with or without pre-cast segments</td>
<td></td>
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<tr>
<td><strong>Pro’s</strong></td>
<td>• Relatively inexpensive</td>
<td>• Crew not exposed to rock</td>
<td>• High advance rates</td>
</tr>
<tr>
<td></td>
<td>• Crew not exposed to rock</td>
<td>• Can erect lining while boring</td>
<td>• Tight turn radius</td>
</tr>
<tr>
<td></td>
<td>• Short shield, less prone to trapping</td>
<td>• High advance rates</td>
<td>• Inexpensive</td>
</tr>
<tr>
<td></td>
<td>• Better steering ability</td>
<td>• Can operate as a Single Shield in poor ground</td>
<td>• Easy mob/demob.</td>
</tr>
<tr>
<td></td>
<td>• No need of shotcrete</td>
<td></td>
<td></td>
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<tr>
<td><strong>Con’s</strong></td>
<td>• Slow advance rates</td>
<td>• Expensive</td>
<td>• Crew more exposed to rock</td>
</tr>
<tr>
<td></td>
<td>• Cyclic operation since machine forces are reacted via tunnel lining (cut/ring build)</td>
<td>• Prone to becoming stuck in high overburden</td>
<td>• Gripper pressure (~4MPa)</td>
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<tr>
<td></td>
<td></td>
<td>• Large turn radius</td>
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<tr>
<td></td>
<td></td>
<td>• Large thrust force required (due to shield friction)</td>
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EXCAVATION BY HARD ROCK TBMS
TBM CUTTING FACE
DISC CUTTING

Spacing

Chip Formation

P
## DISC CUTTER DEVELOPMENT HISTORY

<table>
<thead>
<tr>
<th>Cutter Diameter (in)</th>
<th>Cutter Load (lbs.)</th>
<th>Year Introduced</th>
</tr>
</thead>
<tbody>
<tr>
<td>13</td>
<td>20,000</td>
<td>1980</td>
</tr>
<tr>
<td>14</td>
<td>30,000</td>
<td>1976</td>
</tr>
<tr>
<td>15.5</td>
<td>45,000</td>
<td>1973</td>
</tr>
<tr>
<td>17</td>
<td>60,000</td>
<td>1983</td>
</tr>
<tr>
<td>19</td>
<td>70,000</td>
<td>1989</td>
</tr>
</tbody>
</table>
CUTTER WEAR AND REPLACEMENT
NORMAL WEAR

VERY HARD ABRASIVE ROCK
CHIPPING
MECHANICAL FAILURES
BLOCKED CUTTERS, BAD BEARINGS OR SEALS
CUTTER CHANGE OPERATION
HARD FACING OF DISC CUTTER RINGS
MUCK TRANSPORTATION (BELT CONVEYOR)
UNDERGROUND ASSEMBLY
NIAGARA TUNNEL PROJECT ON-SITE ASSEMBLY (OFTA)
COMPLETED TBM ASSEMBLY NIAGARA TUNNEL PROJECT
GROUND SUPPORT
SHOTCRETE ROBOT
STEEL SUPPORT

Wire Mesh Erector as Steel Support Erector

Ring Beams
PRE-EXCAVATION GROUTING
TBM PERFORMANCE PREDICTION

AR = ROP x Utilization x Total shift hours

AR: Daily advance rate (ft/day)

ROP: Rate of Penetration (ft/hr)

CL = Cutter life (cubic yards per cutter change)
TBM PREDICTOR MODEL ROCK DATA

- Uniaxial Compressive Strength (UCS)
- Brazilian (Indirect) Tensile Strength (BTS)
- Cerchar Abrasivity Index (CAI)
- Punch Penetration Index
UNIAXIAL COMPRESSIVE STRENGTH (ASTM D2938-95)

Non-structural Failure

BEFORE

AFTER

Structural Failure

BEFORE

AFTER
BRAZILIAN TENSILE STRENGTH (ASTM D3967-95)

$\sigma_T \rightarrow$ Tensile Strength (psi)

$F \rightarrow$ Failure Load (lbs.)

$L \rightarrow$ Thickness of the disk

$D \rightarrow$ Diameter of the disk
PUNCH PENETRATION TEST

Diagram showing the setup of a punch penetration test. Key components include:
- Applied Load
- Testing machines
  - Upper Platim
- Tool holder
- Indentor
- Penetration
- Rock Sample
- Lower Platim
- Casting material
  - (hydrostone or plaster etc.)
- Cast (Steel Pipe)
CERCHAR ABRASIVITY TEST

Cerchar Abrasivity Index (CAI) has proven to be fairly accurate and is commonly used for cutter life estimation. A series of sharp 90° hardened pins of heat-treated alloy steel are pulled across a freshly broken surface of the rock. The average dimensions of the resultant wear flats are related directly to cutter life in field operation. The geometry of the planned excavation then allows calculation of the expected cutter costs per unit volume of material.

\[ CAI = 0.0254 \sum_{i=1}^{10} d_i \]
WORLD TBM RECORDS - PERFORMANCE

Indianapolis Deep Rock Tunnel
(20.2 ft. diam., 7.6 mile long, limestone/dolomite)

Best day = 410 ft
Best week = 1690 ft
Best Month = 5755 ft.
WORLD TBM RECORDS – LONGEST TUNNEL
Gotthard Base Tunnel, Switzerland
QUESTIONS ?