HARD ROCK TBMs

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Tunneling Consultant
HARD ROCK TBM TYPES

- Main-Beam (open, gripper)
- Single Shield
- Double Shield
MAIN-BEAM HARD ROCK TBM
MAIN-BEAM HARD ROCK TBM
SINGLE SHIELD CROSS-SECTION
SINGLE SHIELD 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>Pro’s</strong></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></td>
<td>Relatively inexpensive</td>
<td>Crew not exposed to rock</td>
<td>High advance rates</td>
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<tr>
<td></td>
<td>Crew not exposed to rock</td>
<td>Can erect lining while boring</td>
<td>Tight turn radius</td>
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<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>
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<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>
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<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>Grippler pressure (~4MPa)</td>
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<td></td>
<td></td>
<td>Large turn radius</td>
<td></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
## Disc Cutter Development History

<table>
<thead>
<tr>
<th>Cutter Diameter (in)</th>
<th>Cutter Load (lbs.)</th>
<th>Year Introduced</th>
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</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
(HERRENKNECHT)
MUCK TRANSPORTATION (BELT CONVEYOR)
MUCK TRANSPORTATION (RAIL HAULAGE)
PORTAL ASSEMBLY
UNDERGROUND ASSEMBLY
COMPLETED TBM ASSEMBLY NIAGARA TUNNEL PROJECT
GROUND SUPPORT
ROCK BOLTING
WIRE MESH

Wire Mesh Erector
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)

\[ \sigma_T \rightarrow \text{Tensile Strength (psi)} \]

\[ F \rightarrow \text{Failure Load (lbs.)} \]

\[ L \rightarrow \text{Thickness of the disk (in.)} \]

\[ D \rightarrow \text{Diameter of the disk (in.)} \]

Normal Failure

Structural Failure

Perpendicular to foliation

Parallel to foliation

Effect of Foliation on Tensile Strength
PUNCH PENETRATION 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

October 15, 2010 and March 23, 2011 MAIN BREAKTHROUGH

October 15, 2010
Tunnel length: 11,156m

March 23, 2011
Tunnel length: 11,088m

(1) Gabi I, Herrenknecht Gripper TBM S-421, Ø 9.58m
(2) Gabi II, Herrenknecht Gripper TBM S-422, Ø 9.58m
(3) Gabi I, Herrenknecht Gripper TBM S-228, Ø 9.58m
(4) Gabi II, Herrenknecht Gripper TBM S-230, Ø 9.58m
(5) Sissi, Herrenknecht Gripper TBM S-210, Ø 9.43m
(6) Heidi, Herrenknecht Gripper TBM S-211, Ø 9.43m
(7) Sissi, Herrenknecht Gripper TBM S-210, Ø 8.83m
(8) Heidi, Herrenknecht Gripper TBM S-211, Ø 8.83m
LIMMERN PUMP STORAGE TUNNEL

5.2 M. Hard Rock TBM

40 degree incline

Double anti-reverse lock system
THANK YOU

Levent Ozdemir