TBM PERFORMANCES AND ROCK MASS EXCAVABILITY RME CLASSIFICATION SYSTEM

Dott. Ing. Remo Grandori
SELI - PRESIDENT
RMR WAS DEVELOPED FOR CONVENTIONAL TUNNELING AND NOT FOR TBM EXCAVATION METHOD

THERE IS NOT A DIRECT RELATIONSHIP BETWEEN RMR AND TBM ADVANCE RATE
RMR AND DS TBMS ADVANCE RATES IN THE 30 KM LONG EVINOS TUNNEL PROJECT (GREECE)- 1994
SELI HAS WORLDWIDE TUNNELING EXPERIENCE WITH OVER 20 TBMS OPERATING AT SAME TIME IN ALL CONTINENTS
THE GILGEL GIBE II AND BELES II PROJECTS IN ETHIOPIA

- 12 KM LONG 8 M DIAMETER HEADRACE TUNNEL
- 7 KMN LONG 8.1 M DIAMETER
- 26 KM LONG 7 M DIAMETER HEADRACE TUNNEL
GILGEL GIBE II FORESEEN GEOLOGICAL PROFILE

INTAKE DRIVE DS TBM

OUTLET DRIVE DS TBM

OMO BASALT

TRACHITE

RHYOLITE
GILGEL GIBE TBMS

26 KM BY N.2 DOUBLE SHIELDED TBMS

NEW 7M DIAMETER TBM WITH SECOND HAND COMPONENTS

BRAND NEW SELI 7 M DIAMETER DS TBM

Dott. Ing. Remo Grandori
BELES TBMS

19 KM BY N.2 TBMS (1 EPB DSU AND 1 DSU)

SELI EPB DSU TBM 8,1M DIAMETER

SELI DSU TBM 8,1 M DIAMETER

Dott. Ing. Remo Grandori
THE EPB DSU CONCEPT

THE EVOLUTION OF UNIVERSAL TBM CONCEPT

TBM IN EPB MODE CONFIGURATION

TBM IN DS CONFIGURATION

Dott. Ing. Remo Grandori
### RME Bieniawski, rev. 3

#### Uniaxial Compressive Strength of Intact Rock [0 - 25]

<table>
<thead>
<tr>
<th>$\sigma_c$ (MPa)</th>
<th>0</th>
<th>5-30</th>
<th>30-60</th>
<th>60-180</th>
<th>&gt;180</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average rating</td>
<td>4</td>
<td>14</td>
<td>25</td>
<td>14</td>
<td>0</td>
</tr>
</tbody>
</table>

#### Drillability [0 - 15 points]

<table>
<thead>
<tr>
<th>Q/V</th>
<th>200</th>
<th>150-69</th>
<th>50-56</th>
<th>20-40</th>
<th>&lt;40</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average rating</td>
<td>15</td>
<td>10</td>
<td>7</td>
<td>3</td>
<td>0</td>
</tr>
</tbody>
</table>

#### Discontinuities at tunnel face [0 - 30 points]

<table>
<thead>
<tr>
<th>Homogeneity</th>
<th>Mixed</th>
<th>0-4</th>
<th>4-8</th>
<th>8-15</th>
<th>15-20</th>
<th>&gt;20</th>
<th>Perpendicular</th>
<th>Oblique</th>
<th>Parallel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average rating</td>
<td>10</td>
<td>6</td>
<td>2</td>
<td>7</td>
<td>15</td>
<td>0</td>
<td>5</td>
<td>3</td>
<td>0</td>
</tr>
</tbody>
</table>

#### Stand UP Time

<table>
<thead>
<tr>
<th>Hours</th>
<th>0</th>
<th>&lt;5</th>
<th>5-12</th>
<th>12-48</th>
<th>&gt;48</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average rating</td>
<td>0</td>
<td>2</td>
<td>10</td>
<td>15</td>
<td>25</td>
</tr>
</tbody>
</table>

#### Groundwater Inflow [0 - 6 points]

<table>
<thead>
<tr>
<th>Liters/sec</th>
<th>&gt;100</th>
<th>50-100</th>
<th>20-50</th>
<th>&lt;20</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average rating</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>5</td>
</tr>
</tbody>
</table>
RME AND TBM ADVANCE RATES RELATION AT GIBE OUTLET DRIVE

Dott. Ing. Remo Grandori

MADRID WORKSHOP 2007
TBM AVERAGE ADVANCE RATE (ARA) PREDICTION FORMULA

\[ ARA \ (m/day) = 60 \times \frac{(RME)}{100} \times Cd \times Ce \times CL + 0.23 \times (RME) - 14.5 \]

- **RME** = Measured/Foreseen RME INDEX
- **Cd** = TBM diameter coefficient = \(1.2058 - 0.0588 \times De\) (Exc. Dia)
- **Ce** = Site efficiency coefficient = \((0.5 + Cc + Cm + Ca)\)
- **Cl** = Learning period coefficient =
Ce = (0,5 + Cc + Cm + Ca )

Cc= Contractor experience coefficient
• No TBM experience (0 TBM projects) = 0
• Small TBM experience (1-5 TBM projects) = 0,05
• Average TBM experience (5-10 TBM projects) = 0,10
• TBM expert contractor (10-20 TBM projects) = 0,20

Cm= Manpower skill and TBM experience
• Poor quality- no skill and no TBM experience = 0
• Average quality- Good skill no TBM experience = 0,1
• Good quality- Good skill & TBM experience = 0,15

Ca = Site area/country logistic
• Transport time to site (< 1 month = 0,075) (> 1 month=0)
• Availability local supplies/workshops No=0 Yes=0,075
Cl = learning period coefficient

- Tunnel length 0-4 km = 0.85
- Tunnel length 4-8 km = 0.90
- Tunnel length 8-12 km = 0.95
- Tunnel length > 12 km = 1
ARA FORECASTS FOR THE GILGEL GIBE II OUTLET DRIVE

• RME 40; ARA = 8,04 m/day
• RME 50; ARA = 13,68 m/day
• RME 60; ARA = 19,31 m/day
• RME 70; ARA = 24,95 m/day
• RME 80; ARA = 30,58 m/day
• RME 90; ARA = 36,22 m/day
SPECIAL EVENTS

- Very large mud/water inflows at the face
- Very Unstable faces (ravelling/running ground, blocky)
- High rapid convergence of tunnel walls
- High ground loads on TBM and supports
- Very hot water inflows
- Gas inflows
- A combination of the above
EVENT AT CHAINAGE 4196 OF GIBE II OUTLET DRIVE TUNNEL

LATERAL ADIT

40 BARS MUDDY/WATER FAULT

EXPLORATORY/DRA INAGE DRILLS HOLES

TBM CHAMBER

Dott. Ing. Remo Grandori
FUTURE RME IMPLEMENTATIONS

- Brenner base service/exploratory tunnel (Granite)
- Val Passirio headrace tunnel (Gneiss)
- All tunnels to be driven in rock by TBM method
CONCLUSIONS

• RME SYSTEM IS A POWERFUL TOOL TO CLASSIFY ROCK FORMATIONS IN TBM DRIVEN TUNNELS
• GIBE II AND BELES II RME DATA ARE VERY GOOD TEST TO VERIFY/FINE TUNE RME
• RME ALLOWS ACCURATE TBM ADVANCE FORECASTS WHEN TAKING INTO ACCOUNT ALSO THE OTHER FACTORS INFLUENCING TBM PERFORMANCES
• SELI PLANS TO UTILISE RME IN ALL FUTURE TBM PROJECTS IN ROCK
• SPECIAL EVENTS ARE ALWAYS POSSIBLE IN ROCK TUNNELING AND CAN INFLUENCE SIGNIFICANTLY THE TBM PERFORMANCES