CUSTOM TAILORED TBMs
TBMs DESIGN and OPERATION
HIMALAYAS GEOLOGICAL CONDITIONS
KATHMANDU – January 2011, 27th
S.E.L.I. was founded in 1950 by Carlo Grandori, engineer and designer of civil works as well as of special construction equipment.

S.E.L.I.’s over 450 engineers and technicians are hard working in all parts of the world to honor the company’s name as well as to maintain the leadership in the TBM technology.

Born as a general contractor in civil engineering works, S.E.L.I. developed in the course of activity its own expertise in the field of TBM tunneling works, construction of shafts and caverns. In addition S.E.L.I continues generating innovative techniques.
known and unknown risks

excavation of long and deep tunnels by TBM in poor geological rock mass conditions, in particular in the Himalayas, is expectably exposed to risks, hence requiring TBM industry to make a step forward

- in construction risks assessment and operation risks management, and consequently

- in TBM design and technology.
“Squeezing conditions and difficult fault zones lay ahead of a new attempt to drive a TBM through the folded and tortured geology of the Himalaya formations in India.”
known and unknown risks

SELI’s approach to this task takes advantage from:

- the fact that company is simultaneously TBM tunnelling consultant, TBM manufacturer, TBM tunnelling specialist contractor, and also developer and manufacturer of particular materials such as resins and foams to be used for rock mass treatment.
- the experience gained on over 100 TBM tunnelling projects totalling some 700km, successfully executed and completed regardless, in most of the cases, of the encountered geological adverse conditions.
executed and completed projects with DSU

<table>
<thead>
<tr>
<th>Nº</th>
<th>Project</th>
<th><strong>diameter (m)</strong></th>
<th><strong>Length (m)</strong></th>
<th><strong>Period</strong></th>
<th><strong>Country</strong></th>
<th><strong>Client</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Orichella</td>
<td>4.32</td>
<td>4,100</td>
<td>1972-1975</td>
<td>Italy</td>
<td>ENEL</td>
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<td>Yellow River tunnel n° 6, 7, 8</td>
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<td>ENEL SpA</td>
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</table>
executed and completed projects by means of DSU

<table>
<thead>
<tr>
<th>No.</th>
<th>Project Name</th>
<th>Mileage (m)</th>
<th>Year(s)</th>
<th>Country</th>
<th>Contractor/Partner</th>
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<tr>
<td>29</td>
<td>Poza Honda</td>
<td>4.04</td>
<td>15,500</td>
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<td>30</td>
<td>Wanjiazhai Yellow River (4)</td>
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<td>86,920</td>
<td>China</td>
<td>Wan Long Joint Venture</td>
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<td>31</td>
<td>Acquedotto del Piceno</td>
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<td>Mohale Tunnel</td>
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<td>17,000</td>
<td>Lesotho, S.A.</td>
<td>Mohale Matsoku Contractors (MMC)</td>
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<td>33</td>
<td>Menta</td>
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<td>7,080</td>
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<td>Regione Calabria</td>
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<td>34</td>
<td>Canal de Navarra</td>
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<td>36</td>
<td>Monte Giglio</td>
<td>4.88</td>
<td>8,590</td>
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<td>37</td>
<td>La Joya</td>
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<td>39</td>
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<td>7,800</td>
<td>Viet Nam</td>
<td>Kajima Kumagai Song Da JV</td>
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<tr>
<td>41</td>
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<td>Gammon India</td>
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<td>Dradados</td>
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<td>45</td>
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<td>17,500</td>
<td>Ethiopia</td>
<td>Salini S.p.A.</td>
</tr>
<tr>
<td>46</td>
<td>Gilgel Gibe Omo-Intake drive</td>
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<td>8,500</td>
<td>Ethiopia</td>
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<tr>
<td>47</td>
<td>Dez Ghomrud</td>
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<td>48</td>
<td>Llobregat</td>
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<td>5,316</td>
<td>Spain</td>
<td>UTE FCC - COPISA</td>
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<td>49</td>
<td>Tana Beles-Tairace tunnel</td>
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<td>3,700</td>
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<td>Dradados - Judau JV</td>
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<td>51</td>
<td>Brennerro</td>
<td>6.12</td>
<td>9,292</td>
<td>Italy</td>
<td>BBT - Brenner Base Tunnel</td>
</tr>
</tbody>
</table>

**Total Mileage:** 499,683 m

- 255,093 m (51%)

*Types of Projects:*
- Hydropower tunnel
- Water conveyance tunnel
- Transportation tunnel
most of the TBM tunnelling technology and know-how development are aimed at:

- creating the most appropriate design for preventing or avoiding the occurrence and/or mitigating the impact of known and/or foreseeable risks,

- creating the necessary capabilities and conditions for promptness of reaction for implementing supplementary support measures for drainage or strengthening of the rock mass in the event of unknown and/or unforeseeable risks.
TBM tunnelling cases history or lessons learned

below some assessments are presented,

✓ based on SELI’s experience gained during the execution and completion of numerous TBM tunnelling projects
  ▪ in similar conditions of length and depth extents, poor and adverse geology, and
  ▪ effectively in quality of TBM tunnelling specialist contractor,

and

✓ for suitable reflection when envisaging a project of TBM tunnelling works:
it is almost a certainty that the actual geo-mechanical conditions of the rock mass to be encountered along the tunnel alignment,

i.e. distribution of rock mass classes, behaviour of the rock mass upon excavation, and in particular for a combination of great tunnel length, tunnel depth and poor geology,

would not be completely correctly predicted and/or assessed.
it is almost a certainty that the combination, at a particular section of the tunnel, of

- poor geological and hydro-geological conditions,
- great length and depth of tunnel, and
- the possible occurrence of any other adverse condition

would result in an extraordinary event at the heading face or in the heading zone
it is almost a certainty that most of the possibly to be encountered exceptional geological conditions and its related effect of hindrance to the advance would be overcome

✓ with the definition of appropriate technical solutions and detailed methods of work,
✓ through the mobilization of selected experienced crew and deployment of suitable equipment,
✓ by means and by the use of suitable particulars materials.
TBM tunnelling
cases history or lessons learned

SELI’s risk management basic opinion

• the tunnel and TBM should be designed with the view to overcome all known foreseeable risks, and the same principle should apply to the definition and implementation of boring procedures, and

• the tunnelling organisational structure should be prepared to implement particular technical solutions to overcome unknown unforeseeable risks, and whenever required for achieving the objective of tunnel completion.
Tunnel design
response to minimize or to mitigate risks

SELI cooperates with designer at all stages of design, from conceptual design to detailed design, and in addition, based on

- joint geological observations and collections of geomechanical data carried out regularly during the excavation, and

- preparation of interpretive geotechnical mapping critical sections along previously excavated and lined tunnel where surrounding rock mass is determined as deemed to receive treatment are subsequently strengthened through radial grouting.
Tunnel design
response to minimize or to mitigate risks

tunnel lining final design safety factor is generally improved

• by adequately increasing segmental lining thickness in respect of other projects executed in more favourable conditions,

• by implementing an extensive drilling and grouting patterns to give rise to an additional annulus of consolidated rock mass along most critical sections.
TBM design response to minimize or to mitigate risks

in a first stage and based on the proven capabilities of Double Shield Universal TBM to successfully drive through very poor and adverse geological conditions in other regions of the world, SELI’s adopted the approach of enhancing the DSU basic design features,

DSU design criteria was reviewed to accommodate required modifications, among others to power and thrust, for over-boring, for allowing performance of rock mass stabilization works at the face
pre-consolidation grouting and/or stabilization measures can be executed from TBM tail shield, through holes through the gripper shield specifically designed for the purpose.

Typical example of application in poor rock mass conditions or crossing of discontinuities and shear zones.
TBM tunnelling – special measures

- Void filled with resin

- Collapsed material consolidated with chemical grout mix

**typical example of application for fore-poling**
SOME EXAMPLES of TUNNELLING PROJECTS where DEFORMATIONS, SQUEEZING were OVERCOME BY DSU TBM

- LOS ROSALES (Colombia)
- PAUTE (Ecuador)
- EVINOS-MORNOS (Greece) - *Flysch*
- EOS Lot C (Switzerland)
- UMICRAY ANGAT TRANSBASIN TUNNEL (Philippines) – *Andesitic agglomerate and high cover*
- ABDALAJIS HIGH SPEED TRAIN TUNNEL (Spain) – *Claysilt, rapid convergences*
- PIEVE VERGONTE (Italy)
- VARZO HEADRACE TUNNEL (Italy) – *Antigorio & Gneiss and high cover*
- VAL VIOLA (Italy)
- LA JOYA (Costarica)
- SAN FRANCISCO (Ecuador)
- GILGEL GIBE II HEADRACE TUNNEL (Ethiopia) – *Basalt with high cover*
- BELES HEADRACE TUNNEL (Ethiopia) – *Basalts, Tuffs, Lacustrin formations*
- BRENNER RAILWAY TUNNEL (Italy)
TBM design
response to minimize or to mitigate risks
special measures

- increase of cutter-head torque to equivalent level of EPB type TBM,
- redesign of main and auxiliary thrusts with capacity well above the normal standards for the different range of diameters,
- redesign of the shields cylinder shape with a conical geometry
- fitting of cutter-head with over-cutting/over-boring tools,
- fitting the TBM with drilling equipment capable to perform, through shields and cutter-head supplementary measures for rock mass drainage or strengthening.
HIGH CONIC SHIELDS DESIGN

- shields designed to have conical geometry, as a result allowing for some squeezing to occur quickly with minimum risk of TBM entrapment
- telescopic articulation design to prevent packing of the joint in loose ground

progressively increasing crown clearances from the nominal excavation diameter:
- front shield 8.5 cm
- gripper shield 13 cm
- tail shield 16 cm
- segmental lining 19 cm
provision for possible continuous over-excavation: standard overcutting 8 to 10cm on radius, special overcutting adjustable with additional 10cm, by manual out-spacing of the peripheral cutters to provide extra space for squeezing and preventing loading of shields,

SELI has developed, in collaboration with the Rock Mechanics Department of Rome University, a design CAD software for estimating the required overcutting for a given TBM diameter and in particular conditions.
in a second stage and in view of responding to the risk of occurrence of extreme variability of geology associated with prevailing poor rock mass conditions and water or silts inflows, SELI developed the DSU-EPB TBM, a dual mode TBM with capability of shifting from one operational mode to the other without requiring any modification.
SELI’s first TBM DSU-EPB was prepared for the headrace tunnel of Beles project in Ethiopia. Shifting from DSU to EPB mode requiring:

- belt and hopper removal,
- fitting of auger arm,
- adjustments to cutter-head mucking arrangements,
- adjustments to gearboxes,
- adjustments to telescopic system,
- adjustments to articulation.
EVOLUTION – ACTUAL

DSU-EPB latest generation

shifting from DSU to EPB mode does not require changes

shifting from double shield to mono shield mode is simplified and immediate
TBM operation
response to minimize or to mitigate risks

A logical process of risk management could be defined as:

- identification of risks/(uncertainties),
- analysis of the implications, specific and combined,
- response to minimize/mitigate risk,
- provision for appropriate contingencies.

This process is applicable for TBM operation, i.e. risk management during construction, and bearing in mind that

"control of operation is exercised by and through people"
## TBM operation risk management - typical form

<table>
<thead>
<tr>
<th>Geotechnical Baseline Report</th>
<th>Identification of most significant hazard nature</th>
<th>Interpretive description</th>
<th>Estimated probability of occurrence</th>
<th>Key potential preventive measures</th>
<th>Most significant potential risks impacts</th>
<th>Potential key mitigation and contingency measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>geological</td>
<td>- jointed and blocky rock mass,</td>
<td>- repeated conditions</td>
<td>high</td>
<td>to forewarn of possible adverse conditions, especially in the case of variations of muck aspects, excavation parameters;</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>- sheared and crushed extensive contact zones between adjacent formations,</td>
<td>preliminary hazard ranking: high</td>
<td></td>
<td>- to monitor changing ground conditions,</td>
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<td></td>
<td></td>
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<td></td>
<td>- to drill horizontal or ascending percussion pilot holes ahead of the face to investigate the presence of a possible broken zone, discontinuity, etc.</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>- to probe holes to typically extend 30m ahead of the face, with adequate overlapping (minimum 8m) where continuous reconnaissance will be required.</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>- to note penetration rate, possibly water colour, water outflow and losses, description of cuttings.</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>- possible TBM improper steering and/or defective lining installation when crossing such formation or when encountering such discontinuity,</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>- ravelling of cuttings at the heading face, causing possible blockage of cutterhead and/or shield,</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>- to reduce TBM advance speed,</td>
<td></td>
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</tr>
</tbody>
</table>

**Note:** Information and data contained in the Geotechnical Baseline Report.
people in effect constitute the best “asset” of company and their role and performance are essential in relation with risk management,

the impact of any of or all identified risks during risk assessment exercise or during operation can be aggravated by the inappropriate performance of any individual and/or ultimately the tunnelling organizational structure employed in the project.
SEL I are of the opinion

- that “it is preferable to bore a tunnel with a bad TBM and a good crew than trying to make work a good TBM with a bad crew”,

and

- that the most important factor for a successful execution and completion of a TBM tunnelling project is related to deployment of an experienced and capable crew.
TBM operation response to minimize or to mitigate risks

SELI’s “esprit de corps”

most important factor in SELI’ success in approaching TBM tunnelling under adverse geological conditions is related to the trust that all individuals deployed for the entire organizational structure put into the final capability to break-through despite the encountering of any difficulty during tunnel driving; in such a situation, all individuals would participate in a team effort to generate and implement the solutions and measures to overcome the problems
CLOSING REMARKS

TBM design, operation and risk management
HIMALAYAS geological conditions

• foreseeing the unforeseeable is also a challenging exercise, better carried out at the stage of desk studies, and construction of a long and deep tunnel is always a challenge, particularly in the Himalayas,

• risk management of any tunnelling project is expected to start effectively when the amount of uncertainty about the project is the greatest,

• feasibility, construction final time and cost, final behaviour of any tunnel are dominated by geology,

• SELI are of the opinion that TBMs can be tailored to the needs deriving from the project assessed geology,
• tunnelling projects exposed to severe risks are successfully completed based on appropriate contract arrangements,

• known and unknown risks and risk allocation strategies: main functions of construction contracts are
  ➢ work transfer define work that one party will do for the other
  ➢ risk transfer define how the risks inherent in doing the work will be allocated between the parties
  ➢ motive transfer inspire motives in contractor that match those of the client
CLOSING REMARKS

TBM design, operation and risk management
HIMALAYAS geological conditions

selection of appropriate strategy on the retention or distribution of risks, i.e. determination at the start of the project of form of contract, will maximize impact and effectiveness in realizing a successful project, [e.g. conventional approach, EPC, partnering, ……….]

- key objectives for the client are generally:
  - to obtain a fair price for the work,
  - to enter into an agreement with a contractor who possesses the necessary skill and resources to obtain the assurance of the tunnel project being completed within the required time, cost and quality standards.

- SELI’s form of managerial approach is similar to “Partnering”.
TBM design, operation and risk management
HIMALAYAS geological conditions
KATHMANDU – January 2011, 27th

Dhanyaa'baad
Dhanyawad
Thank You