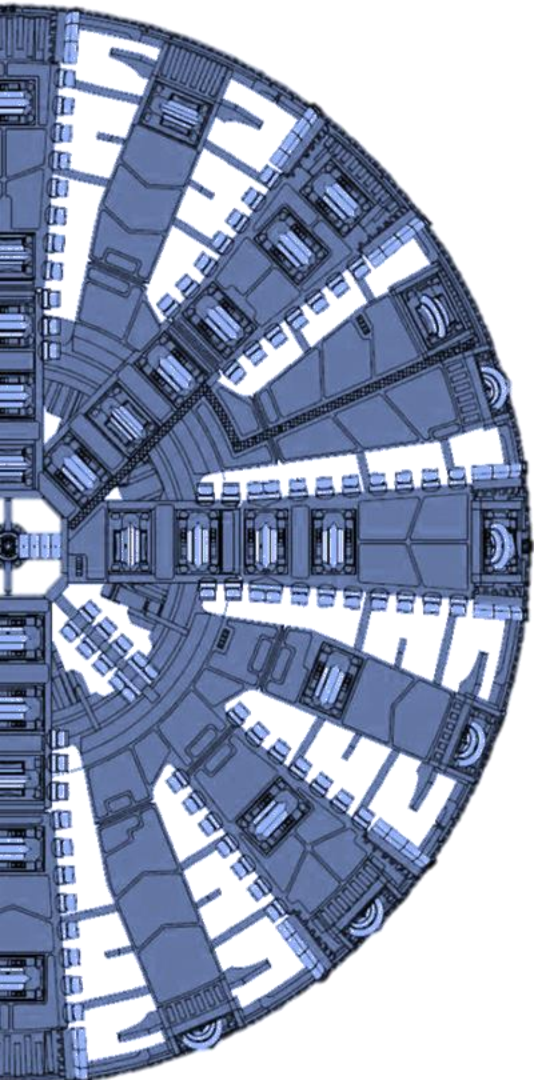


Les mardis de l'AFTES

Paris - Soirée du 22 Novembre 2022

# Défis et risques spécifiques associés au creusement des tunnels à forte profondeur, nouvelle recommandation du WG17 de l'ITA-AITES

**Gerard SEINGRE** (*BG Ingénieurs Conseils*)

*Tuteur du WG17 ITA-AITES*

# Préambule

- **Quel est le facteur prépondérant pour le choix d’un tunnelier pour l’excavation d’un tunnel de base ?**
- **Cas des tunnels de base sous les Alpes, rétro-analyse sur 25 ans**

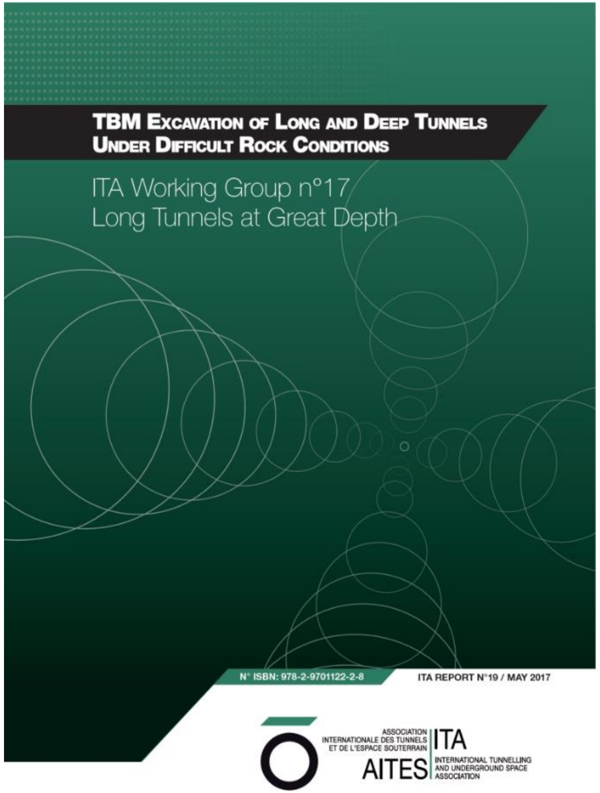
| | | |
|---|---|---|
| Loetschberg Sud | (CH) | TBMs à grippers |
| Gothard (Bodio Faido) | (CH) | TBMs à grippers |
| Brenner Nord | (Au) | TBM à grippers, TBMs simple jupe |
| Brenner Sud | (I) | TBMs double jupe |
| Lyon-Turin SMP4 | (F) | TBM simple jupe |
| Lyon-Turin CO6 | (F) | TBMs à grippers (DCE) => TBM simple jupe (EXE) |
| Lyon-Turin CO5 | (F) | TBM à grippers * |

- **Conclusion ?**

# Rapport du groupe 17 de l’AITES

## ITA report n°19

## TBM Excavation of long and deep tunnels under difficult rock conditions



# Nécessité d'emploi des tunneliers pour les tunnels de base de grandes longueurs

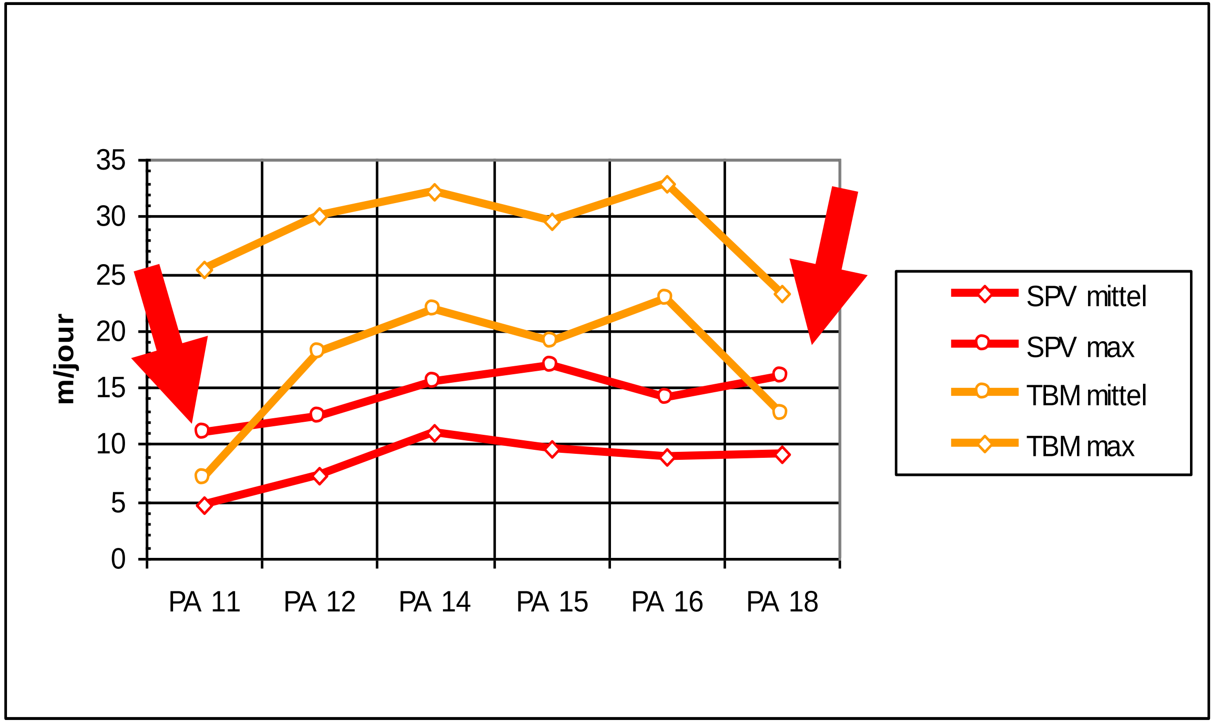
Grandes longueurs

Durées et coûts des projets
⇩
Industrialisation des méthodes de construction

Maximisation de l'usage des tunneliers

**La combinaison des fortes contraintes et de la qualité du massif rocheux peut affecter fortement les vitesses d'avancement des tunneliers**

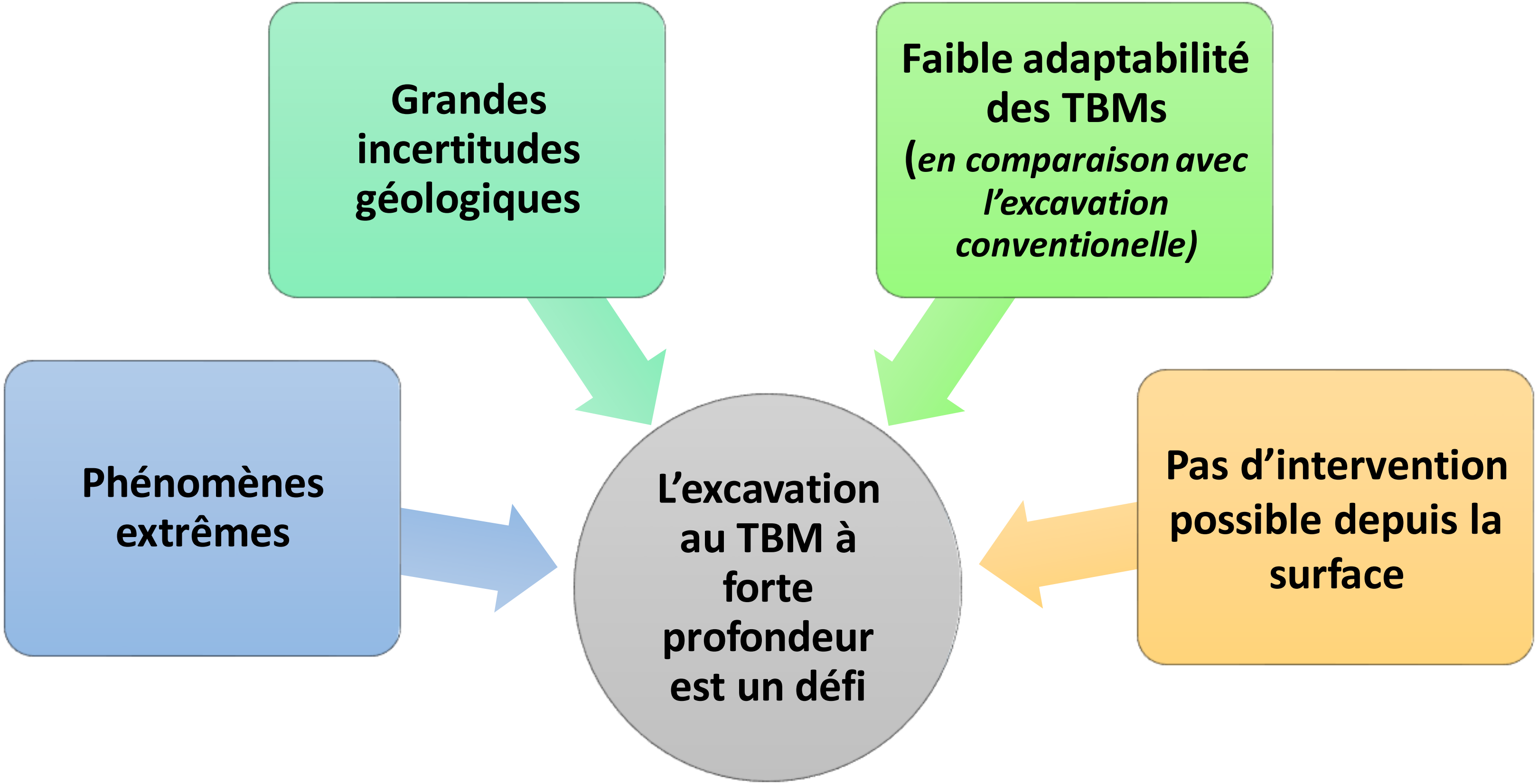
# Influence de la qualité du massif rocheux sur les performances des TBM en comparaison avec l'excavation conventionnelle




## ❖ Loetschberg Sud

- **Avancements parallèles traditionnel et TBM**
- **Tronçon PA11 : flambage de bancs dans des calcaires**
- **Tronçon PA18 : dureté et abrasivité dans du granit massif**

# Risques de l'excavation TBM à forte profondeur



# Objectifs du rapport

❖ **Établir une directive à l'usage des concepteurs, des propriétaires et des entrepreneurs portant sur :**

- **Langage technique commun**
- **Classification simplifiée des dangers géotechniques principaux**
- **Conséquences de ces phénomènes sur les différents types de tunneliers**
- **Les (contre-) mesures à mettre en place**

Tunnel de base du Gothard, dégagement d'un TBM bloqué

# Identification des risques

❖ **Phénomènes (scénarios de danger) qui sont amplifiés à forte profondeur**

- Ecaillage, rockburst
- Fortes convergences
- Flambage de bancs
- Instabilités de front
- Fortes venues d'eau
- Fortes pressions d'eau
- Fortes températures

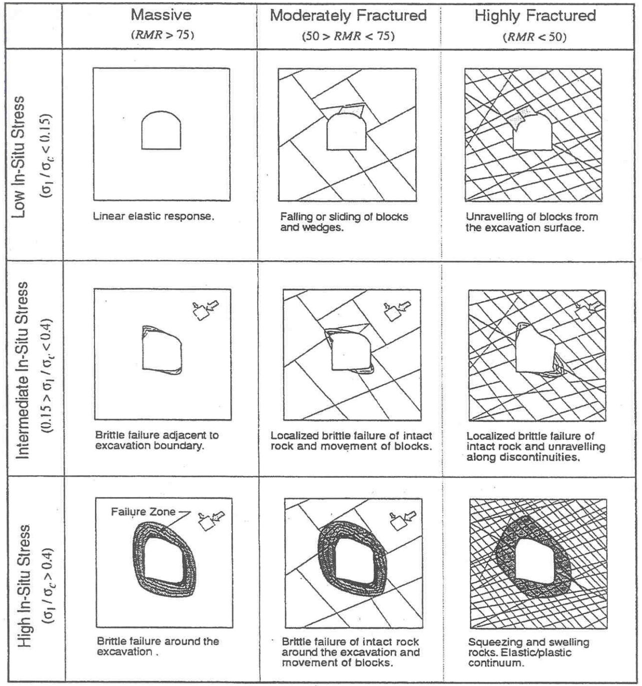
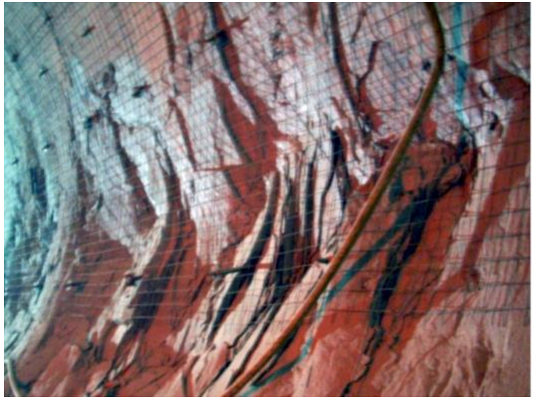
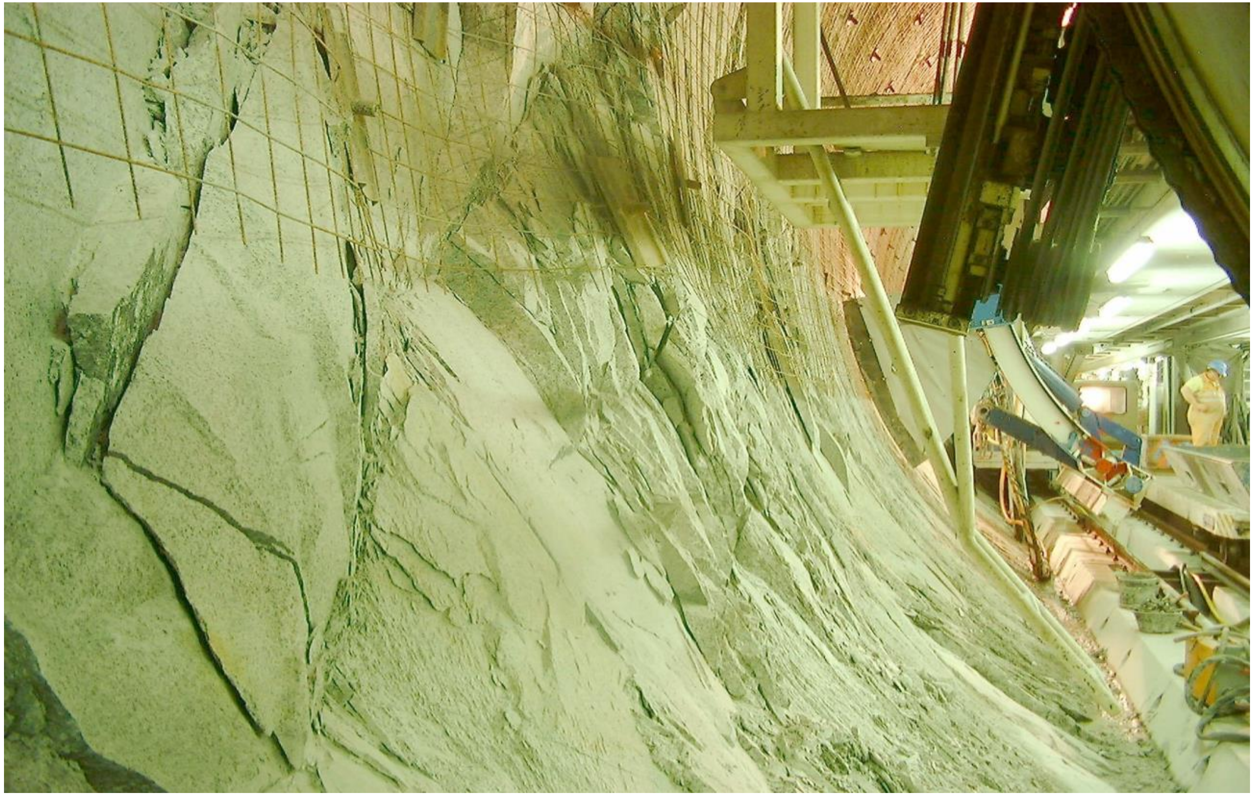
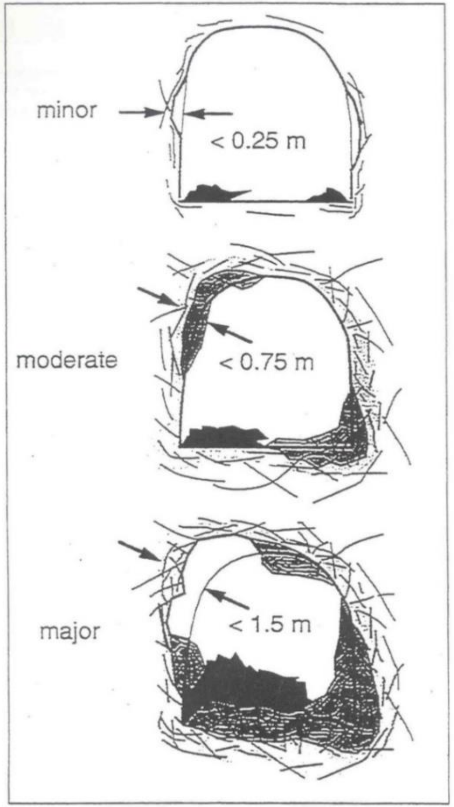



Figure 2: Rock mass behaviour matrix (Martin *et al.* 1999)



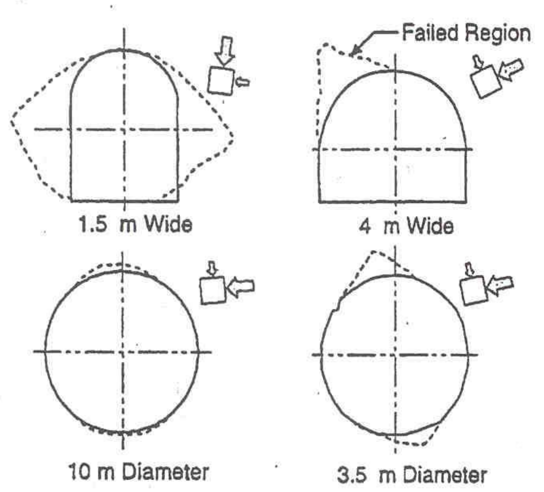
# Ecaillage dans du rocher massif






Doc. P. Kaiser & al.

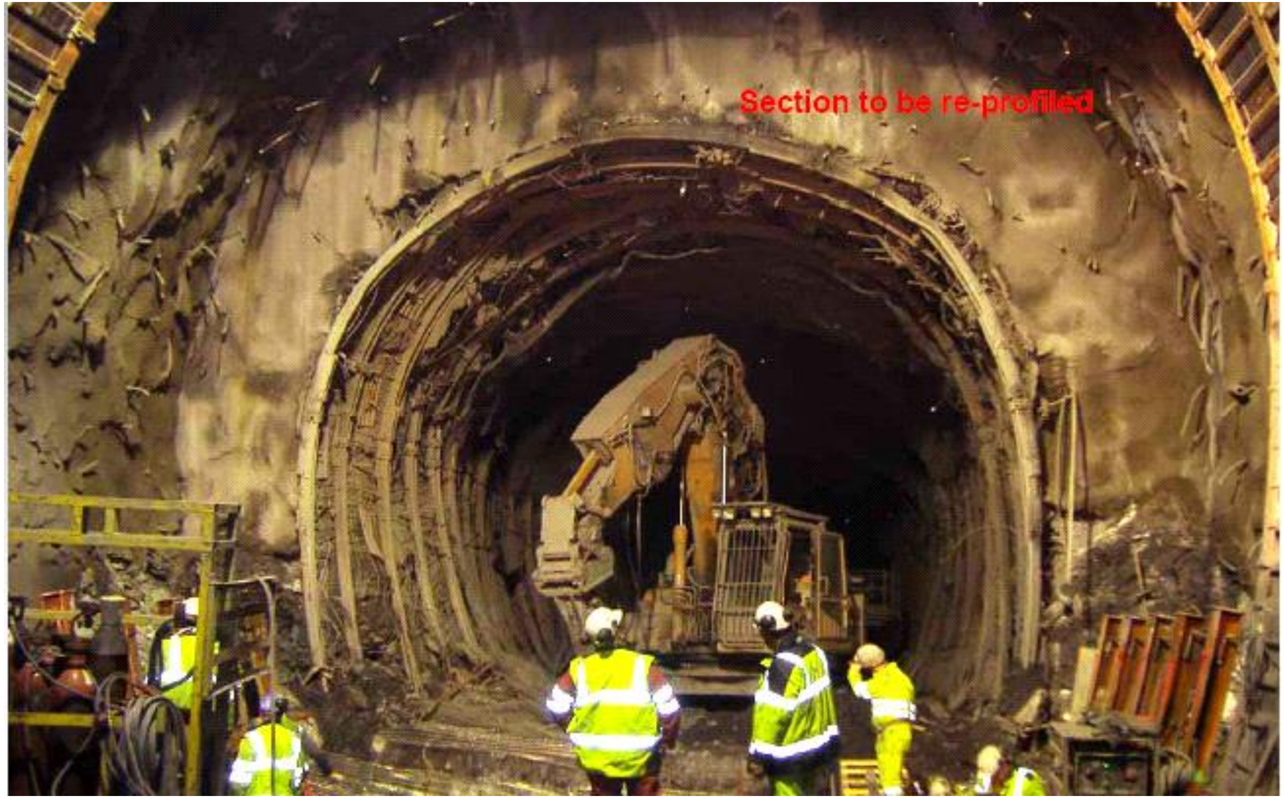
# Rockburst

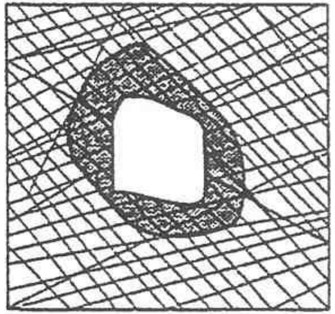



- Doc. Martin, Kaiser and Mc Creath

OLMOS TRANS-ANDEAN TUNNEL

# Fortes convergences

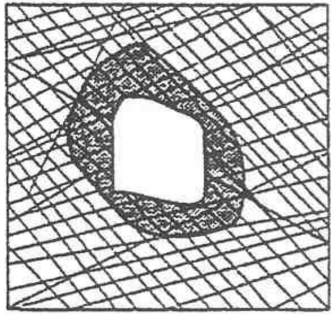



Descenderie de St-Martin – La Porte, Lyon-Turin

Convergences métriques dans le Carbonifère à moyenne profondeur

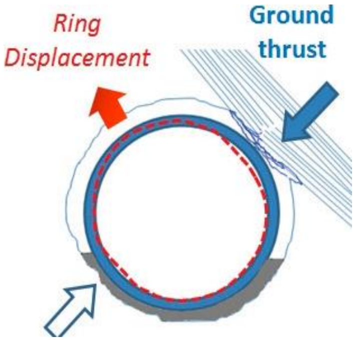
# Fortes convergences

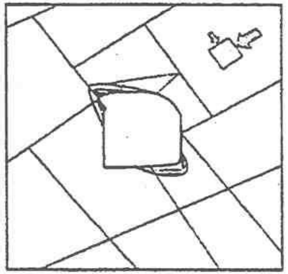



Tunnel de base du Loetschberg Nord

Soutènement d'urgence d'un rameau dans le Carbonifère à forte profondeur

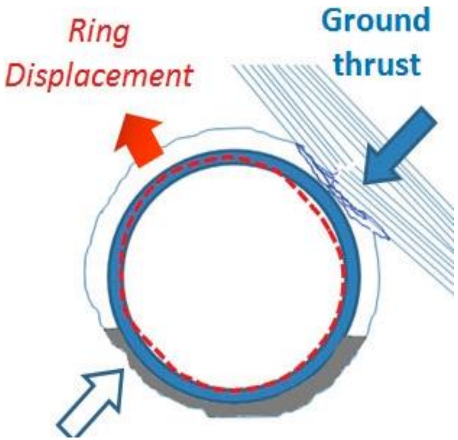
# Différence entre flambage de bancs et convergence



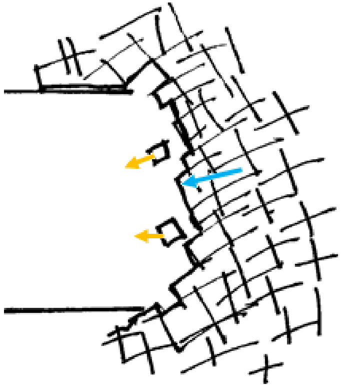



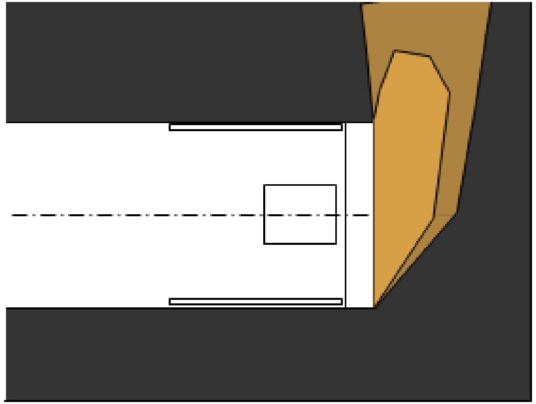
Localized brittle failure of intact rock and movement of blocks.

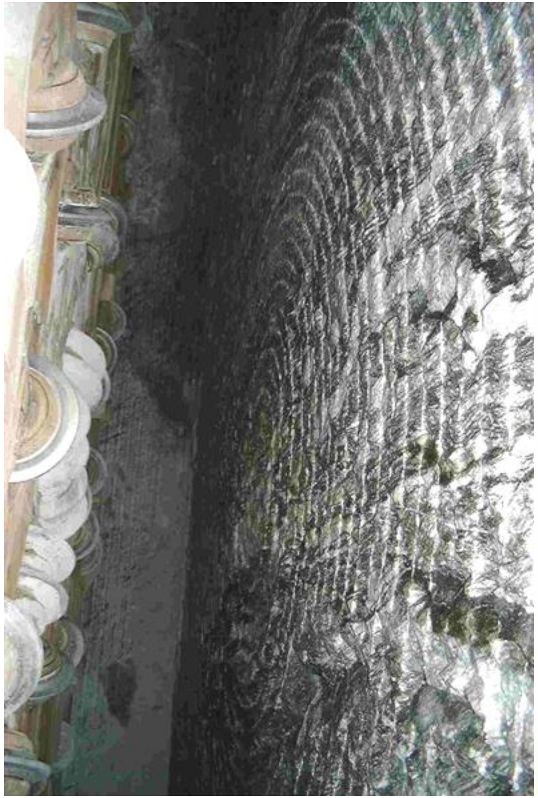
# Flambage de bancs en radier




# Instabilités de front







# Fortes venues d’eau, fortes pressions d’eau

Forage de reconnaissance, Nant de Drance


Venue d’eau dans la tête, Lake Mead

**Besoin important de refroidissement si la température de l’eau est élevée !**

# Méthodologie basée sur l’échange d’expériences

# Méthodologie basée sur l'échange d'expériences

- D'énormes progrès ont été réalisés dans les 20 dernières années
- Recueil de l'expérience de projets importants
- 20 projets dans 15 pays

Worldwide date base collected by the members of the ITA Working Group 17 on the TBM tunnelling experience in difficult rock conditions gained over the last 20 years

| LIST OF PROJECTS | | | | | DEFINITION OF THE HAZARD SCENARIOS | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Brittle behaviour | | Highly deformable behaviour | | Presence of water | | | | Environmental aspects |
| Number | Project name | Country | Type of TBM | Diameter [m] | Spalling | Rock-burst | Buckling | Squeezing | Extremely high water inflow (clear water) | High water pressure | Mud inrush | Face instability | High temperature |
| 1 | Lake Mead | USA | Single shield | 7,2 | | | | ✓ | ✓ | ✓ | ✓ | ✓ | |
| 2 | Frejus safety tunnel | France-Italy | Single shield | 9,46 | | | ✓ | | | | | | |
| 3 | Gothard base tunnel - Lot Bodio | Switzerland | Hard Rock TBM with Grippers | 8,83 | | | | | | | | ✓ | |
| 4 | Gothard base tunnel - Lot Faido | Switzerland | Hard Rock TBM with Grippers | 9,43 | ✓ | | | ✓ | ✓ | ✓ | | ✓ | |
| * 5 | Olmos transandino tunnel | Peru | Hard Rock TBM with Grippers | 5,35 | ✓ | ✓ | | | | | | | |
| 6 | Loetschberg base tunnel, south section (Steg and Raron drives | Switzerland | Hard Rock TBM with Grippers | 9,43 | ✓ | ✓ | ✓ | | | ✓ | | ✓ | ✓ |
| 7 | Nant de Drance | Switzerland | Hard Rock TBM with Grippers | 9,45 | ✓ | | ✓ | | | ✓ | | | ✓ |
| * 8 | La Maddalena exploratory tunnel | Italy | Hard Rock TBM with Grippers | 4,5 | | ✓ | | | | | | | ✓ |
| * 9 | Uma Oya Multipurpose Development projetc tailrace tunnel | Sri Lanka | Double shield | 4,3 | | | | | | | | ✓ | |
| * 10 | Pahang-Selangor Raw Water Transfer Project | Malaysia | Hard Rock TBM with Grippers | 5,2 | ✓ | ✓ | | | ✓ | | | | ✓ |
| 11 | Hida tunnel - main tunnel | Japan | Hard Rock TBM with Grippers | 12,8 | | ✓ | | | ✓ | ✓ | | ✓ | |
| 12 | Kargi tunnel | Turkey | Double shield | 9,84 | | | | ✓ | | | | | |
| 13 | Niagara Tunnel Project | USA | Hard Rock TBM with Grippers | 14,4 | ✓ | | | | | | | | |
| 14 | Lesotho Haighlands Water Project | Lesotho | Hard Rock TBM with Grippers | 5 | | | | | | | | ✓ | |

* NB : These datasheet will be fully completed in the next edition

# Conséquences des dangers sur le choix du tunnelier

## ❖ Aspect primordial dans le choix du type de tunnelier et la minimisation des risques

- **Identification préliminaire de tous les scénarios de danger possibles**
- **Identifier et évaluer les conséquences prévisibles concernant les types de tunneliers**
- **Sélection et conception d'un tunnelier approprié en conséquence**

Tunnel d'accès à l'aménagement Nant de Drance

Tunnel de base du Gothard, temperature eau 43°C

# Conséquences des dangers sur le choix du tunnelier

❖ **Les conséquences peuvent être différentes selon les types de tunneliers en ce qui concerne leurs impacts sur l'exploitation des tunnels et la sécurité des travailleurs**

- **Identification des conséquences sur la base de l'expérience partagée des membres du groupe de travail 17**
- **Évaluation des impacts sur la base de la directive sur l'analyse des risques de l'AITES (GT2)**

| CONSEQUENCE LEVEL | |
|---|---|
| | **Not concerned** |
| 1 | **Negligible :** No further consideration of the hazard is needed |
| 2 | **Unwanted** : mitigation measures shall be identified. The measures shall be implemented as long as the costs of the measures are not disproportionate with the risk reduction obtained |
| 3 | **Unacceptable :** The hazard shall be reduced at least to Unwanted, regardless of its mitigation costs |

# Conséquences des dangers sur le choix du tunnelier

❖ **Les conséquences peuvent être différentes selon les types de tunneliers en ce qui concerne leurs impacts sur l'exploitation des tunnels et la sécurité des travailleurs**

| PHENOMENA HAZARDS | CONSEQUENCE LEVEL | | | | IDENTIFICATION OF CONSEQUENCES ON TBM | LOCATION | | |
|---|---|---|---|---|---|---|---|---|
| | OPEN | SINGLE SHIELD | DOUBLE SHIELD | | | TUNNEL FACE | TBM AREA | BACK-UP AREA |
| | | | | | **Not concerned** | | | |
| | | | | 1 | **Negligible :** No further consideration of the hazard is needed | | | |
| | | | | 2 | **Unwanted :** Risk mitigation measures shall be identified. The measures shall be implemented as long as the costs of the measures are not disproportionate with the risk reduction obtained | | | |
| | | | | 3 | **Unacceptable :** The risk shall be reduced at least to Unwanted, regardless of the costs of risk mitigation | | | |
| **Highly deformable behaviour** | | | | | | | | |
| **Squeezing and buckling** | 2 | 2 | 2 | | Jamming of the cutterhead | | | |
| | 1 | 2 | 3 | | Jamming and damage of the shield | | | |
| | 2 | | | | Jamming and damage of the back-up | | | |
| | | 3 | 3 | | Overstress of the segmental lining | | | |
| | 2 | | | | Overstress of the support | | | |
| | 3 | | | | Inadmissible high tunnel convergences | | | |

# Dangers et conséquences selon le type de TBM

## ❖ Pour chaque phénomène / danger

- Les conséquences sont évaluées en fonction de la position d’occurrence
- L’impact des conséquences est évalué sur la base d'un jugement d’ingénieurs

| CONSEQUENCE LEVEL | |
|---|---|
| | **Not concerned** |
| 1 | **Negligible :** No further consideration of the hazard is needed |
| 2 | **Unwanted :** Risk mitigation measures shall be identified. The measures shall be implemented as long as the costs of the measures are not disproportionate with the risk reduction obtained |
| 3 | **Unacceptable :** The risk shall be reduced at least to Unwanted, regardless of the costs of risk mitigation |

| PHENOMENA HAZARDS | CONSEQUENCE LEVEL: OPEN | SINGLE SHIELD | DOUBLE SHIELD | IDENTIFICATION OF CONSEQUENCES ON TBM | LOCATION: TUNNEL FACE | TBM AREA | BACK-UP AREA |
|---|---|---|---|---|---|---|---|
| **Brittle behaviour: Rockburst, spalling** | | | | | | | |
| **Spalling** | | | 2 | Blocking of the telescopic part of the shield | | ■ | |
| | 2 | | 2 | Gripper bracing difficulties | | ■ | |
| | | 1 | 1 | Cracks in the segmental lining | | | ■ |
| | 1 | | | Damage of the support | | | ■ |
| | 2 | | | High cleaning effort in invert (time consuming) | | ■ | ■ |
| **Rock-burst** | 3 | 3 | 3 | Damage of TBM[2] | ■ | | |
| | 2 | 2 | 2 | Damage of the cutterhead and/or the cutting tools[3] | ■ | | |
| | 3 | 3 | 3 | Injuries of the workers during face inspections | ■ | | ■ |
| | | 2 | 2 | Damage of the segmental lining[4] | | | ■ |
| | 2 | | | Damage of the support | | | ■ |
| | 3 | | | Injuries for workers | | ■ | ■ |
| | 3 | | | Damage of the back-up ; Damage of the belt conveyor | | ■ | ■ |

# Choix et implémentation des contre-mesures

❖ **Pour chaque phénomène / danger et chaque type de tunnelier**

- **Liste des mesures possibles pour affronter chaque danger**
- **Evaluation de la difficulté de mise en place des mesures en tunnel**
- **Recommandations pour la prise en compte dans la conception de la machine**

| DIFFICULTY LEVEL TO IMPLEMENT MITIGATION MEASURE ON SITE | |
|---|---|
| (grey) | **Not concerned** |
| ✔ (green) | Easy to implement on site, to be previously considered in the design |
| ⚠ (yellow) | Medium difficulty of implementation |
| ❗ (red) | Very difficult to implement, (could have an impact on the requirements) |

# Choix et implémentation des contre-mesures

| PHENOMENA HAZARDS | LEVEL OF DIFFICULTY TO IMPLEMENT THE MITIGATION MEASURE | | | | EXAMPLE OF MITIGATION MEASURES TO IMPLEMENT |
|---|---|---|---|---|---|
| | OPEN | SINGLE SHIELD | DOUBLE SHIELD | ■ | **Not concerned** |
| | | | | ✔ | Easy to implement on site, to be previously considered in the design |
| | | | | ⚠ | Medium difficulty of implementation |
| | | | | ❗ | Very difficult to implement, (could have an impact on the requirements) |
| **Brittle behaviour: Rockburst, spalling** | | | | | |
| **1- Spalling** | ■ | ■ | ✔ | | 1.1) Selection of the appropriate type of the telescope in order to limit the material accumulation, and so prevent its blockage |
| | ■ | ■ | ⚠ | | 1.2) Operation of the double shield TBM as a single shield TBM. (The prediction of spalling is difficult, so these changes of mode will probably require cleaning of the telescopic section before) |
| | | ⚠ | ⚠ | | 1.3) Improvement of the annular void filling in order to stabilize the ring as early as possible:<br>• by a correct design of the method of injection<br>• by calibrating the methods on site (changing the materials, the location, using bi-component, injection from tailskin or segments) |
| | ✔ | ■ | ■ | | 1.4) Installation of radial bolting (friction anchors) in combination with wire mesh and eventually ribs |
| | ✔ | ✔ | ✔ | | 1.5) Appropriate torque reserve high torque low speed gear) |
| **2- Rock-burst** | ✔ | ✔ | ✔ | | 2.1) Execution of subhorizontal destructive drilling eventually combined with blasting around the perimeter of the TBM (in order to release the in-situ stresses) |
| | ✔ | ⚠ | ■ | | 2.2) Drilling of large diameter holes (approximately 100 mm), as close as possible to the cutterhead (in order to release the in-situ stresses) |
| | ✔ | ✔ | ✔ | | 2.3) Avoid front loading cutterhead; change cutter tools from inside (back-loading cutterhead) |
| | ❗ | ❗ | ❗ | | 2.4) Avoid face inspections and work in front of the cutterhead in risk zone. |

# Merci de votre attention


GT 17 AITES 2022