TUNNEL FACE STABILITY WITH MECHANIZED TUNNELING
GENERAL CONCEPTS

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TBM face stability control

When tunneling with full face machines in urban areas there are some specific aspects that influence the tunnelling risks and that must be taken into account in the design and the construction procedures.

Urban environment
Shallow overburden
Structures on ground surface
Foreign objects in ground
Constraints for alignment
Restriction for: impossibility of road closure; place of attack, material transport, access to TBM, exploration and carrying out of auxiliary measures (i.e. ground reinforcements), high visibility of damage.
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Geological and hydrogeological conditions
Properties of the recent geological formations
Presence of a man made filling (sometimes of unknown depth)
Frequently changing conditions
Presence of ground water

Non – perfect (i.e. not as designed) performance of the tunneling method
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An optimal design must be based on risk analysis and risk management which must address the decision and choice to be taken and also influence the construction management.

In fact this approach permits after the identification of all potential hazards, to assign to each of them a probability of occurrence and to allocate an index of gravity-severity to the consequences. With this picture in mind is possible to define:
• the solutions to be used to reduce the probability of occurrence of negative events;
• the measures for reducing the gravity of the consequences of a negative event.

(Kovari, 2000, 2004; Guglielmenti et al., 2002; Guglielmetti, Mathab, Xu, 2007)
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The most relevant risk scenarios in urban area when tunnelling with full face machines inside a soft soil are:

**Limiting condition for the machine**
(that is to say a condition for which the machine is not working as designed)

• Excessive wear of the tools
• Excessive use of conditioning agents, grease, ect.
• etc.

**Interferences with the local environment and accidents**

• Face collapse which can reach the surface
• Damage of already existing constructions both on surface or underground (i.e. subsidence)
• Underground water pollution
• etc.
In the present lecture we will analyse the problem of face stability which can cause the following type of accidents:

- face collapse which can reach the surface
- damage of already existing constructions both on surface or underground (i.e. subsidence)
The first set of choices which permit the activation of countermeasures to be adopted to face these risk scenarios are:

1) the choice of a correct machine for the local urban environment and geology;

2) the correct management of the excavation process (control of face counter-pressure, evaluation of the amount of extracted material to avoid overexcavations, correct and proper filling of shield body annulus etc.)
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First option for risk reduction

With specific reference to the correct choice and management of the full face machines it is necessary to control the face stability:

a) to correctly evaluate the face pressure to be applied to guarantee the stability and correctly apply with reference of the local environment;

b) to properly treat (condition) the ground to permit the face pressure to be applied by the machine;

c) to control the excavation process to avoid over-excavation (monitoring of the ground and of the machine performances)

If these options are not sufficient, it is necessary to use a second set of options for risk reduction.
1) Definition of the stabilizing pressure to guarantee the stability

2) Definition of the failure mechanism
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Design aspects

The definition of the appropriate EPB face pressure need to be considered on a project-by-project basis taking into proper account the soil properties, the groundwater content and the TBM design.

Groundwater pressure: in some types of rock such as weak or broken rock the principal reason for using a closed-face machine is to control groundwater.

The operating pressure should be a small margin, perhaps 10%, above the existing hydrostatic pressure.

In water bearing granular material it is necessary to apply operating pressures to resist both hydrostatic and soil pressure.

In both cases it is necessary to ensure that no risk of ground loss from the crown.

(BTS, 2005)
Unstable ground: in non-water bearing granual material where there is no water pressure to balance and where the soil pressure may be small it is difficult to determine the operating pressure. It is necessary to operate the machine at a pressure that ensures the bulk chamber remains full at all the times to guard against loss of ground from the tunnel crown. In soft clays and silts that can flow, it may be appropriate to change from resisting soil or hydrostatic pressure to a pressure that approximates to full overburden pressure.
Modification or conditioning of the excavated spoil is a process for both slurry and EPB tunnelling system.

For EPB shields conditioning agents, usually foam or foam/polymer solution, are injected under pressure into the spoil as it is excavated, to assist the tunnelling process in two ways:

✓ When mixed with the soil, the conditioning fluid reduces the permeability and the internal friction of the material which flow through the bulk chamber and the screw conveyor for discharge into the muck-haulage skips at the atmospheric pressure.

✓ The reduction of permeability of the material enables the creation of the plug in the screw conveyor to form and ensure that earth pressure balance support of the tunnel face is maintained.
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Stability Control

HDS – version with SLURRY FACE SUPPORT for soil with no or low cohesion (gravel, sand, silt) and for ground with hard inclusions – for tunneling under groundwater table.

EPB – version with FACE SUPPORT BY PRESSURIZED SOIL for cohesive clayey soil (loam, clay, marl) for tunneling below groundwater table.
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Stability Control

MSD – version for “DRY” OPERATION, (if necessary with MACHANICAL FACE SUPPORT – for tunneling through all soil formations above groundwater table.
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EPB Soil Conditioning

Earth pressure distribution diagram

- Earth pressure
- Excavation chamber
- Low pressure gradient
- Injection
- Screw conveyor
- Discharge
- Without injection
- With injection
- Plug area
- 100%, 95%, 90%, 85%
- 80%
- 70%, 50%, 0%

plug in the screw conveyor effect
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Monitoring of buildings and of the surface

Torino metro – courtesy GTT-Torino
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Monitoring of machine performance

To monitor an EPB machine the following parameter are used:

- the pressure inside the bulk chamber;
- the weigh of extracted material (after the screw drive)

Many pressure sensors are applied inside the bulk chamber to measure and keep under control the pressure of the spoil.

This control is a key parameter for the correct management of the machine and for the control of tunnel face stability.

Guglielmetti et al., 2002
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Monitoring of machine performance

Average value of earth pressure at the face and of the weigh of the extracted material.
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Monitoring of machine performance

Average value of earth pressure at the face and of the weigh of the extracted material.
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Secondary option for risk reduction

a) Constructional measures
   – Ground improvement from the surface
   – Ground improvement from underground works
   – Prepared grouted blocks for stopping the machine
   – Preventive structures

b) Additional measures
   – evacuation of buildings
   – closure of roads
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Ground improvement

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Ground improvement

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Ground improvement

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Ground improvement

Zimmerberg Tunnel

Zurich; Kovari, 2004
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Preventive structures
Zimmerberg Tunnel

Zurich; Kovari, 2004
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Prepared grouted blocks for stopping of machines

Longitudinal section

Cross section

Tunnel

grouted body