A New AFTES Guideline “Safety and Mechanization”
How These Issues Can Be Integrated During Early Stages of Design

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1. INTRODUCTION

In underground operations, safety issues during construction are closely related to the methods of execution. In particular, mechanized tunnel construction performed with a TBM, leads to a set of constraints for safety. The new AFTES guideline “Safety and Mechanization” [1] concerns the design phase of a project.

Located in the Western Paris, the duplex tunnel of the highway link A86 SOCATOP, was considered a model of safety during construction. Despite all precautions taken by the contractors, on March 5, 2002, a fire started at about 300m behind the tunnelling machine (TBM). The team of workers took refuge inside the air lock chamber in the TBM. They had to wait for almost 20 hours before the public rescue service managed to arrive. Luckily, no-one was injured thanks to thorough training of the crews. Additionally, crews were very familiar with safety procedures allowing good coordination with rescue teams [2]. One of the major difficulties encountered by the public rescue service was the accessibility to the front of the tunnel due to the constraints of the site while under construction.

After such event, the underground professional community decided to further improve the level of safety on a mechanized tunnel, not only as a protection against the risk of fire, but more generally, taking into account safety requirements such as, for example, to facilitate self-rescue of workers, or the need to convey a stretcher with an injured person from the front of the TBM.

In order to find answers to these issues, a Working Group was created including all underground professions in France. This group is today composed of engineers, owners, contractors, TBM manufacturers, health and safety coordinator and public rescue service. Each profession brings his own perspective with the goal of better integrating safety concepts during construction.

Several constraints are related to the intervention conditions of the public rescue service inside a tunnel utilizing mechanized construction. In this regard the AFTES Working Group has come to some conclusions which are included in their recommendations. [1]

One of the goals of this recommendation is to define a simple scheme easy to understand and apply by different professionals. For this purpose, we used tunnel diameters and lengths to the nearest rescue point as key dimensions of a grid to help design and plan each step of the construction process.

As we will see later in this paper, safety issues appear to be particularly difficult to manage in small inner diameter tunnels although these tunnels (mostly hydraulic) are amongst the most frequently constructed around the world.
This paper is organized as follows; in Section 2 we introduce the key elements used to characterize a mechanized tunnel construction and the safety system. In Sections 3 and 4 the main recommendation of the AFTES guideline is outlined. In Section 4 we discuss the impact of these guidelines in the early stages of tunnel conception. We conclude the paper with some final remarks.

2. DEFINITIONS

2.1 Manned and Unmanned TBMs

A manned TBM requires full-time working shifts inside the machine; e.g. a single-shield TBM, a hard rock TBM (with grippers), or a double-shield TBM.

An unmanned TBM does not need full-time working shifts inside the machine, since it only requires workers for maintenance intervention. This category includes micro-tunnelling and pipe-jacking.

2.2 Access Point and Distances

An access point is an area which allows physical communication between the tunnel and public rescue service under the following conditions:

- Public rescue service can access the tunnel with fire fighting and emergency vehicles as well as safety equipment
- An existing reliable communication system is in operation with the tunnel [3]
- It enables the provision of first aid facilities

Examples of access points are:

- Portals or cut and cover entrance tunnels
- Entrance from a shaft platform or intermediate shaft platform
- Emergency station or emergency exit
- Cross-passages from another existing tunnel nearby

In relation to the distance from the nearest access point, three different cases are defined, each resulting from both the intervention conditions of public rescue service and the transposition of existing regulations for some type of tunnels:

- Case A: Distance from the nearest access point less than 200m
- Case B: Distance from the nearest access point is between 200m and 500m. In this case, escape equipment for workers is necessary
- Case C: Distance from the nearest access point is in excess of 500m. In addition to the escape equipment for workers, at least one safe chamber inside the TBM is also necessary. If it is not possible for the crew to self-rescue to an access point, one safe chamber allows the workers to wait for the arrival of public rescue service; in case of smoke for example. These cases are used in Figure 3, in Section 4.

2.3 Escape Walkway Specification

A key requirement necessary both to enable workers self-rescue and/or for the access of public rescue service is to have enough free space for a continuous dedicated walkway up to the front of the tunnel.

Given the specific characteristics of mechanized tunnels and the little free space available near the front, one of the first tasks of the AFTES working group has been to define the necessary dimensions of walkways. The group defined the dimensions of nominal escape walkways and minimal escape walkways.
The nominal escape walkways have been defined based on the standard dimensions of safety walkways of urban public transportations; e.g. underground, suburban trains. It requires a height of 2.2 m and a width of 0.7 m as shown in Figure 1. One of the characteristics of the nominal escape walkways is that grade changes must be limited in number and must be accomplished using a stairway. The nominal escape walkways can be locally reduced up to the dimensions of minimal escape walkways. The minimal escape walkways require a height of 1.5 m and a width of 0.6 m as shown in Figure 1. Finally, ladders are acceptable only if the geometrical conditions (constraints) do not allow for a stairway.

![Diagram of Nominal and Minimal Escape Walkways](image)

**Figure 1:** Nominal and minimal escape walkway dimensions

### 3. APPLICATION TO THE MECHANIZED TUNNELS

The size and location of walkways in a tunnel under mechanized construction depends on the inner diameter of the tunnel and the position along of the tunnel (machine, transition zone, back-up train, tunnel).

It is a normal procedure for the owner to define the diameter of a tunnel with respect to its final purpose. Tunnel diameters are the result of calculations of flows, trains speeds, etc. The actual recommendation leads the owner to consider the safety during construction with a very high priority and even to modify the time schedule or the final tunnel design diameter accordingly.

The main recommendations of the walkways application with respect to the inner diameter of the tunnel are detailed below and summarized in Figure 2.
3.1 For Tunnel Diameters 3.00m and Larger

A nominal escape walkway (green) all along the tunnel and on the back-up train should be devoted to the workers and the public rescue service. The integration of this specific walkway in the section of the tunnel leads to **recommend a minimum inner diameter of 3.00 m for manned TBMs** (i.e. with permanent working shifts inside the machine).

There are no additional restrictions on the circulation of workers since they have a dedicated walkway.

Locally, on the back-up train it is possible to accept reduced walkways (red) with the minimal dimensions defined in Section 2.3 (see Figure 1). A specific analysis is required for the transition zone and the machine.

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**Figure 2:** Walkways application and TBMs, depending on the inner diameter and the location.
3.2 For Tunnel Diameters Between 2.20m and 3.00m

The narrow space does not allow dedoting a special walkway in the tunnel for the workers and rescuers; therefore, the public rescue service must circulate on the track with some restrictions. So this leads to privilege the use of unmanned TBMs.

A specific analysis is required for the back-up train, the transition zone and the TBM.

In this case, circulation by foot of workers in the tunnel is not allowed.

3.3 For Tunnel Diameters Less Than 2.20m

The different safety constraints lead to strongly recommend unmanned TBMs.

Even on the track, it is not possible to free enough space to allow the nominal walkway.

4. INTEGRATION DURING EARLY STAGES OF DESIGN

The goal of the guideline is to help the tunnel community to better manage safety by integrating safety requirements during the early stages of conception, in particular for those underground projects that are long, without intermediate access, and presenting a small inner diameter.

The main concern of the designer should be to define the access of the rescue teams as early as possible. In this regard the two main topics are the early construction of the auxiliary constructions and if not possible the diameter of the tunnel since it clearly appears that safety can be well managed if the teams can reasonably reach the potential victims.

In this respect, the engineer should consider the construction of the auxiliary infrastructure as a critical task in the construction schedule in order to make them available as early as possible for rescue; e.g. for twin tunnels, the opening of cross-passages should be built near the back of the machine. This simple analysis can modify the construction schedule in order to complete these different tasks early enough to make them available for rescue. The success of the rescue teams is directly related to the ease of their intervention. This statement leads logically to introduce this constraint with the highest priority in the design plan.

This tunnel diameter category between 2.20m and 3.00m is the most sensible because the access of rescuers is obviously difficult in the small free space available. The engineering team should study economic and technical solutions to balance the technical needs and to reduce risks while improving the safety level during construction. These solutions could be an increase of the inner diameter and/or the early construction of auxiliary infrastructure, such as an intermediate access shaft, for example.

Leaving enough space for walkways near the front is another issue that can be resolved in the design phase. The walkways on the machine, on the transition zone and on the back-up train of the TBM are particularly difficult to design and are closely linked to the inner diameter of the tunnel and the specification of the TBM. The TBM manufacturers and the contractors could improve the safety design of their mechanized machine in the early stage of design, imposing a free space for walkways.
The two following criteria; diameter and access points are linked. The weight of each of these criteria can be evaluated and sorted with a third data which is the length of the tunnel. One can easily understand that the requirements in terms of rescue team access to the workers depends on many factors; one being the distance to be covered by rescuers. Clearly, the shorter the tunnel, the sooner (and easier) the rescue team arrives. The table below (see Figure 3) shows combinations of these data and provides the reader with a guideline grid for the organization of the accesses for each tunnel length and diameter.

The recommendations for the design of safety in mechanized tunnel with respect to the inner diameter of the tunnel and the distance from the nearest access point are summarized in Figure 3.

<table>
<thead>
<tr>
<th>Tunnel length from the nearest rescue access point</th>
<th>Case A</th>
<th>Case B</th>
<th>Case C</th>
</tr>
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<tbody>
<tr>
<td>$L_{tunnel\ bored} \leq 200$ m</td>
<td>WALKWAYS APPLICATION depending on the location (tunnel, back-up train, transition zone, machine)</td>
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<tr>
<td>$\phi_{inner} \geq 3,00$ m</td>
<td>Escape equipment for workers</td>
<td>Escape equipment for workers</td>
<td>Escape equipment for workers</td>
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<tr>
<td>$2,20 &lt; \phi_{inner} &lt; 3,00$ m</td>
<td>SPECIFIC ANALYSE by the profession (Owners, Engineers, Contractors, TBM manufacturers, Health &amp; Safety coordinator, Public rescue service) to integrate safety issues during construction</td>
<td>=&gt; Promote the execution of SAFE CHAMBER =&gt; Adopting specific equipment (e.g. electric) =&gt; Restricting pedestrian circulation</td>
<td>=&gt; Add intermediate access point to avoid Case C =&gt; Privilege the use of &quot;UNMANNED TBMs&quot;</td>
</tr>
<tr>
<td>$\phi_{inner} \leq 2,20$ m</td>
<td>Use of &quot;UNMANNED TBMs&quot; strongly recommends</td>
<td></td>
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Figure 3: Intervention condition of public rescue service depending on the inner diameter and the access distance

5. CONCLUSIONS

This AFTES guideline represents a common view shared among engineers, owners, contractors and TBM manufacturers, health and safety coordinator, and public rescue service. It represents a first important step with the identification of the minimal requirements corresponding to a consensus among the underground professions in France.

Finally we should note that the requirements concerning the dimension of the walkways or the access point distances are applicable to other underground works independent from the methods of construction.
6. REFERENCES

