ITAtech Guidelines on Monitoring Frequencies In Urban Tunnelling

ITAtech Activity Group
MONITORING

N° ISBN : 978-2-9700858-4-3

ITAtech REPORT N°3-V2 / MAY 2015

ITAtech

Author list

Authors

Eric Gastine, itmsoil SA

Martin Beth, Soldata SA

Felix Amberg, Amberg Engineering AG

Klaus Chmelina, Geodata Group

Klaus Rabensteiner, Geodata Group

Co-Authors

Further members of the AG monitoring who contributed to the guideline

Oliver Schneider, Amberg Technologies AG

Stefano Cespa, T.R.E. Srl

Thomas Edelmann, Herrenknecht AG

Michael Günther, VMT

Johannes Hansen, Atlas Copco

Reviewers

ITA WG 2

ITA tech AG Design

ITAtech Report n°3-V2 – MONITORING FREQUENCIES IN URBAN TUNELLING – N°ISBN 978-2-9700858-4-3 : MAY 2015

Layout : Longrine – Avignon – France – www.longrine.fr

ITAtech Guidelines on Monitoring Frequencies In Urban Tunnelling

ITAtech Activity Group
MONITORING

>> TABLE OF CONTENTS

KEY WORDS :

This guideline has been established reflecting very specific site and contract conditions (see also chapter 1: Introduction). Consequently the use and the description of the key words may differ slightly from their standard use. In this context explicit reference is made to the ITA report #9 of WG 2 on 'Monitoring and Control in Tunnelling Construction'.

Risk: In this guideline the term 'risk' refers to any deviation in the expected hydro-geotechnical and structural behaviour which may lead to a significant impact on a tunnel project in urban environment, including the construction itself as well as the surrounding areas with existing buildings etc.

Monitoring: In this guideline the term 'monitoring' refers to hydro-geotechnical and structural parameters of tunnelling works in urban areas which are controlled by technical sensors. Other parameters (such as noise, vibrations and other environmentally relevant parameters), which may be part of a monitoring system, have been excluded as they do not contribute to the risk as it is defined herein.

Monitoring as such is part of the corresponding overall risk management (see ITA Guidelines for Tunnel Risk Management).

>> Introduction

Responding to an increasing demand of underground infrastructures, monitoring of hydro-geotechnical and structural parameters during the construction of urban tunnels in soils and rock (except hard rock) is a field of activity which has seen impressive technological changes and progress in the past years.

In the majority of the cases the construction of such urban underground infrastructures is to be carried out in difficult ground conditions and / or with limited knowledge about the ground parameters. In consequence the so-called 'observation method' according to Eurocode 7 is applied:

Eurocode 7, Section 2, chap. 2.7 Observation method (1) If the prediction of the geotechnical behavior is difficult, it may be appropriate to apply the so-called observation method which consists in the control and, case given, in the modification of the design during the construction.

The monitoring and the control are thus essential parts of the applied method and consequently also part of the overall risk management.

The ITA report 'Monitoring and Control in Tunnelling Construction', ITA report #9, ITA WG 2, 2011 describes in detail the procedures, the different stakeholders and their responsibilities etc which are to be implemented for a state-of-the art monitoring.

However, quite often it is seen that unclear specifications lead to inappropriate risk management processes. In particular it is quite common that the frequencies in which measurements are to be taken are not clearly defined and/or are left to the later discretion of construction stakeholders, or that measurement frequencies applied do not correspond to the needs of an optimized risk management process (too many or not enough measurements).

Measurements frequencies of hydro-geotechnical and structural parameters may :

- not be defined or
- be defined insufficiently or
- left to the interpretation of stakeholders who are not fully aware of their relevance

Which may lead to :

- the lack of adequate detection of anomalies and trends
- accidents
- higher costs

Measurement frequencies also may not be defined in an adequate manner to the nature of hydro-geotechnical and structural risks. This may lead to an insufficient availability of data, resulting in :

- an insufficient anticipation of anomalies and trends leading to potential risks
- accidents
- higher costs

or, on the contrary to an excessive demand for information which than may result in :

- unreasonable high requirements for sensors, monitoring software capabilities and large databases

Therefore, the objectives of this guideline are firstly to outline some aspects of the dynamics of the hydro-geotechnical and structural risks and their relevance within an adequate risk management process, secondly to draw the construction stakeholders attention to the need for clear specifications in terms of frequencies and finally to propose simple practical guidelines.

The intention however is not to define the type of instruments or monitoring schemes which have to be specified as part of the risk management. The documents listed in chapter 6 'References' provide state-of-the-art recommendations in this regard.

This guideline may be applied in cases (bids etc) where the aspects of monitoring and control and in particular clear specifications for measurement frequencies are not taken care of or even are missing entirely.

Every induced change of the naturally given stress distribution within the soil and/or the rock should be considered as a potential ignition for deformations and resulting structure responses. Any reaction to a critical development of the stresses and strains in the limited timescales given requires the earliest possible recognition of these changes and an adequate anticipation of the soil structure's typical response time.

Therefore the data evaluation in the risk management process should begin as early as possible in the processes which trigger this change, like the extraction of soil (i.e. monitoring of TBM parameters, stress sensors at SCL Tunnels) or the pressures and volumes of material injected or extracted during the underground works.

Deformations are a result of changing pressures, stresses or volumes. For understanding the way of soil/rock-structure behaviour due to the induced changes in stress, pressure or volume several correlating evaluations have to be calculated and their results verified by monitoring.

The constructional risk management processes depend on a sufficient number of measurements in order to be able to observe the inducing parameters such as stress and pressures changes, volume loss as well as the range and speed of soil/rock-structure deformations above and around the tunnel or stations. It also relies on good accessibility to data adapted to the decision making process and the availability of a risk management team and the corresponding procedures.

2.1. PROPS / RETAINING WALLS / WATER INGRESS

In case of urban tunnels the time span until deformation arrives at and/or affects the surface and construction can take several hours to several days. This depends on several conditions, among which are :

- the nature of the soil/rock and groundwater above the tunnel
- the depth, diameter, excavation method and sequence etc of the tunnel
- the behaviour of soil/rock when underground structures and foundations affect their geotechnical parameters

2.2. STATIONS: RUPTURE OF PROPS / RETAINING WALLS / WATER INGRESS

For cut and cover stations and access shafts the appearance of significant movement affecting existing structures can take from one hour to several hours or even to days.

This depends on :

- hydro-geotechnical conditions around the station
- depth and dimensions of retaining structure
- construction phasing and process, including propping and anchoring systems
- the behaviour of soil/rock when underground structures and foundations affect their geotechnical parameters

2.3. FURTHER PARAMETERS

There are other parameters which might be part of a monitoring scheme, such as noise, vibrations, dust etc.

These parameters can be related to :

- disturbance of people, installations etc in the vicinity of the works
- health and safety of persons working on the project

Although such parameters are seldom critical for the immediate project safety they have a significant and growing impact on projects and can in particular put the project schedule at risk (reduction of shifts, modification of process, etc.). The appearance of noise, vibration etc, affecting workers, inhabitants and installations is almost instantaneous.

This depends on :

- nature of soil and structures
- distance and geometry
- characteristic of source

However as none of these parameters are directly endangering the structural safety of the construction in progress and its vicinity and because this guideline is about safety related monitoring, these parameters are not further considered.

3. MONITORING FREQUENCIES

The concept of measuring frequency covers several realities that are the source of misunderstandings on sites:

	MANUAL	AUTOMATIC
Reading Frequency	Site reading frequency	Reading frequency of the logger (measurement is not necessarily stored but signal is digitalized and alarm can be triggered)
Acquisition Frequency	Site Acquisition frequency (Data is registered)	Acquisition frequency of the logger (measurement is stored locally)
Transmission Frequency	Frequency with which the operator downloads or sends measurements to the central servers	Frequency with which acquired measurements are sent from the logger or collected at the logger and sent to the servers
Storage Frequency	Frequency with which transmitted data are validated and stored in the databases and made available on the web	Frequency with which transmitted data are validated and stored in the databases and made available on the web
Reporting & Interpretation Frequency	Frequency with which data are processed and interpreted	Frequency with which data are processed and interpreted

Table 1: Definitions of frequencies

It is recommended that the monitoring frequency is defined as the slowest frequency between acquisition, transmission and storage frequency. The availability of information therefore depends directly on monitoring frequencies as defined above.

4 >> Guideline on monitoring frequencies

Monitoring frequencies must be adapted to the typical timescales in which the risk occur and shall in addition anticipate time for counter measures to be adequately implemented.

Indeed, weekly measurements of inclinometers for instance are hardly suitable to be part of the risk management for urban excavations. Similarly, daily levelling measurements above a tunnel face may not turn out to be sufficient for monitoring settlements when decompressions return in 2 or 3 hours. Finally manual measurement of construction noise rarely falls when machinery nuisance triggers disturbances.

Examples of this kind could be multiplied. The objective of the practical guidelines below is to provide some methodological elements for predicting the typical risk occurrence times and to take them into account in the establishment of measurement frequencies. The recommendations listed in chapter 6 'References' outline the important role of the designer in this regard. However, as reality shows this, is not always the case. So the elements given in this guideline may be applied for monitoring frequencies of underground construction in urban areas in cases where no other values are given and / or no corresponding hydro-geotechnical evaluations of such elements have been carried out and thus no satisfactory definitions of the elements can be found in the contractual documents.

4.1. APPROPRIATE MONITORING FREQUENCIES

It is recommended that the following three steps are taken:

1. Estimate the typical time of occurrence of risks and countermeasure time.
2. Define areas of risk occurrence (active and warning areas).
3. Set the monitoring frequencies.

4.1.1. Risk Management

The first step, before any works yet have started, is to estimate within the risk management process the typical time of occurrence of risks. This estimate may be based on the experience of similar work done in neighbouring geotechnical conditions (excavations in the city, past experience on other structures, borings in similar geotechnical contexts). The local experience of geologists and the advice of engineers can be crucial in this respect for gathering converging elements.

One can also rely on experience based on the conduction of prior in situ tests and / or by carefully observing the evolution of stresses and strains in the construction of an underground structure in the city and / or by mathematically modelling the construction of such infrastructures.

The result of this first stage will provide an overview of the typical time of occurrence of the risk as shown below:

ORIGIN OF DEFORMATION	TYPICAL HAZARD OCCURRENCE TIME (DEFINITION)	ESTIMATE
Tunnel TBM or conventionally excavated (e.g. SCL tunnels)	Time delay between excavation of the tunnel and movements of 1 mm generated on the surface.	4 - 6 h
Station diaphragm wall	Time delay between of excavation of the wall and occurrence of movements of 1 mm at the nearest building.	1 - 2 h
Compensation grouting	Time delay between the start of the compensation grouting and the occurrence of movements of 1 mm on the surface.	1 – 60 minutes

Table 2: Typical hazard occurence times

4.1.2. Definition of Areas

In a second step the sizes of the observation areas are defined.

It is distinguished between a **Vigilance Zone** and an **Active Zone** which is embedded in the vigilance zone. The active zone is thus the part of the vigilance zone around the area where work is carried out in the tunnel or stations and it consequently may shift according to the progress of the work.

In the vigilance zone, the background monitoring and close-out monitoring is carried out, while in the active zone the active monitoring is applied.

Together with the sizes of the areas also the period during which measurements should be taken are given.

As stated in previous chapters, the indications for the definition of the zones as given in the attached drawings and the specifications below may be used if no information of zones etc are given in the tender and / or contractual documents. These zones and their dimensions do not necessarily correspond to 'zones of influence' etc which are defined by the designer of the project. If such other zones and dimensions are given by the designer in the tender documents they do prevail.

Vigilance zone – background monitoring:

The background monitoring corresponds to a phase of initial observation of the ground, groundwater, buildings and structures along the route. If carried out during a period sufficiently long before the construction starts, background monitoring provides information on the natural movements of corresponding parameters during a cycle of seasons. However the period should be sufficiently long in order to make sense of matters at the onset of additional deformation related to construction work.

VIGILANCE ZONE	TUNNEL	STATION
Zone of monitoring	Laterally: - twice the depth or - 100 m on either side of tunnel axis (whatever is larger) Length: 1000m plus the work area and plus 150 m in front of the working area	- twice the depth of walling or -100 m on each side of station wall (whatever is larger)
Period of monitoring	Must allow the registering of natural movement of structures affected by thermal yearly changes, groundwater and / or ground movements prior to construction. It is recommended to start at least six months to a year in advance	Must allow the registering of natural movement of structures affected by thermal yearly changes prior to construction. It is recommended to start at least six months to a year in advance

Table 3: Background monitoring

Vigilance zone – vigilance monitoring:

In the vigilance zone also the so called vigilance monitoring is carried out. It starts as soon as the work starts in this zone according to table.

VIGILANCE ZONE	TUNNEL	STATION
Zone of monitoring	Laterally: - twice the depth or - 100 m on either side of tunnel axis (whatever is larger) Length: 1000m plus the work area and plus 150 m in front of the working area	- twice the depth of walling or -100 m on each side of station wall (whatever is larger)
Period of monitoring	Must allow the registering of movement of structures, groundwater and ground due to construction.	Must allow the registering of movement of structures, groundwater and ground due to construction.

Table 4: Vigilance monitoring

Active zone

The active area is the area close to the works where changes in the relevant risk parameters are highest. It also may be called the 'Zone of fast hazards'.

If no information is given in the tender and / or contractual documents, the indications for the definition of the Active Zone as given in the attached drawings and the specifications below may be used. Generally the Active Zone follows the progress of the construction and - mainly but not exclusively – the excavation front respectively:

ACTIVE ZONE	TUNNEL	STATION
Zone of monitoring	Laterally: - depth of tunnel axis plus half the tunnel diameter - 50 m on either side of the tunnel (whatever is larger) Length: - depth to tunnel plus one diameter in front of tunnel face - 50 m ahead of tunnel face whatever is larger - 500 m behind tunnel face	- depth of walling around limits of excavation - 50 m (whatever is larger)
Period of monitoring	During all construction including all construction of civil works/main bearing structures, including the installation of the retaining structures	During all construction including all construction of civil works/main bearing structures, including the installation of the retaining structures

Table 5: Active monitoring

Vigilance zone - Close out monitoring:

The close out monitoring in the vigilance zone is the observation of parameters if they indicate that only residual changes happen. Close out monitoring may monitor the late decompressions and allows the transition to the long-term monitoring of the work by the operator. If no process or no values are given in the bidding document it may be assumed that this moment is given 3 months after the final load bearing structures have been put in place.

In this regard it is important that the monitoring concept for long-term monitoring is established before completion and hand-over of the constructional works. The aim of this long-term-monitoring plan is to allow the transmission of the work history and it lays the relevant base for a long-term monitoring.

VIGILANCE ZONE	TUNNEL	STATION
Zone of monitoring	Similar initial background monitoring on each side of tunnel axis	Similar background monitoring on each side of station axis
Period of monitoring	Period of close out monitoring must allow control of structure movements until completion of the site	Period of close out monitoring must allow control of structure movements until completion of the site

Table 6: Close-out monitoring

TUNNEL

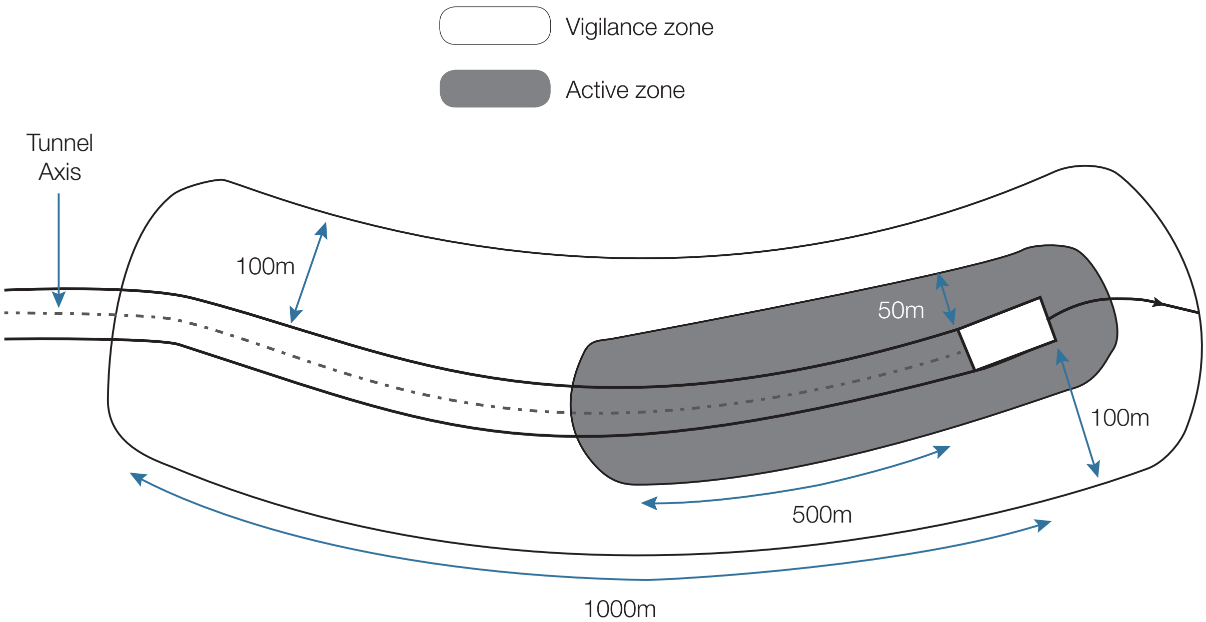

Illustration 1 : Diagram of the vigilance and active zones in running tunnel construction

STATIONS

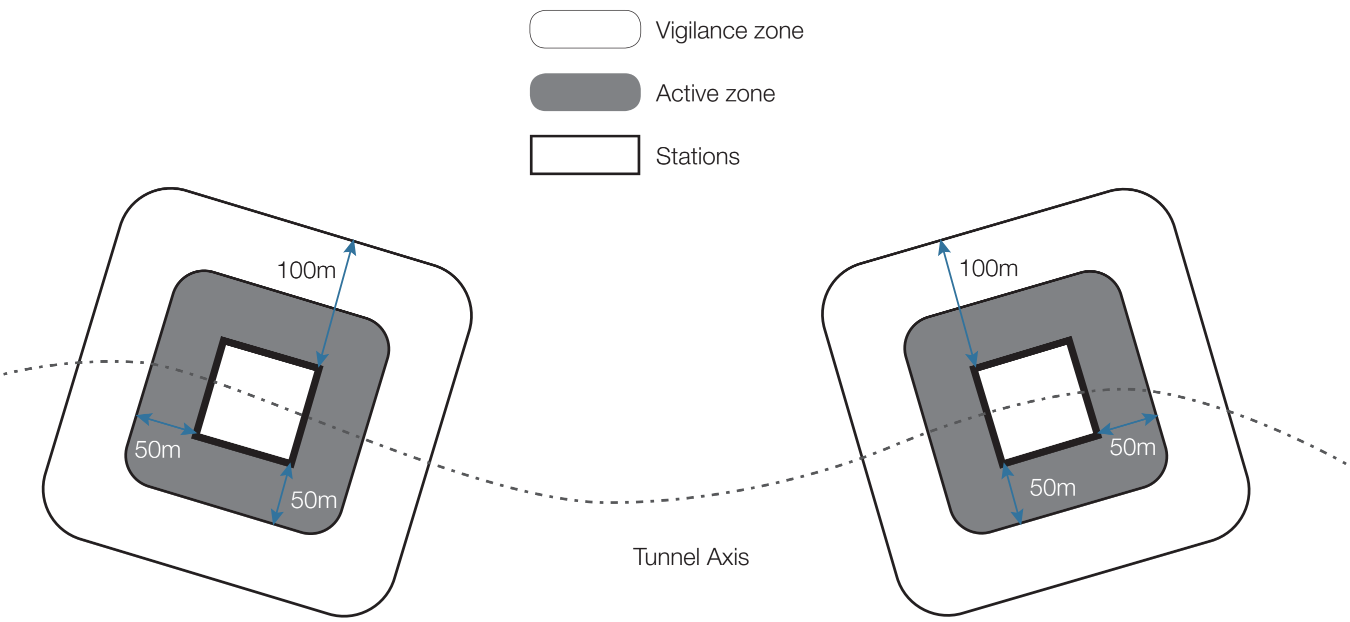

Illustration 2 : Diagram of the vigilance and the active zone, during the Station's construction

4.1.3. Measurements

Define the chart of monitoring frequencies as in figure 1 and figure 2:

- Active zone where maximum monitoring frequency must be applied
- Vigilance zone where lower monitoring frequencies can be applied
- Background and close out zones where much lower frequencies are necessary

If no corresponding information is given in the tender and / or contractual documents, the indications for the frequencies of measurements as given in the attached table below may be used.

Special cases such as structural movements are not covered with the following figures and need to be defined separately. Redundancy of measurements has not been considered in the table and may occur.

na: not applicable to the specific box
me: measurement taking

TUNNEL (TBM PARAMETERS)	BACKGROUND MONITORING	VIGILANCE MONITORING	ACTIVE MONITORING	CLOSE-OUT MONITORING
Pressures (face, grout, etc.)	na	na	1 me /10 '' - 30 ''	na
Excavated volumes	na	na	1 me /10 ''	na
Injected volumes (Grout, Bentonite loss, etc.)	na	na	1 me /10 ''	na
Forces (contact, push rams, etc.)	na	na	1 me /10 ''	na
Cutting diameter, copy cutter if applicable	na	na	1 me /10 ''	na
TUNNEL (MONITORING ABOVE GROUND)				
3D displacements of buildings and structures (automatic or manual)	2 me / 1 month	1 me / 4h	1 me	1 me / 1 month
Levelling of ground (automatic or manual)	2 me / 1 month	1 me / 4h	1 me	1 me / 1 month
- Tiltmeter on buildings - Liquid / electronic levels in buildings - Crackmeters on buildings	1 me / 1 day	1 me / 1h	1 me / 15'	1 me / 1 month
Piezometers (automatic or manual)	2 me / 1 month	1 me / 4h	1 me / 1h	1 me / month
Radar Interferometry	1 me / 20 days	na	na	1 me / 1 day
TUNNEL (MONITORING IN THE CROSS SECTIONS)				
3D displacements of structures (automatic or manual)	na	na	1 me / 1h	1 me / 1 month
Horizontal ground displacements, for ex. In place inclinometer (automatic or manual)	1 me / 1 month	1 me / 1 day	1 me / 4h	1 me / 1 month
Vertical ground displacement, for ex. extensometer (automatic or manual)	1 me / 1 month	1 me / 1 day	1 me / 4h	1 me / 1 month
Strain gauges in lining (automatic or manual)	na	1 me / 1 day	1 me / 1h	1 me / 1 month
Total pressure in lining (automatic or manual)	na	1 me / 1 day	1 me / 1h	1 me / 1 month
TUNNEL (MONITORING OF ALREADY CONSTRUCTED PARTS, FOR EX. IN THE TUNNEL LINING DURING THE EXCAVATION OF CROSS CUTS)				
3-d displacements, for ex. survey, levelling, inclinometer chains (automatic or manual)	1 me / 1 month	1 me / 4h	1 me / 1h	1 me / month
STATIONS				
Survey (automatic or manual)	1 me / 1 month	1 me / 4h	1 me / 30'	1 me / 1 month
Levelling (automatic or manual)	1 me / 1 month	1 me / 4h	1 me / 30'	1 me / 1 month
Inclinometers (automatic or manual)	na	1 me / 1 week	1 me / 1 day	1 me / 1 month
Strain gauges on props (automatic or manual)	na	1 me / 1 day	1 me / 1h	na
Load cells on temporary tiebacks (automatic or manual)	na	1 me / 1 day	1 me / 1h	na
Piezometers (automatic or manual)	1 me / 1 month	1 me / 1h	1 me / 15'	1 me / 1 month

Table 7 : Proposed monitoring frequencies

5 >> References

Monitoring Underground Construction – A best practice Guide, British Tunnelling Society, October 201, https://www.britishtunnelling.org.uk/?sitecontentid=34729AAF-DBDA-45C8-B54F-2AD74DF4FCC5

Guidelines for Tunnelling Risk Management, TUST Vol. 19, Nr. 3, pp. 217 – 237, ITA WG 2, 2004, https://www.ita-aites.org/en/publications/wg-publications/70-guidelines-for-tunnelling-risk-management

Settlement Induced by Tunnelling in Soft Ground, TUST Vol.22, Nr. 2, pp. 119 – 149, ITA WG 2, 2007, https://www.ita-aites.org/en/publications/wg-publications/66-settlements-induced-by-tunnelling-in-soft-ground

Monitoring and Control in Tunnelling Construction, ITA report #9, ITA WG 2, 2011, https://www.ita-aites.org/en/publications/wg-publications/65-monitoring-and-control-in-tunnel-construction

longrine.com - (21186-07/15)

ITA Secretariat c/o EPFL - Bât. GC - Station 18 - CH - 1015 Lausanne - Tel. : + 41 21 693 23 10 - Fax : + 41 21 693 41 53
Email : secretariat@ita-aites.org - Web : www.ita-aites.org