ITAtech Guidelines on Monitoring Frequencies in Urban Tunnelling

ITAtech Activity Group
MONITORING

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KEY WORDS :

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.

Real time monitoring: In this guideline the term 'real time' is defined as any time scale appropriate to monitor and describe technically a specific phenomenon. It has nothing to do with the often used «immediate» monitoring or «continuous» monitoring term which both are confusing as they do not stand any necessary delay for reading, acquiring, transmitting, processing, storing, validating, interpreting and reporting data.

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. Monitoring is as such a part of the corresponding overall 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. Monitoring has thus become an essential part of the overall risk management which normally is implemented for such type of construction works.

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, the 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 but to underline the necessity of clear specifications for measurement frequencies which are adapted to the underground - structure dynamics and risk management objectives.

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. TUNNELS: PROGRESSION OF DEFORMATION

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. NOISE AND VIBRATION OF SURFACE WORK

Although noise and vibration 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 and vibration affecting workers, inhabitants and construction is almost instantaneous.

This depends on :

- nature of soil and structures (for vibration)
- distance and geometry
- characteristic of noise / vibration source

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

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

4 >> Guideline On Measurement 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. These elements 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. DEFINITION OF APPROPRIATE MONITORING FREQUENCIES WITHIN THE RISK MANAGEMENT PROCESS

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 Process

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 for the excavation of a metre of tunnel to generate a movement of a millimetre on the surface	4 - 6 h
Station diaphragm wall	Time for the occurrence of movements of a centimetre at the nearest building	1 - 2 h
Compensation grouting	Time for the occurrence of surface movements of a millimetre	30 – 60 minutes

Table 1: Risk occurrence 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.

If no information is given in the tender and / or contractual documents, the indications for the definition of the zones as given in the attached drawings and the specifications below may be used.

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 2: 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 3: 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:

VIGILANCE ZONE	TUNNEL	STATION
Zone of monitoring	Laterally: - depth of tunnel axis plus half the tunnel diameter or - 50 m on either side of the tunnel (whatever is larger) Length: - depth to tunnel plus one diameter in front of tunnel face or - 50 m ahead of tunnel face whatever is larger - 500 m behind tunnel face	- depth of walling around limits of excavation or - 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 4: Active monitoring

Vigilance zone - Close out monitoring:

The close out monitoring in a specific area is the observation of parameters after this specific area has left the vigilance zone and / or the monitored parameters indicate that the 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. 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 5: Close-out monitoring

TUNNEL

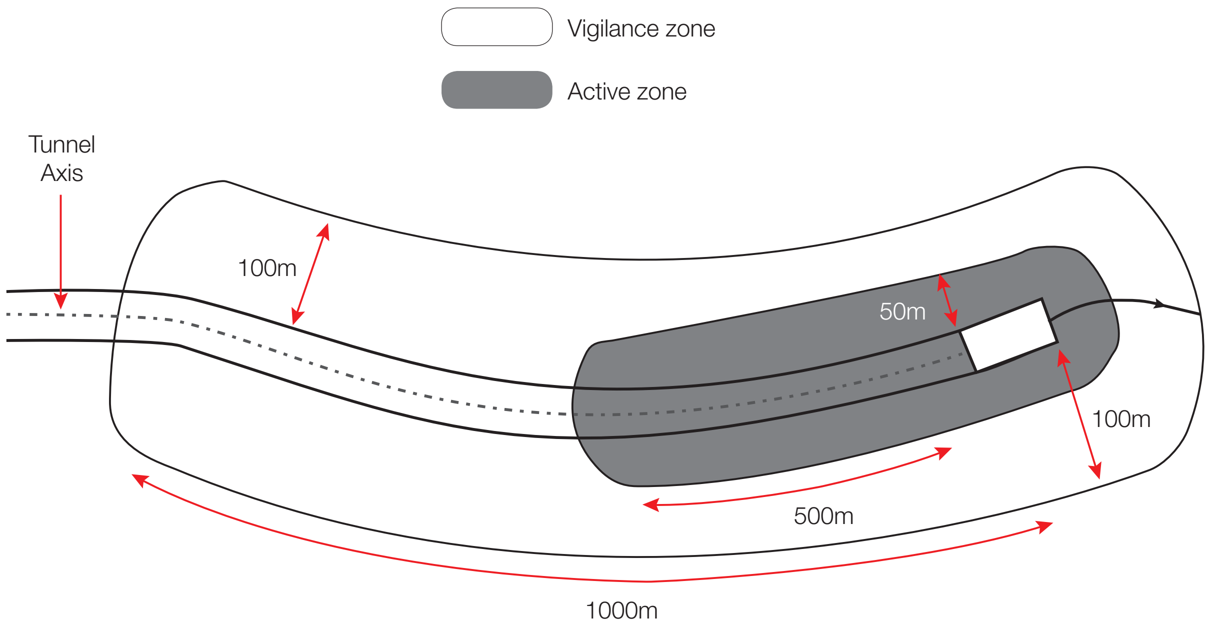

Figure 1 : Diagram of the vigilance and active zones in running tunnel construction

STATIONS

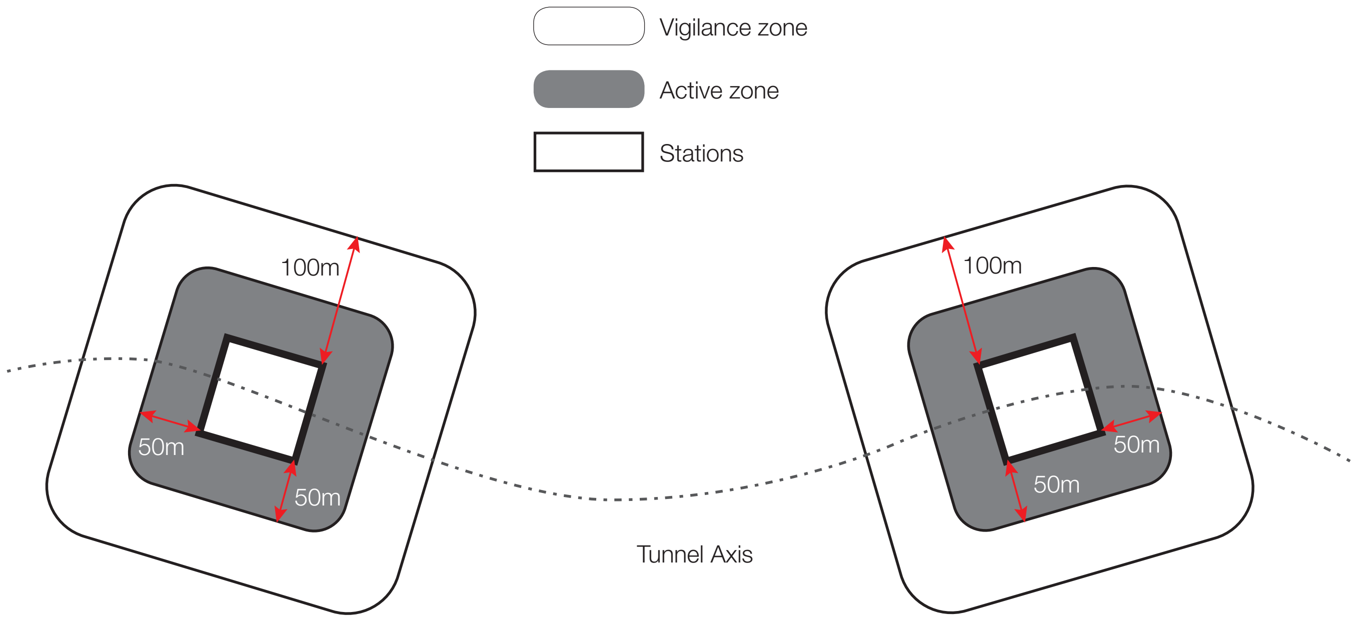

Figure 2 : Diagram of the vigilance and the active zone, during the Station's construction

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.

na : not applicable to the specific box
m : manual readings
a : automated readings
me : measurement taking

TUNNEL (TBM PARAMETERS)	BACKGROUND MONITORING	VIGILANCE MONITORING	ACTIVE MONITORING	CLOSE-OUT MONITORING
Pressures (face, grout, etc.)	na	na	1 me /10 ''	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)				
Survey (automatic or manual)	1 me / 1 month (m, a)	1 me / 4h (m,a)	1 me / 30' (a) (m: na)	1 me / 1 month (m/, a)
Levelling of ground (automatic or manual)	1 me / 1 month (m, a)	1 me / 4h (m,a)	1 me / 30' (a) (m: na)	1 me / 1 month (m/, a)
- Tiltmeter on buildings - Liquid / electronic levels in buildings - Crackmeters on buildings	1 me / 1h (a)	1me / 4h (a) 1me / 24 h (m)	1 me / 15' (a) (m: na)	1 me / 1h
Piezometers	1 me / 1 month	1 me / 1h (a)	1 me / 15' (a) (m: na)	1 me / month
Radar Interferometry	1 me / 1 month	na	na	1 me / 1 month
TUNNEL (MONITORING IN THE CROSS SECTIONS)				
3D displacements	1 me / 1 month	1 me/ 4h	m (a: na)	1 me / 1 month
Horizontal ground displacements (for ex: In place inclinometer	1 me / 1 month (a, m)	1 me / 1 day (a, m)	1 me / 5' (a) (m: na)	1 me / 1 month
Radial displacements (for ex: extensometer)	1 me / 1 month	1 me / 1 day (a, m)	1 me / 5' (a) (m: na)	1 me / 1 month
Strain gauges in lining	na	na	1 me / 5' (a) (m: na)	1 me / 1 month
Total pressure in lining	na	na	1 me / 5' (a) (m: na)	1 me / 1 month
TUNNEL (MONITORING OF EXISTING PARTS, FOR EXAMPLE: EXCAVATION OF CROSS CUTS)				
3-d displacements (survey, levelling)	1 me / 1 month (a, m)	1 me / day (a, m)	1 me / 30' (m: na)	1 me / month (a, m)
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
In place inclinometers	na	1 me / 5' (a)	1 me / 1' (a)	1 me / 1 month
Strain gauges on props	na	1 me / 5' (a)	1 me / 1' (a)	na
Load cells on temporary tiebacks	na	1 me / 5' (a) (m: na)	1 me / 1' (a) (m: na)	na
Piezometers	1 me / 1 month	1 me / 5' (a)(m: na)	1 me / 1' (a) (m: na)	1 me / 1 month

Table 6 : Proposed measurement frequencies

5 >> References

Monitoring Underground Construction, British Tunnelling Society, October 2011
Guidelines for Tunnelling Risk Management, ITA WG 2, 2004

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