香港岩土及岩土環境工程專業協會

AGS (HK)

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TUNNEL CONSTRUCTION GUIDELINES
03 - GUIDANCE NOTE ON TUNNEL INSTRUMENTATION

EXPECTATIONS

Before embarking on any instrumentation exercise it is important that the Engineer defines exactly what questions he/she is trying to answer. Commonly these fall into the following main areas:

- How to monitor a construction activity for best feedback on design?
- How best to manage the works in order to optimize performance and safety?

The Engineer must also identify what it is possible to measure. This is defined by the accuracy, repeatability and stability of the instruments taking the readings and also by the amount of natural movement taking place on the structure to be monitored. Often, instrumenting a structure shows that it is moving without construction influence. The main external influences being variations in inter alia temperature (which may be hysteretic), wind, moisture content, tides, topography, air pressure and salinity. Many of these changes occur on a daily, monthly and seasonal basis and can close to the trigger levels commonly used for sensitive structures (see Table 1).

Table 1: Effect of ambient conditions on Piezometers

	Effect	Result on Piezometers	
		10 m head	100 m head
Salinity	Higher density 1,025 kg/m^3	0.25 m	2.5 m
Air pressure	External load on the water column 100 mBar	1 m	1 m
Temperature	Vibrating wire instrument frequency	Negligible at depth	Negligible at depth

Sampling limitations should also be considered since the availability of suitable sampling locations can influence results significantly.

In addition slopes, earthworks and reclamations, no matter how old, may show residual settlements and movements. A period of background monitoring should always be employed to identify these trends.

STATUTORY REQUIREMENTS

The scope of instrumentation is normally outlined within the Geotechnical Risk Assessment (GRA) Report which forms part of the consultant's brief. The GRA will also include an assessment of the sensitivity of structures, utilities nearby and geotechnical structures along the tunnel alignment and present proposals for monitoring requirements. A full survey and condition assessment is required to be completed, normally 3 months ahead of any excavation work. Systems for the management of geotechnical and tunnel data are required according to TGN25 – Geotechnical Control of Tunnel Works.

GENERAL REQUIREMENTS

Prior to any instrumentation exercise it is important to undertake a degree of due diligence on the structures to be monitored. Have they moved in the past and in what way? It is important to understand the sensitivity, accuracy and repeatability of the instruments proposed and marry this with the amount of background movement expected and the amount of movement likely to be caused by the works. All instruments must be properly calibrated and assessed for drift. Recalibration in hardware and firmware, and correction in reporting software if there is any suggestion of drift. Building some redundancy into monitoring systems can help identify this, e.g. survey the tops of D-walls for comparison with deflected amount.

DESIGN CONSIDERATIONS

A monitoring design should cover the following stages:

Background monitoring: to assess the ambient movements of structures, ground and groundwater. This may require several months or years to identify the proper natural background range of values and fluctuations. Three months of monitoring is normally used as a minimum period. Monitoring at this stage is commonly survey and piezometric monitoring only.

Risk assessment and condition assessment: Defines the susceptibility of both the ground and the structures on or in the ground to the proposed works. Defines the serviceability limits upon which AAA schemes are based. These are normally a two part process, a “search” identifying the foundation types and structural susceptibility to damage and the damage assessment for the most susceptible to calculate the allowable movements.

Identify design prediction values: Predictions based on numerical analysis are used to identify areas requiring particular monitoring.

Identify modes of failure: Prior to design the Engineer must have a clear appreciation for how structures behave when their foundations move and how utilities behave when the ground moves? Instrumentation can then be placed in the correct locations and orientations to measure this.

Identify sampling locations: Assess the require spacing of instruments to faithfully reproduce observed patterns without aliasing and to ensure peak values are identified.

Consider reading frequency and transmission frequency: Is it post construction monitoring or continuous monitoring or real time? If real time what delay in transmission time is acceptable.

Identify types of instruments.

Identify AAA (Alert, Action, Alarm) values and corresponding response plan.

MONITORING FROM THE GROUND SURFACE

Ground Deformation: Settlement monitoring using a digital level (expect accuracy to +/- 1mm). Check temporary benchmarks on a regular basis and correct for benchmark movement. Magnetic (MPBX) and rod extensometers for deep movements. Since the bottom magnet may not be stable the pipe top of MPBX should be surveyed and used as a reference. Inclinometers for lateral movement adjacent to tunnel but can also be installed horizontally at portals to measure convergence ahead, at and behind the face.

Piezometric changes: Standpipes and piezometers are normally used to determine the hydrostatic water level and the piezometric pressure at various depths. Halcrow buckets are used to monitor the highest level attained during a period of observation and are frequently used during the investigation stages to determine the seasonal variations without the need for frequent visits.

Building distortion: Building movement can be classified as total settlement, differential settlement, tilt, shear, tension and rotation. This is most readily monitored using a combination of survey levels, prisms, tiltmeters and crack gauges. It is important to consider a building and its connection to surrounding utilities.

Utility monitoring: Both the utility and the ground surrounding the utility should be monitored. Holes should be excavated to the utility and a steel rod coupled to the top of the utility to allow monitoring to be undertaken at the surface. Points should be arranged to suit the way in which the utility will deform and should enable the maximum angular distortion to be identified at key locations. The designer should take into account the spacing of joints and the location of stiffer portions of the utility which are likely to focus bending. Note that if the rod cannot be placed on the utility then care should be taken to tamp any filling material prior to rod placement.

MONITORING WITHIN THE TUNNEL

Convergence: Tunnel convergence can be monitored using a variety of cable and rod extensometers in addition to the installation of prisms and monitoring of distance and coordinate movement using a total station. Close to shafts it may be possible to survey with respect to a stable reference and present data in global coordinates. Where this is not possible, relative coordinates are used to define changes in distances. Note that up to 60% of movement may have already occurred before such instrumentation can be installed within drill and blast tunnels. Note also that prisms mounted on structural members may show the results of bending about supports rather than true inward convergence. On TBM tunnels the annulus between the constructed ring and the cut profile may be recorded continuously by sensors on the TBM.

Monitoring stress in linings: In concrete linings concrete stress cells and strain gauges may be placed behind and within the concrete to measure contact stresses and loads in various directions within the lining. In segmentally lined tunnels these may be cast into the segment in the factory. Note that thermally induced stresses may be significant within cast in situ linings.

TYPES OF CONTINUOUS AND AUTOMATIC MONITORING

Continuous monitoring uses a data logger to continuously sample data over a period of time. For this to be real time the data must also be sent to a database and processed for display within minutes of the readings being taken. Continuous monitoring is normally used where immediate response to changes is not important but knowledge of the dynamic response is. This is often used in the early stages of projects to determine the background trends in data. Most alarm systems will require real time rather than continuous monitoring. The commonly used optical robotic automatic deformation monitoring systems (ADMS) are not realtime and require at least 1 hour to complete a survey. For quasi real time structural monitoring wireless tilt meters or optic fibre systems may be required to augment.

TYPES OF REMOTE MONITORING

Satellite based methods include differential GPS and synthetic aperture radar interferometry. DGPS can give close to real time results but movements in the Z direction are at best +/- 4mm currently. PSInsar frames are available at 3 week intervals so are only good for identification of long terms trends, however they can be processed retrospectively. Ground based systems are currently in use in mine slopes and for analysis of structural dynamics and appear promising for the future.

Laser ranging or LiDAR gives an appealing visualisation of a tunnel but with accuracies of the order of 10-20mm these are not currently used for movement monitoring. Localised laser and radar ranging from fixed positions is currently in use in structural dynamics applications.

RECOMMENDED READING

Burland, J.B. and Wroth, C.P. (1974). Settlement of Buildings and Associated Damage. SOA Review, Conference on Settlement of Structures, Cambridge, Pentech Press. London, pp. 611-654.

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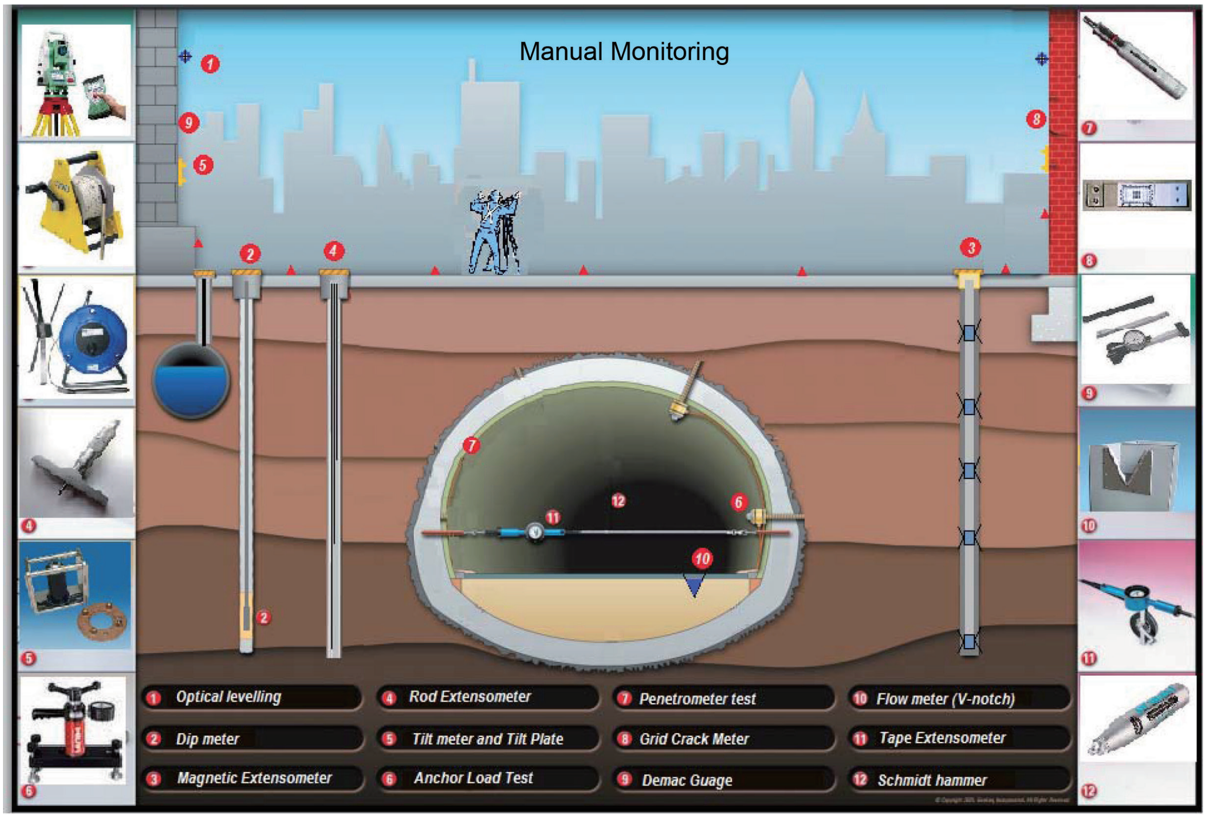
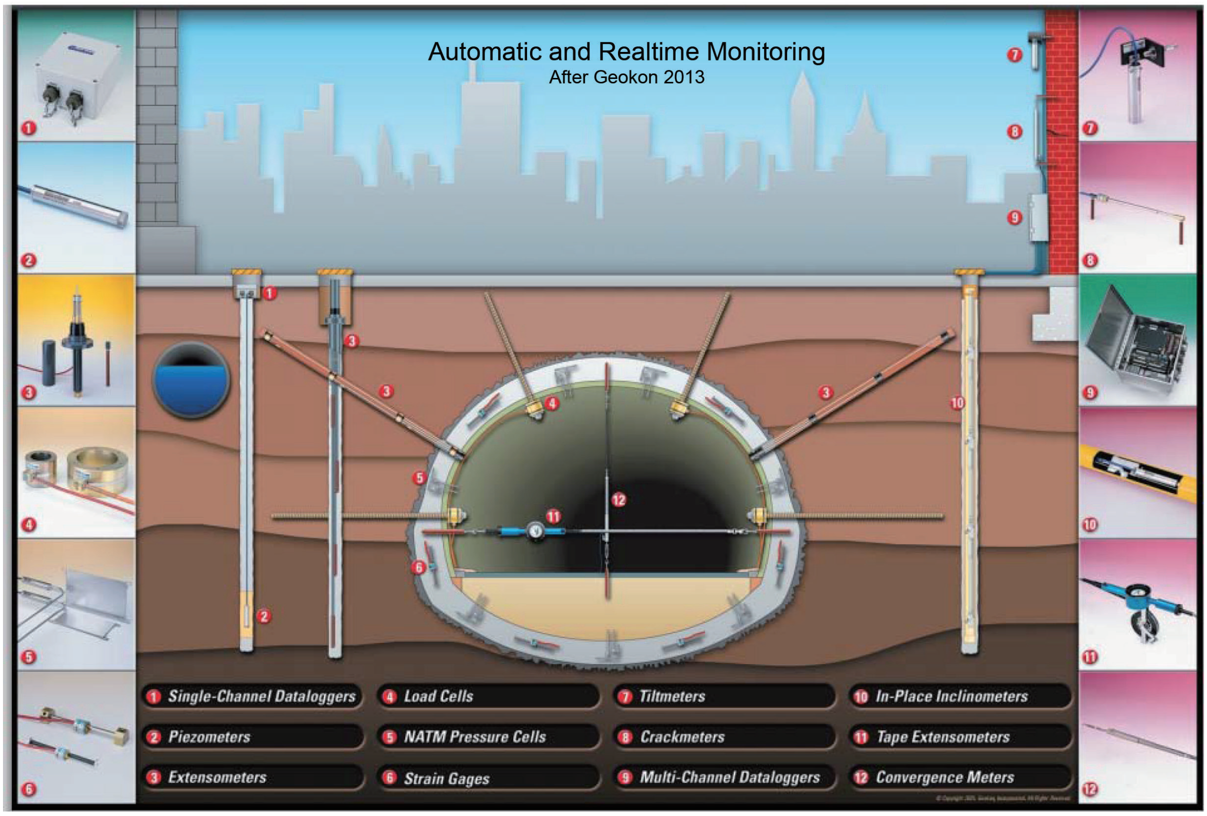
Dunnicliff, J. (1988, 1993). Geotechnical Instrumentation for Measuring Field Performance, New York, J. Wiley.

Mair, R.J., Taylor, R.N. and Burland, J.B. (1996). Prediction of Ground Movements and Assessment of Risk of Building Damage. Geotechnical Aspects of Underground Construction in Soft Ground, pp. 712-718, Balkema, Rotterdam.

Geotechnical Engineering Office (2005). Hong Kong Technical Guidance Note 25, Geotechnical Risk Management of Tunneling Works.



Manual Monitoring
1 Optical levelling
2 Dip meter
3 Magnetic Extensometer
4 Rod Extensometer
5 Tilt meter and Tilt Plate
6 Anchor Load Test
7 Penetrometer test
8 Grid Crack Meter
9 Demac Guage
10 Flow meter (V-notch)
11 Tape Extensometer
12 Schmidt hammer



Automatic and Realtime Monitoring
After Geokon 2013
1 Single-Channel Dataloggers
2 Piezometers
3 Extensometers
4 Load Cells
5 NATM Pressure Cells
6 Strain Gages
7 Tiltmeters
8 Crackmeters
9 Multi-Channel Dataloggers
10 In-Place Inclinometers
11 Tape Extensometers
12 Convergence Meters