New instruments improve site characterization with time based measurements

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ABSTRACT: Construction projects are becoming more challenging and require as much instrumentation information as possible. Two new types of instruments have been developed by Solexperts to satisfy these needs. Both instruments have been field proven. The MagX extensometer is based on the magnetostrictive measurement principle. The displacement of 20 positions along a 15 m curved or straight measuring line can be simultaneously measured with high precision. The instrument is configured as a manual or automatic device. The Reverse Head Extensometer (RHX) continuously monitors the propagation of deformation during excavation providing important continuous time-relative information about excavation activities to control the excavation process, optimize design and site activities. It consists of up to 20 extensometer modules. The data logging head is located at the deepest point of the borehole instead of at the surface. This reverse configuration allows collection of continuous time-relative data as its modules are successively destroyed by the excavation.

1 INTRODUCTION

Geotechnical and tunneling projects all around the world are becoming more and more challenging. Often projects are situated in sensitive areas (e.g. cities, historical buildings or near structures such as dams or power plants) where any kind of unexpected behavior must be detected at an early stage to prevent significant damage. These projects put higher demands on surveillance and monitoring technology. The “observational method” allows optimization in the construction process for safety, time and economy by providing more accurate and dense measurement data so that the construction method can be adjusted to meet the actual site needs.

The MagX and Modular Reverse Head Extensometer are two newly developed instruments from Solexperts. These instruments make high precision time-relative displacement measurements providing more information about a site’s actual conditions. These instruments offer a number of advantages over more traditions system such as sliding micrometers or rock anchors. They are proving to be valuable tools for today’s challenging projects.

2 THE MAGX EXTENSOMETER

The MagX (Magnet eXtensometer) can precisely measure the position of up to 20 magnets along the axis of a borehole. Axial displacements along the borehole can be calculated by comparing later measurements to initial measurements. The borehole has a minimum diameter of about 50 mm and a maximum length of 15 m. Both, periodic manual and long-term continuous monitoring are possible.

The advantages of the MagX are the speed of the measurements, its ease of use, high precision and repeatability, use in small borehole diameter and the flexibility of the probe.

2.1 Measurement principal

The MagX probe has a 15 m long flexible wave guide sensor that contains ferromagnetic material (i.e. the material is a collection of tiny permanent magnets).

The ferromagnetic material experiences a magnetostrictive effect (i.e. it changes size) when a magnetic field is applied because the tiny magnets change orientation. When the material is not magnetized, the tiny magnets are randomly arranged.
When the material is magnetized, the tiny magnets are oriented with their axes approximately parallel to one another.

Ring shaped position magnets are fixed to a guide tube that is installed along the axis of the borehole. The MagX is inserted into the borehole through the guide tube. The probe's wave guide slips through the guide tube and the centre of the position ring magnets (Figures 3 & 4). The position magnets apply an axial magnetic field on the ferromagnetic material in the wave guide.

A short electrical current pulse (a current wave) is sent down the wave guide producing a magnetic field in the wave guide. The interaction of the position sensor's axial magnetic field with the magnetic field produced by the current wave traveling down the wave guide causes a twisting at the location of the position sensor.

As the current wave travels down the wave guide past the position sensor it causes mechanical twisting (strain) that results in an ultrasonic wave. The location of the position sensor is determined by the time between when the current pulse is sent and when the ultrasonic wave is detected.

This technology yields very high accuracy measurements. There is no need for recalibration of the MagX probe during its working life.

2.2 Borehole setup

Up to 20 ring shaped position magnets are placed around a plastic or stainless steel guide tube (minimum distance between magnets is 100 mm). The guide tube and the position magnets are either grouted into the borehole or fixed in place with a spring anchor system.

The grouted position tube yields very accurate measurements and has a minimum borehole diameter of 36 mm.

The spring anchors allow fast grout free installation in boreholes with a minimum diameter of 35 mm. There are two types of spring anchors: a single spring anchor for upward installation and a double spring version for all directions. The single spring anchor version may be used to install measurement boreholes to monitor roof bolts in mines. The double spring anchor is installed by a special tool and is designed for higher accuracy/repeatability in larger diameter borehole (52 mm).

Because the probe is flexible the guide tube can also be installed on curved surfaces. The surface installation can be used for many kinds of engineering structures (e.g. historical buildings, bridges, dams and tunnel lining).

2.3 Measurement setup

The MagX can be configured as a portable instrument for periodic manual readings or as a semi-permanently installed instrument for continuous long-term monitoring.

The portable MagX consists of the probe itself and a readout unit with the PDA, power supply and data converter. The probe is inserted into the borehole and the location of the position magnets are measured and stored together with the borehole information, time and date. Back in the office, the data are downloaded from the readout unit to a pc for the analysis.

The portable MagX is an easy to use, lightweight probe that can quickly measure axial displacements in a borehole. The information for each borehole is entered only once into the PDA; later it's chosen from a drop down list. The time to measure a borehole is less than a minute. The portable MagX can be used in mining (for roof
bolting and strata control), in tunneling (for radial deformation measurements) and for other engineering tasks which require periodic, high precision displacement measurement.

The MagX can be semi-permanently installed for continuous measurements. The MagX probe may be connected to an automatic data acquisition system (e.g. Solexper’s GeoMonitor) for simultaneous measurement of all position magnets. Axis displacements are calculated by comparing current measurements to initial measurements.

When monitoring is no longer required, the MagX probe can be removed for use at another site. Only the guide tube and position magnets remain in the borehole.

2.4 Example data

There are several different ways to display the measurements from the Portable MagX probe. Figure 5 shows a plot of the differential displacement between the zero reading and a later reading versus the initial position of the measurement points. Regions of significant movement (critical zones) can easily be identified on this type of plot. Figure 6 shows a plot of measurements versus time for six of the 20 measurement positions. This plot shows how displacements develop over time. Another common plot type is the integrated plot which shows the total displacement along the borehole relative to a fix point. Generally the deepest point of the borehole is chosen as fix point.

3 THE REVERSE HEAD EXTENSOMETER (RHX)

3.1 Introduction

Today more than ever, tunnels are driven at considerable depths through weaker and more complex rock formations. To work efficiently and safely under these conditions, tunnel driving is often successfully managed using a type of “observation method”. This requires the excavation of the tunnel be continuously monitored and the tunnel support system adjusted as needed. Elements that may be adjusted based on this process include: rock bolting, distance between steel ribs, thickness of the primary shotcrete lining, length of attack, etc.

Monitoring of the “extrusion”, i.e. the axial displacement ahead of the face is a very important quantity for understanding the rock behavior. Classical instrumentation for this measurement includes the Sliding Deformeter for monitoring in soft ground and the Sliding Micrometer (Kovári et al., 1979) for monitoring in rock. These instruments require measurement casings be installed in boreholes drilled in front of the tunnel face. Measurements are manually taken by sliding a probe along the measurement casing to obtain readings at successive measurement points. Measurements may only be made when excavation is not being performed.

Sliding micrometer measurements were planned for the Gotthard Base tunnel in Switzerland but high overburden pressure (2700 m) and high water pressures (100 bar) severely damaged the measurement casings after only a short period of time.

The Reverse Head Extensometer (RHX) was developed to resist these harsh conditions and provide automatically continuous measurements ahead of the tunnel face. Additionally, unlike the Sliding Micrometer, the RHX makes automatic autonomous measurements even while excavation work in the tunnel is being performed. The continuous measurements provide valuable information about the site conditions that can not be obtained using other measurement systems.
3.2 Design of the RHX

The RH-Extensometer (RHX) was developed to make automatic continuous measurements ahead of the tunnel face. The measurement rods and logging head are cemented into a borehole drilled into the face of the tunnel. The head of the RHX, containing the logger, is installed first and is furthest away from the tunnel face. Measurements are made even as the measuring rods are being successively destroyed during advancing excavation because the logging head is the furthest from the tunnel face and the last to be destroyed. Currently RHX are between 40 and 80 m in length and monitor up to 16 measuring points.

The RHX is made up of 2 components. The first component contains the measuring rods. The rods are placed in a row and built telescopically. Each measuring rod is connected to an anchor. A central tube connects the rods together. The data communications cable, which is also used for data readout, is located in the central tube.

The anchoring points as well as the length and pitch of the telescoped central tube are customized during manufacturing to the needs at the site.

The second RHX component is the logger head. The head contains the processor, data storage, A/D converter and power supply. The logger records the relative distance between the rods at a preset rate. The data are downloaded from the logger memory by a readout device that is connected to the data communications cable in the central tube.

3.3 Installation procedure

The RH-Extensometer is manufactured to the customer’s specifications and delivered and stored in modules at the construction site. The system is assembled in front of the borehole and the logger (data acquisition unit) is started. The RHX is then inserted in the borehole and the annulus between the RHX and the borehole is grouted. After the grout has set, the displacement transducers measurements are zeroed and the initial measurement is done. Later measurements are made at a predefined, user specified recording rate by the logger in the instruments head.

The borehole for the RHX needs to have a diameter of 64 mm. The borehole may be used for geological exploration prior to installation of the system.

Generally, two RHX are installed in the tunnels face at the same time. One RHX measures the closer region of the face and the other measures the region further from the face. The second RHX has a long central pipe so that the first anchor of the second RHX is at the same position as the last anchor of the first RHX (see Figure 8). This overlapping setup allows relative movements of the first RHX head to be detected resulting in a continuous measuring line along the tunnel axis (shown in Figure 8).

It is possible to initially install only the RHX that is closer to the tunnel face. The second RHX is installed later after the tunnel has advanced to within 2 or 3 tunnel diameters of the head of the first RHX (assuring that the head of the first RHX is not affected by the radius of influence of the excavation). This procedure can significantly reduce the amount of drilling and may prove to be cost effective.

3.4 RHX and sliding micrometer measurements

RHX measurements differ in several ways from classic “line-wise” Sliding Micrometer measurements. The RHX provides important continuous time-relative information about the excavation activities that can be used to control the excavation process and optimize design and site activities.

To make sliding micrometer measurements the casing is first installed in a borehole drilled into the front of the tunnel face. The distance between the measurement marks in the casing is one meter, resulting in a dense measurement grid. One measurement point is lost with each meter of excavation.

Figure 9 shows typical measurements of a sliding micrometer in a tunnel face (Rossi, 1995). The diagram shows the relationship between excavation process and extrusion of the face. Every measurement series is a snapshot of the actual conditions because measurements are only possible when excavation is stopped.
In this example sliding micrometer measurements were manually made after each 1-meter excavation step. A person at the tunnel face makes the meter-by-meter measurements requiring approximately 1 hour for a 30 m measurement series. During this time the tunnel face is blocked for most other working activities.

Measurements and a basic layout of a single RHX are shown in Figure 10. The distance between two measuring anchors is 3 meter, resulting in a lower resolution of points per meter in the direction of the tunnel compared to the sliding micrometer measurements. Unlike the sliding micrometer measurement series, which are made only once per excavation step, the RHX measurements are uninterrupted. The nonstop recordings (for example 1 measurement per hour) yields important information not available from the manually measured sliding micrometer.

The RHX information shows the complete reaction to the excavation activities, not just a snapshot of a excavation's state. The data show that the deformation speeds up immediately after an excavation and then slows down after a certain time. Boring of anchors also causes an increase of deformation speed, because of the drilling process. Later when the anchors are set, the deformation completely stops. With this time-relative information, the length and number of anchors as well as the face treatment can be optimized.

The geological characteristics and mechanical behaviour of the rock in front of the face can be predicted if overlapping RHX are installed. Additionally, the disturbed zones can be recognized early enough to allow appropriate countermeasures to be applied. To monitor the behaviour and condition of the face during longer down times (Christmas holidays for example), the RH-Extensometer can be connected to a long-term monitoring system.

Figure 11 shows measurements from 4 overlapping RHX in a deep base tunnel in Switzerland. The relationship between advancement and extrusion of the face can be clearly identified. The closer the face advances to the measurement anchor the larger and faster the deformations become. Longer periods of no advancement result in a slow down of the deformation.

The effect of a new series of anchor bolts is shown in Figure 12. At point 1 the extrusion of the face is speeds up (slope is increasing) because the end of the last anchoring layer is reached, and the time between excavation steps is very short (see the solid line in Figure 12). At point 2, new rock bolts are installed, the extrusion of the face slows down and the section close to the face becomes consolidated because it is tied back by the shotcrete and the bolts.
3.5 Conclusions

The Reverse Head Extensometer (RHX) is a new tool that offers many advantages over the classical instrumentation. RHX can be easily employed in tunnelling projects with difficult geological lithologies and harsh conditions. RHX offer continuous monitoring of the tunnel face and is a valuable tool and another step toward obtaining a completely controlled excavation process.

REFERENCES


