

Displacement measurements ahead of a tunnel face using the RH Extensometer

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ABSTRACT:

The RH-Extensometer (*Reverse Head Extensometer*) was developed to carry out continuous displacement measurements ahead of the tunnel face. Readings are made despite successively removing parts of the measuring rods in the course of the excavation procedure. This is possible because the head of the extensometer, containing the sensors and a data logger, is placed at the base of the borehole (i.e. it is the furthest away from the tunnel face and the last element to be reached). The recorded measurement data are transferred to the operator at the face of the tunnel by radio transmission. RH-Extensometer monitoring has a great advantage over commonly used Sliding Micrometer measurements because the monitoring does not interfere with the excavation procedure and provides continuous measurements. Practical experience using this new device in highly squeezing rock comes from the 57 km long Gotthard Base Tunnel in Switzerland, where convergence from 0.5 up to 0.7m regularly occurs in a controlled manner during excavation of the 13m diameter twin tunnel.

INTRODUCTION:

Nowadays tunnels frequently have to be driven at considerable depths and through weaker and more complex rock formations than ever before. To work efficiently and safely under these conditions, tunnel driving is often successfully managed using a sort of “observation method”. This requires the excavation of the tunnel to be continuously monitored and the tunnel support system possibly adjusted (Lunardi P. 1998). The elements that may be modified 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 behaviour. Classical instrumentation includes the *Sliding Deformeter* for monitoring in soft ground and the *Sliding Micrometer* (Kovári, at al. 1979) for monitoring in rock. These instruments require installing measurement casings in boreholes in front of the tunnel face. Readings have to be taken manually by sliding the probe along the borehole to carrying readings at successive measurement points.

Sliding micrometer measurements were planned for the Gotthard Base tunnel in Switzerland but high overburden pressure (2700m) and high water pressures (100bar) severely damaged the measurement casings after a short period of time. The Reverse Head (RH)-Extensometer was developed to resist these harsh conditions and automatically provide continuous measurements ahead of the tunnel face. Additionally, unlike the *Sliding Micrometer*, it allows readings to be taken without affecting the work in the tunnel.

DESIGN OF THE RH-EXTENSOMETER

The RH-Extensometer was developed to make automatic continuous measurements ahead of the tunnel face. The rods and measurement head are cemented into a borehole drilled into the face of the tunnel. Measurements are made even as the measuring rods are being successively destroyed during advancing excavation because the head of the extensometer, containing the sensors and a data unit, is placed at the base of the borehole (i.e. it is the furthest away from the tunnel face and the last to be destroyed). Currently RH-Extensometers are between 30 and 40m in length and monitor 6 measuring anchors.

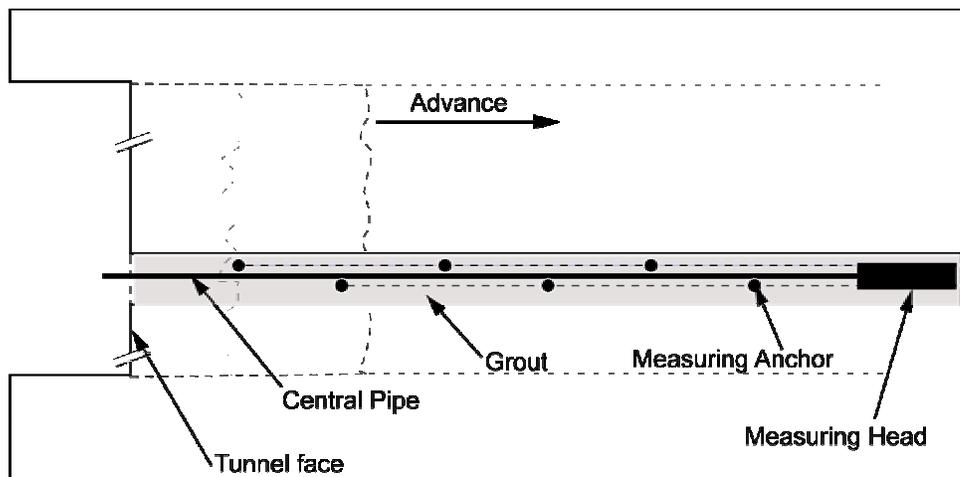


Figure 1 Scheme of a RH Extensometer

The measuring head (Figure 1 and 2) consists of two parts: 1) a measurement unit with six displacement transducers, a temperature and optionally a pore water pressure sensor and 2) a data unit which monitors, stores and transmits the data. The range of the displacement transducers is 500mm with an accuracy of ± 0.1 mm.

The data unit consists of a data logger, a radio transmission module with external antenna and a battery. The battery powers the system for three to four months depending on the surrounding temperature and data acquisition rate. The data logger can record at a rate between 1 measurement per second and 1 measurement per day. The sampling rate can be modified when communications with the instrument are

established and the stored data are downloaded. The data logger can store up to 16000 samples reducing the number of times the data must be downloaded. For example, with a recording rate of 1 measurement per channel per hour the logger will record data for over 80 days before downloading is required.

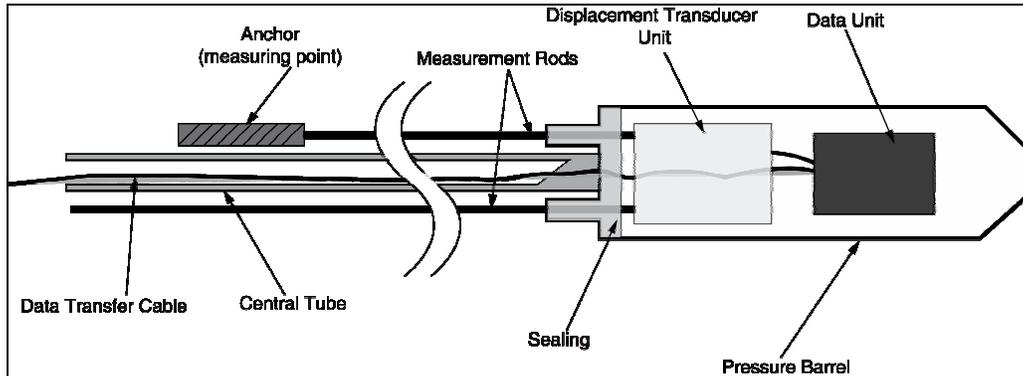


Figure 2 Schematic of the RH-Extensometer head

The data communication can be established by two independent systems. Within the central pipe is a small cable containing communication wires and an antenna. This cable is connected to the measurement head and lies free within the central pipe. This minimises the chance of cable breakage during the excavation process. In radio mode, the cable functions as an antenna. After several excavation steps the central pipe is found and exposed. The readout device, which contains a radio receiver, is placed next to the antenna and the data are transferred.

As a redundant system, the readout unit can be connected to the cable and the data downloaded directly.



Figure 3 Detail view of the RH-Extensometer head

In the Gotthart base tunnel, Switzerland, (contract section Sedrun) the data are read out every 2 to 4 days if the central tube is accessible. The complete data transfer process is very quick and usually requires a stay of less than 10 minutes at the tunnel face.

INSTALLATION PROCEDURE

The six anchoring points as well as the length and the pitch of the telescoped central tube are customized during manufacturing. The RH-Extensometer is delivered and stored coiled at the construction site.

The borehole for the RH-Extensometer needs to have a diameter of 101mm, which can also be used for geological exploration prior to installation of the system. The system is uncoiled and prepared in front of the borehole. The data acquisition unit is then started. The RH-Extensometer is inserted in the borehole and the annulus is grouted. After the grout has set, the displacement transducers measurements are zeroed and the initial measurement is done. Later measurements are then performed at the user specified recording rate.

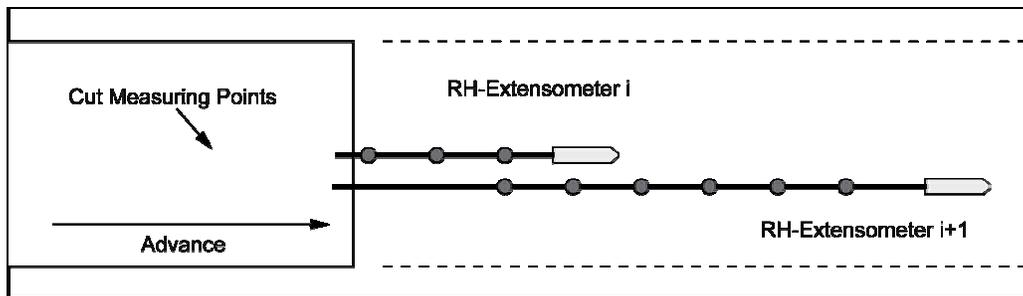


Figure 4 Overlapping installation of RH-Extensometers for continuous measurements

The length of the complete system is tailored to the needs at a given site. Generally the longest anchor is less than 40 m. The position and separation of each measuring anchor can be defined. RH-Extensometers are installed in an overlapping fashion to provide continuous measurements (shown in Figure 4).

There are two options for the overlapping installations. Within the first option two systems can be installed at the same time: one measuring the closer region of the face and the other measuring the region further from the face. The second system is installed with a long central pipe so that the first anchor point of the second system is at the same position as the last anchor of the first system (see Figure 4).

Within the second option, the second borehole is drilled after the face has been advanced close to the end of the first RH-Extensometer. Therefore the total length of drilling is less. In the Sedrun project, the drilling of the two boreholes at the same time (option one) has been found to be money saving compared to option two. The development of a new RH-Extensometer system which allows the emplacement of several systems aligned in one borehole is in progress.

MEASUREMENTS AND CONCLUSIONS

RH-Extensometer measurements differ in several ways from classic “line-wise” *Sliding Micrometer* measurements. Figure 5 shows a typical application of this device in a tunnel face (Rossi, 1995). The sliding micrometer casing is installed in a borehole drilled into the front of the tunnel face.

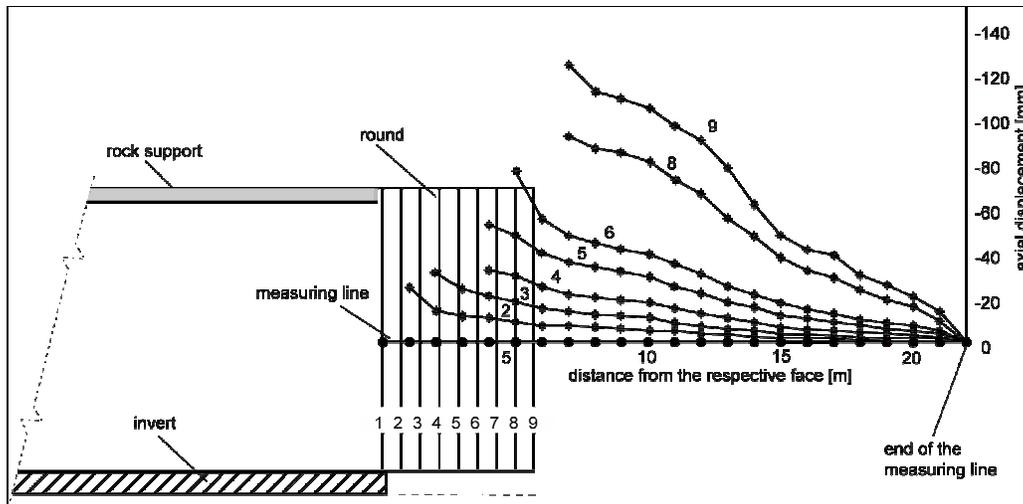


Figure 5 Sliding Micrometer measurements: The variation of the measured axial displacement as a function of the distances from the working face

The distance between the measurement marks in the casing is one meter, resulting in a very dense measurement grid. With each meter of excavation one measurement point is lost. Every measurement series is a snapshot of the actual conditions. The diagram above shows the relationship between excavation process and extrusion of the face. In this example a manual sliding micrometer measurement series is done after each 1-meter excavation step. Each excavation step and the related measurement series is marked with the same number. The measurements are taken by inserting a sliding micrometer probe along the casing. This requires the presence of a person at the tunnel face for some time (approx. 1h for a 30m measurement series). During this time the tunnel face is blocked for most other working activities.

In Figure 6 measurements and a basic plot of a single RH-Extensometer is shown. The distance between two measuring anchors is 3 meter resulting in a lower resolution of points in the direction of the tunnel compared to the sliding micrometer measurements. While the sliding micrometer measurement series are made only once per excavation step, the RH-Extensometer measurements are continuous. The high time resolution (for example 1 measurement per hour) provides much more information even though there are fewer measurement points. The RH-Extensometer information is not only a snapshot of a current state but shows the complete reaction of the mountain to any activity. For example, 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.

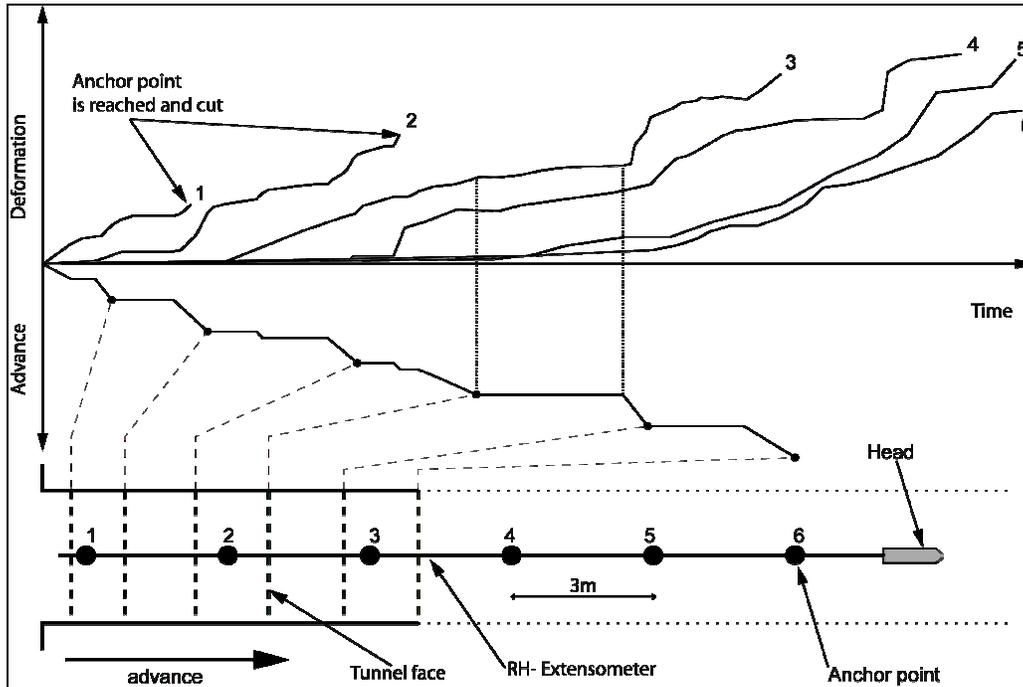


Figure 6 RH-Extensometer Measurement

The geological characteristics and mechanical behaviour of the rock in front of the face can be predicted if a number of overlapping RH-Extensometers are installed. Additionally, disturbed zones can be recognized early enough to allow the 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 7 shows measurements from 4 overlapping RH-Extensometers 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.

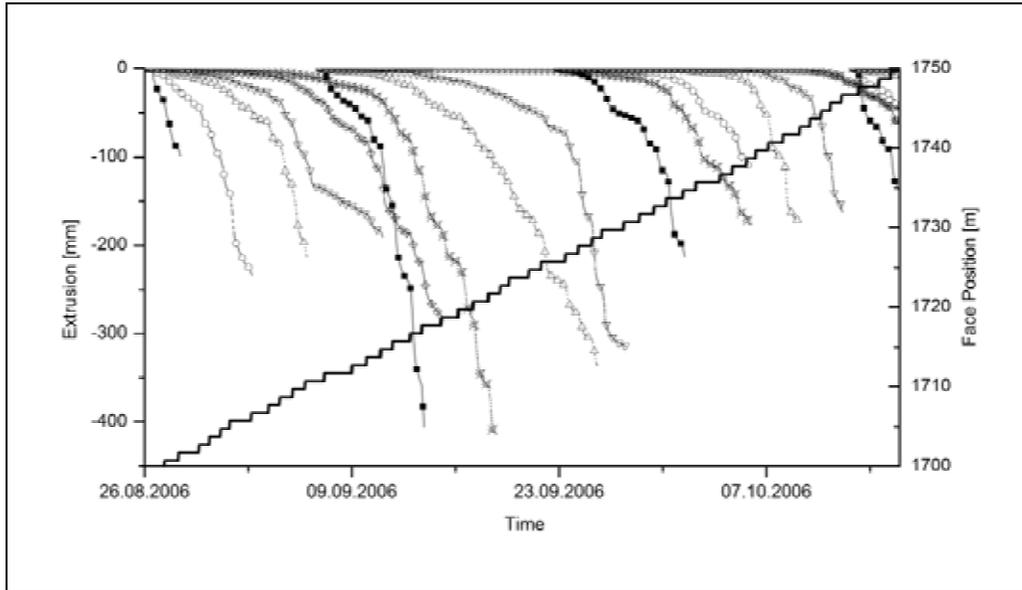


Figure 7 Measurements of overlapping installed RH-Extensometer (RH1699 –RH1747), Sedrun

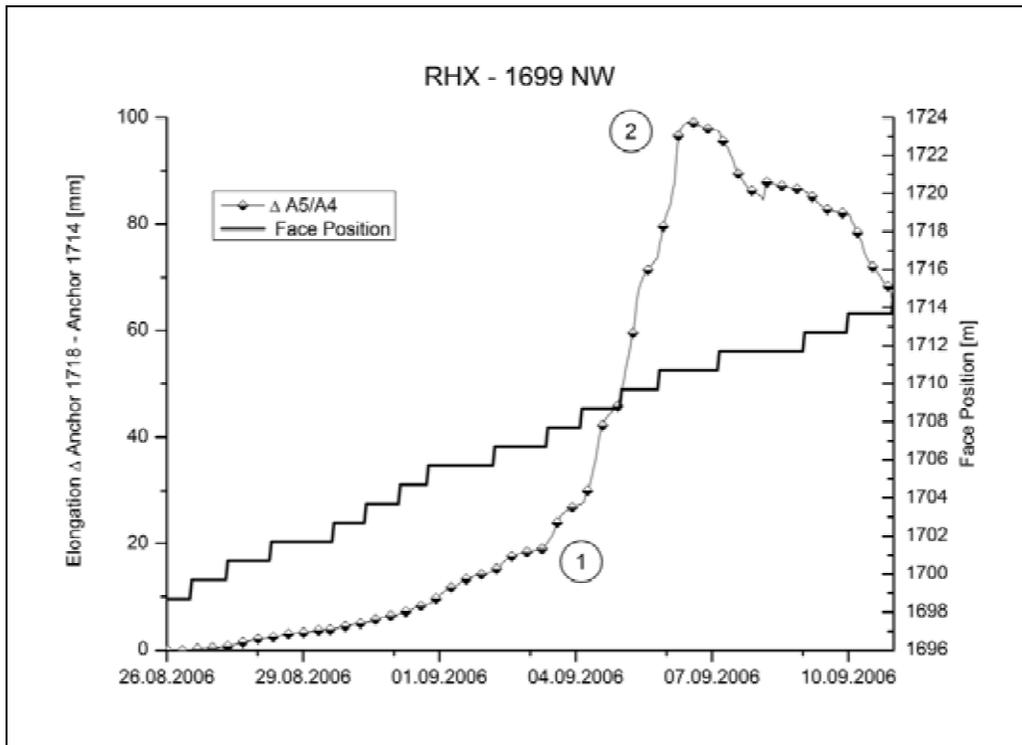


Figure 8 Detail plot: Elongation of two anchoring points of RHX-1699-NW

The effect of a new series of anchor bolts is shown in Figure 8. At point 1 the extrusion of the face is speeding up as the time between two excavation steps is very short (see the solid line in Figure 8) and end of the last anchoring layer is reached. 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.

The Reverse Head Extensometer is a new tool that offers advantages and can be easily employed in tunnelling projects with difficult geological lithologies and harsh conditions. The RH-Extensometer offer continuous monitoring of the tunnel face and is a valuable tool and another step toward obtaining a completely controlled excavation process. The next generation of a RH-Extensometer with wireless sub terrain data transmission and modular structure is on the way.

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