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Äspö Hard Rock Laboratory

Prototype Repository

Instrumentation of the outer plug to monitor strains and deformations

Nancy Bono
Kennert Röshoff

BBK AB

November 2003

Svensk Kärnbränslehantering AB
Swedish Nuclear Fuel
and Waste Management Co
Box 5864
SE-102 40 Stockholm Sweden
Tel +46 8 459 84 00
Fax +46 8 661 57 19

Äspö Hard Rock
Laboratory

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Nancy Bono Kennert Röshoff	2003-11-05
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Abstract

SKB is constructing a full-scale replica at Äspö HRL of the deep repository planned for disposal of spent nuclear fuel in Sweden. The Äspö HRL is now in an operating phase where different aspects required for a deep repository will be studied. The 'Prototype Repository' is one of many research areas situated within the 3600 m long tunnel which descends to a depth of about 460 m.

The Prototype Repository is a test area consisting of a TBM-bored tunnel located at a depth of about 450m below ground surface. It includes six vertical deposition boreholes which have a diameter of 1.75 m and a depth of 8m. Each of these boreholes contain electrically heated canisters that will simulate the heat generated by radioactive waste.

The bored tunnel has now been backfilled with bentonite, and a concrete plug has been constructed to seal off the test area. The primary function of the plug is to isolate the test area from the tunnel system by acting as a mechanical restraint against the backfill material, as well as to permit adequately high groundwater pressures to build up behind the plug. The pressure gradients within the test area should be kept to a minimum so that the deposition hole nearest to the plug will have essentially the same pressures as the other deposition holes. For this reason, there is a requirement that the 'tightness' of the plug be extremely high.

It is planned that contact grouting at the concrete-rock interface will be carried out within the next six months to one year. This contact grouting is intended to improve the contact between rock and concrete, and block the potential seepage paths,. To increase the effectiveness of the contact grouting it is planned to chill the plug prior to the grouting operations. This will facilitate the grouting by maximising the opening between the rock and concrete, and thereby allowing the grout to more fully penetrate into any void spaces. Following the grouting, the chilling system will be turned off, and the plug will expand to be in tight contact with the rock.

In order to monitor the width of the opening between the plug and to rock, joint meters have been installed at the interface during construction of the plug. Strain gages have been installed adjacent to each joint meter so that compression of the concrete itself can be determined separately from the crack width.

In addition to the instrumentation installed around the perimeter of the plug, sensors have also been installed with the interior portions of the plug. These sensors, which are built into lengths of reinforcement steel, were installed to allow comparison of actual and calculated stresses in the structure which will result from the build up of pressures on the back side of the plug.

The objective of this report is to document the selection of the instruments and the details of the instruments as they were installed.

Sammanfattning

SKB skall utföra ett fullskaleförsök på Äspö HRL för simulering av ett slutförvar av högaktivt kärnbränsleavfall i kristallint berg i Sverige. Äspö HRL är inne i en operativ fas där kraven med olika aspekter för ett slutförvar kommer att undersökas och analyseras. Prototypförvaret är ett av flera forskningsutrymmen belägna i den 3 600 m långa tunneln ner till ca 460 meters djup.

Prototypförvaret är ett testområde placerat i en TBM-borrad tunnel belägen på ett djup av 450 m och inkluderar sex vertikala deponeringshål. Hålen är 1.75m i diameter och 8 m djupa. Ett mål med forskningen på denna plats är att undersöka och analysera den bergmekaniska responsen vid uppvärmning av bergmassan. Elektriskt uppvärmda kapslar, som därvid skall simulerar värmen generad från kärnbränsleavfallet, är placerade i deponeringshålen.

Pluggen har byggts, och återfyllning i tunneln har blivit färdig. Pluggens huvudsakliga uppgift är att isolera prototypförsöket med utanförliggande tunnel system genom att fungera som ett mekaniskt stöd mot ”backfill”, men framförallt möjliggöra att ett för försöket tillräckligt högt grundvattentryck kan byggas upp. Tryckgradienten inom försöksområdet skall vara mycket liten, dvs. kapseln närmast pluggen skall i princip ha samma möjlighet att bygga upp ett givet tryck som övriga kapslar. Detta medför att pluggens täthetskrav är mycket högt.

För att blockera läckvägar i kontakten mellan betong och berg utförs normal kontaktinjektering. Resultatet från en sådan kontaktinjektering kan variera av olika orsaker. Spalten kan vara för tunn för att det valda bruket skall kunna penetrera ut i spalten och fullständigt fylla hela tomrummet; spalter har inte kontakt med varandra, eller alternativt har för tunna kontaktvägar som blockerar injekteringen.

För att öka möjligheten för god penetration är föreslaget att krympa pluggen ytterligare genom kylning innan injektering utförs. Genom att på detta sätt öka spaltvidden ökas möjligheten för god penetration av injekteringsmedlet. När sedan kylningen avbryts kommer pluggen att expandera och bli inspänd.

För att kontrollera spaltvidd och verifiera beräkningar, installeras i samband med att pluggen byggs, sprickmätare över kontakten för att möjliggöra mätning av spaltöppning före injektering. Töjningsgivare har installerats i närheten av varje sprickmätare så att kompressionen av betong kan bestämmas oberoende av sprickvidden.

I samband med dimensionering av pluggen har deformationer och spänningar i pluggen beräknats analytiskt och numeriskt. Hela pluggen kommer att vara mer eller mindre tryckt. Skulle dragspänningar genereras är dessa mycket små och genereras mot centrum långt fram på den konkava sidan. För att verifiera de beräknade spänningarna installeras lämpligen töjningsgivare på valda ställen på radiella armeringsstänger. En yttre och en inre grupp har installerats.

Syftet med denna rapport är att dokumentera och presentera val av instrumentering, layout, montering och installation.

Contents

1 Introduction

1.1 Äspö Hard Rock Laboratory

According to the Swedish concept for the deep disposal of spent nuclear fuel, high-level radioactive waste will be stored in a repository constructed as a tunnel system in crystalline bedrock at depths of 400m to 700m. SKB (Svensk Kärnbränslehantering AB) is constructing a full-scale replica of the tunnel repository at Äspö Hard Rock Laboratory (HRL). This laboratory is being used for research work for the final disposal of radioactive waste.

The Äspö HRL is now in an operating phase where different aspects required for a deep repository will be studied, including function, handling techniques and development and testing of equipment. The different aspects will be tested, studied and developed in a number of tests.

1.2 Prototype Repository

1.2.1 General Objectives

The Prototype Repository is one of the tests being conducted within the tunnel system at the Äspö HRL. It will provide a full-scale reference for testing of the design and construction principles, as well as testing of the predictive modelling. The Prototype Repository contains six vertical deposition holes with electrically heated, full-size 'canisters' that will simulate the heat generated by radioactive waste.

The objective of the test is to demonstrate the integrated function of the repository components and a comparison of the results with models and assumptions. It includes testing of the concrete plug, which will isolate the repository area from the tunnel system, with respect to both construction methods and performance.

1.2.2 Instrumentation of the outer plug

The primary function of the outer plug is to isolate the test area from the tunnel system by acting as a mechanical restraint against the backfill material. In addition it must permit adequately high groundwater pressures to build up behind the plug. The pressure gradients within the test area should be kept to a minimum so that the deposition hole nearest to the plug will have essentially the same pressures as the other deposition holes. For this reason, there is a requirement that the 'tightness' of the plug should be extremely high.

The potential seepage routes are primarily within the contact between the plug and the rock surface, as well as through fractures in the rock surrounding the plug. Little to no seepage is expected to occur through the plug itself.

When a concrete plug is constructed, the contact between the plug and the rock is typically good. However, certain difficulties are normal where air openings are located at the top, and the plug will experience shrinkage as a result of the hardening process.

This shrinkage effect can be reduced with appropriate concrete techniques and additives. However a certain amount of shrinkage will occur and it can not be anticipated that there will be perfect contact between concrete and rock at all points.

In order to improve the contact and to block the seepage paths, contact grouting will be conducted. To increase the effectiveness of the contact grouting it is planned to chill the plug prior to the grouting operations. This will facilitate the grouting by maximising the opening between the rock and concrete, and thereby allowing the grout to more fully penetrate into any void spaces. Following the grouting, the chilling system will be turned off, and the plug will expand to be in tight contact with the rock.

In order to monitor the width of the opening between the plug and to rock, joint meters have been installed at the interface during construction of the plug. Strain gages have also been installed adjacent to each joint meter so that compression of the concrete itself can be determined separately from the crack width.

In addition to the instrumentation installed at the perimeter of the concrete plug, sensors have also been installed with the interior portions of the plug. These sensors, which are built into lengths of reinforcement steel, were installed to allow comparison of actual and calculated stresses in the structure which will result from the build up of pressures on the back side of the plug.

1.2.3 Objectives of this report

This report presents the layout and selection of instruments, details of the completed installations, and a brief description of the data collection system.

2 Prototype Repository Layout

The Prototype Repository is located at a depth of about 450m as shown in Figure 2-1 in the tunnel system at Äspö HRL. The length of the Prototype test tunnel is 90m.

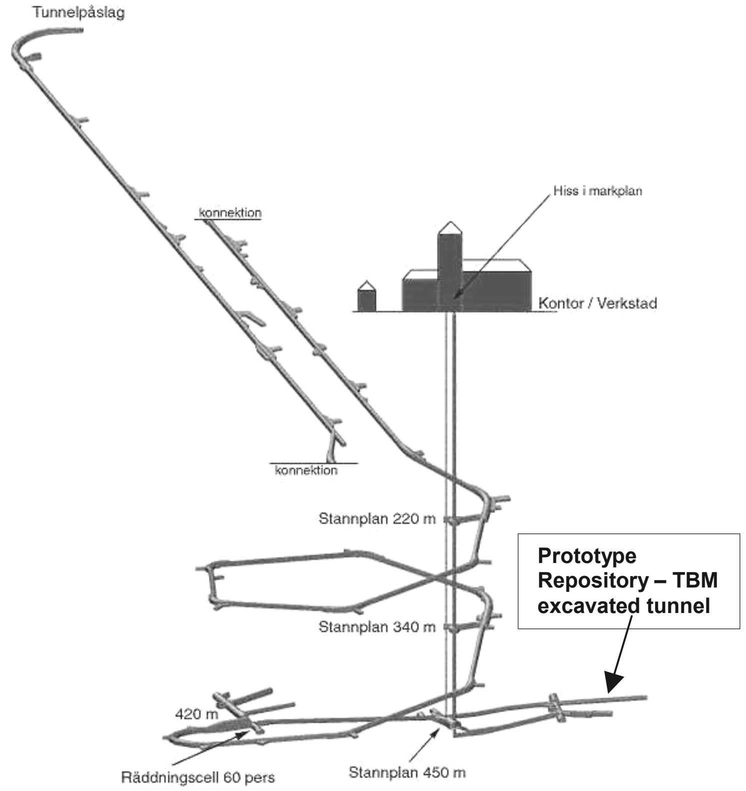


***Figure 2-1**. Location of the Prototype Repository at Äspö HRL.*

The Prototype Repository consists of two test sections (I and II) with four and two depositions holes respectively (see Figure 2-2). The outer plug has been constructed to seal off the test area from the tunnel system, and to permit groundwater pressures to build up behind the plug. The outer plug is shown schematically, together with the instrument locations in Figures 2-3 and 2-4.

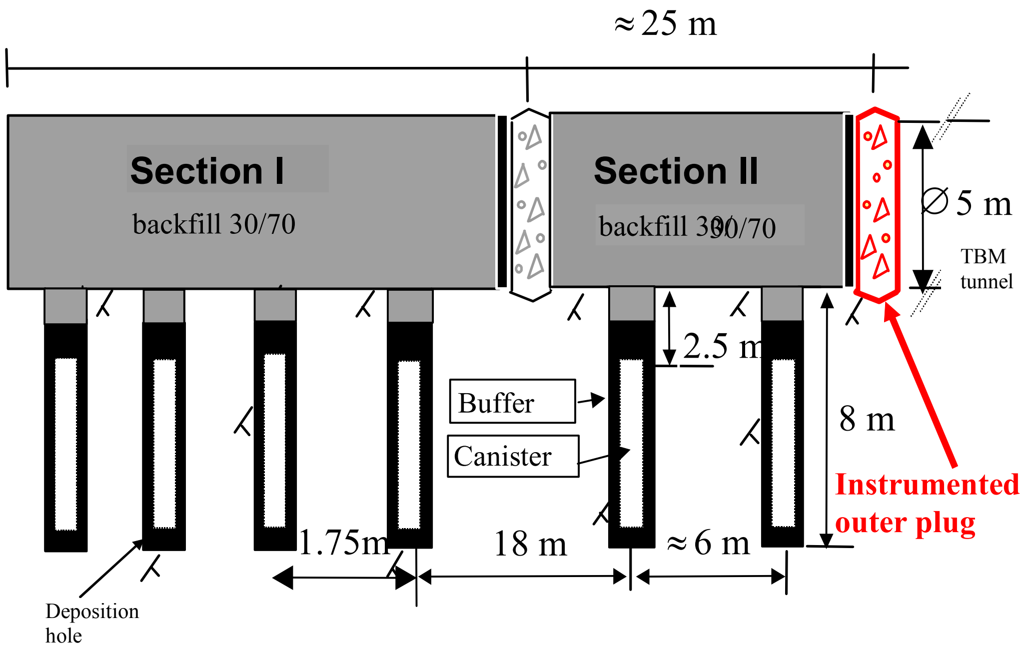
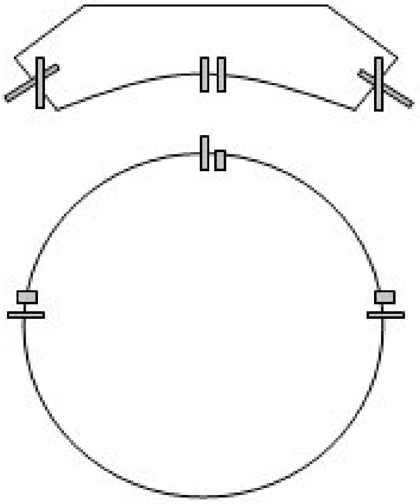


Figure 2-2. *Schematic view of the layout of the Prototype Repository and deposition holes (not to scale)*



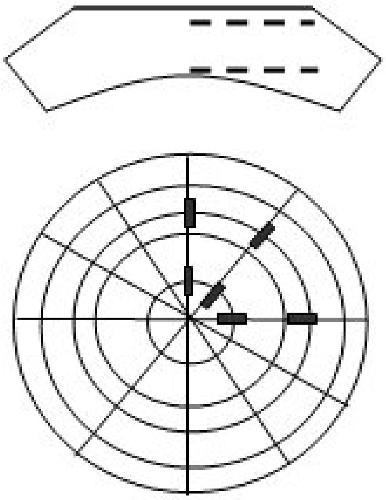


Figure 2-3. *Plan and elevation view of outer plug with joint meter locations (not to scale)*

Figure 2-4. *Plan and elevation view of outer plug with rebar gage locations (not to scale)*

3 Selection and installation of instrumentation

The instrumentation for monitoring of deformations and strains in the outer plug were selected to accommodate the anticipated range of movements and stresses, as well as the physical environment and conditions in which these sensors would be installed.

3.1 Instruments at the concrete-rock interface

3.1.1 Joint meters

The Geokon model 4400 vibrating wire embedment jointmeter was installed for monitoring deformations at the concrete-rock interface. A total of six of the transducers were installed at the locations shown in Figure 2-3 (referred to as 09:00, 12:00 and 03:00, as on a clock face). At each of these locations a pair of jointmeters was installed; one installed parallel to the tunnel axis, and the other perpendicular to the rock surface. The instrument is shown in Figure 3-1.

■ Model 4400 Embedment Jointmeter shown with socket removed.

Figure 3-1. *Geokon Model 4400 Embedment Jointmeter*

The jointmeters are designed to measure displacements across joints and cracks in concrete, rock, soil and structural members. The transducer consists of a vibrating wire in series with a tension spring, and displacements are accommodated by stretching of the tension spring, which produces an associated increase in wire tension.

The sensors were installed by first boring holes into the rock at each installation locations. These holes were 120mm deep and 80mm in diameter. The socket, seen to the right in the photo above, was then fixed into the borehole using Hilti Hit-Hy 150/330 adhesive anchor system, with the injection proceeding from the base of the borehole outward. After the adhesive compound had hardened, the instrument was screwed into the socket threads found at the far end of the socket. The gages were then adjusted to allow measurement of both elongation and compression by gently pulling the gage body away from the socket and temporarily fixing it with electrical tape which will give way under forces resulting from the concrete. Details of the instrument are shown in Figure 3-2.

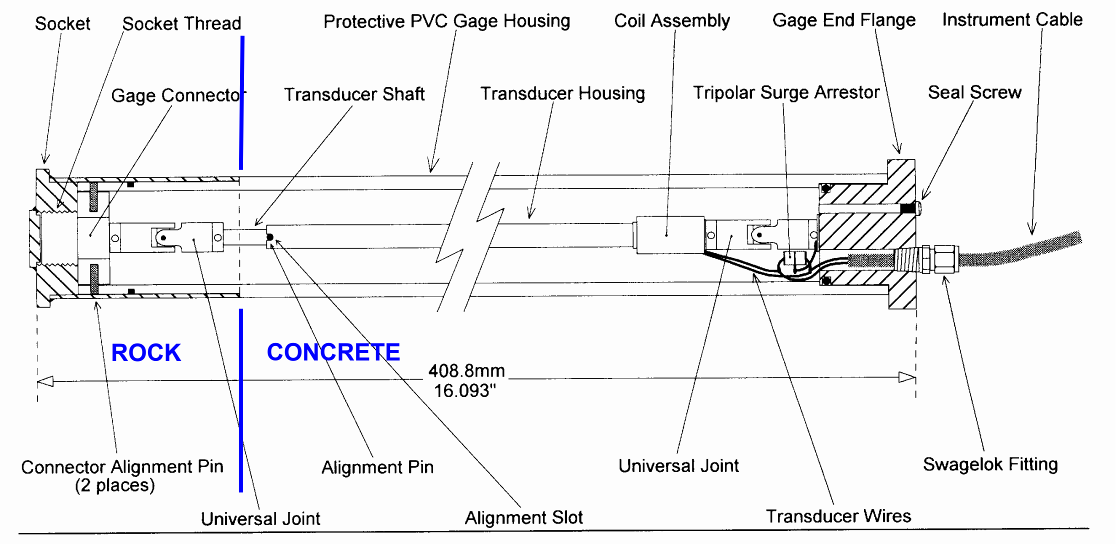


Figure 3-2. *Geokon Model 4400 Vibrating Wire Embedment Jointmeter*

A thermistor is located inside the vibrating wire transducer housing so that the temperature can be measured at the instrument location. These temperature measurements can be used in the data reduction to correct for the effects of thermal expansion of the gage itself.

These gages were further modified with an additional Swageloc fitting to permit additional protective polyamide tubing was attached to the gage. This tubing was fastened to the sensor, and a 10m length was placed over the standard instrument cable to provide additional protection to the length of cable embedded within concrete.

3.1.2 Strain gages

The Geokon model 4200 concrete embedment strain gage was installed parallel to each jointmeter. A total of six of these strain gages were installed for the purpose of measuring the strain within the concrete. By using these measurements the total deformation measured in the jointmeters could be separated into movements across the joint, and strains within the concrete mass along the length of the 400mm length of the jointmeter.

The gage is shown in Figure 3-3.

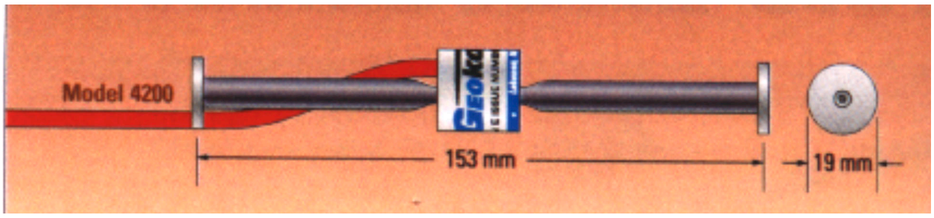


Figure 3-3. Geokon Model 4200 Concrete embedment strain gage

The model 4200 strain gage is designed for direct embedment in concrete, and has a 153mm gage length. It is commonly used for strain measurements in foundations, piles, bridges, dams, etc. Strains are measured using the vibrating wire principle where a length of steel wire is tensioned between two end blocks that are embedded directly in the concrete. Deformations of the concrete mass will cause the two end blocks to move relative to each other thus altering the tension in the steel wire. Each gage also contains a thermistor so that temperatures can be read at the gage location.

The strain gages were installed by fixing additional angled sections of reinforcing steel to the existing reinforcement details. These small diameter rebar sections were placed in such a way that the strain gages could be loosely suspended with plastic tie-wires from each end of the gage at the desired location. The gages were placed parallel to the associated joint meter, however at a distance of about 250mm so that each instrument would not influence the measurements taken at the adjacent sensor.

3.2 Strain gages within the concrete plug

In addition to the instrumentation installed at the interface between the concrete plug and rock, sensors have also been installed with the interior portions of the plug. These sensors, which are built into lengths of reinforcement steel, were installed to allow confirmation of stresses that will be induced within the structure when pressures build up on the back side of the plug.

The Geokon Model 4911A Vibrating wire rebar strain meter was used to measure strains within the concrete, and to allow comparison of calculated to measured concrete stresses as pressures build up behind the plug.

The rebar strain meter is shown in Figure 3-4.

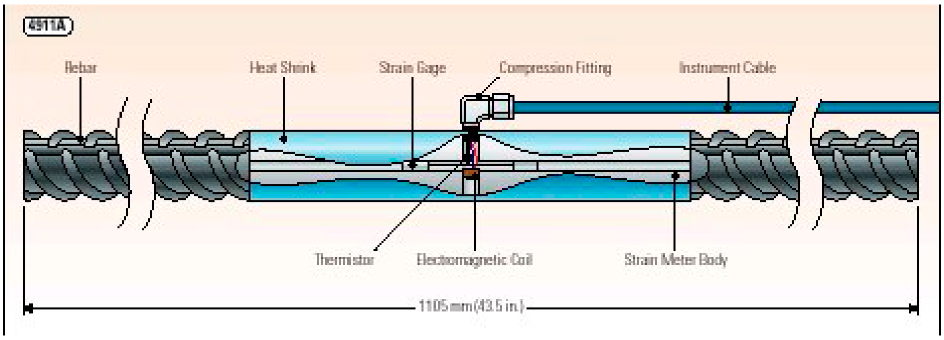


Figure 3-4. Geokon Model 4911A Rebar Strain Meter

The reinforcing steel sections on either side of the central strain gage area are long enough to provide adequate contact with the surrounding concrete so that the measured strains inside the steel are equal to the strains in the surrounding concrete. Thermistors are also built into the instruments so that an evaluation of thermally induced strains can be made. The gages installed in the plug were modified slightly from the manufacturer's standard detail in that an additional fitting was connected at the compression fitting to allow placement of a polyamide tube over the instrument cable over the length embedded within concrete to provide additional protection to the cable.

The gages installed were manufactured from sections of No.8 reinforcing steel which have a diameter of 25.4mm (1 inch) and the total length of each instrumented section of reinforcing steel is 1105mm. The gages are made of steel having f_y of 414MPa (60,000psi) and a Young's modulus of E-value of $2x10^5$MPa ($20x10^6$psi).

These lengths of instrumented reinforcing steel were placed into the plug in addition to the originally designed reinforcement steel. There were no sections of the existing steel removed and replaced, but rather there are additional reinforcing bars within the instrumented zone of the plug. The rebar strain meters were welded at each end to sections of standard 25mm diameter steel bars, as shown in Figure 3-4. A total of six length of steel were fabricated (with two gages on each of the 3.5m lengths) and installed within the plug.

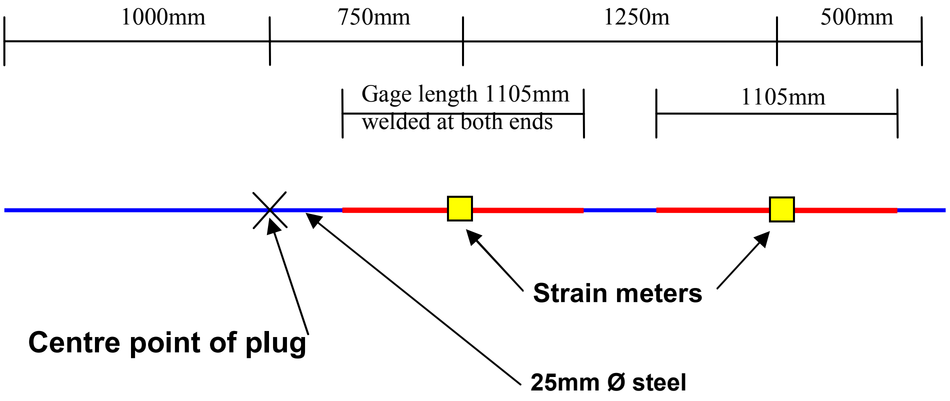


Figure 3-4. *Dimensions of the Rebar strain meters and 25mm diameters reinforcing steel*

3.3 Summary of selected instruments

The following numbers and types of instruments were selected for installation to allow monitoring of the concrete plug.

Table 3-1. Summary of plug instruments

Instrument location	Instrument type	Total number installed
Jointmeter perpendicular to concrete-rock contact	Geokon model 4400	3
Jointmeter parallel to tunnel axis	Geokon model 4400	3
Strain gage perpendicular to concrete-rock contact	Geokon model VCE-4200	3
Strain gage parallel to tunnel axis	Geokon model VCE-4200	3
Rebar strain gages in plug	Geokon model 4911A	12

4 As-built locations of instruments

4.1 Jointmeters

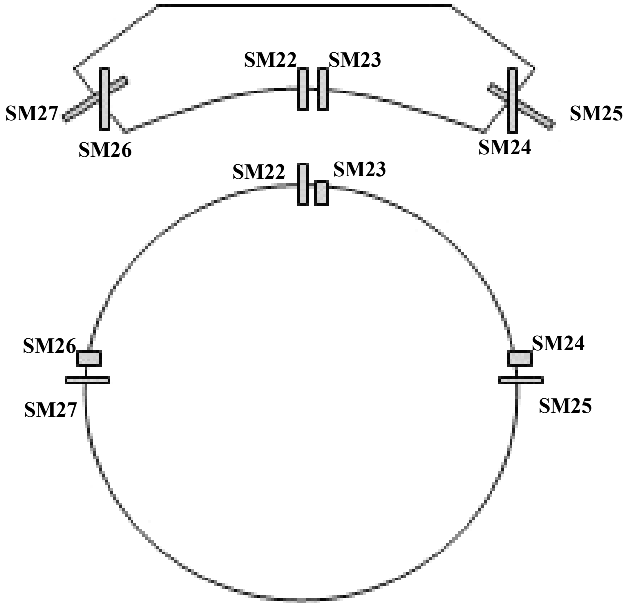


Figure 4-1. Plan and elevation view of plug with joint meter identification numbers

Table 4-1. Summary of joint meters

Serial number	SICADA ID code	Location/orientation	x	y	z
03-47726 **(SM26)**	PXPPL2001	Left side; 09:00; parallel to tunnel axis	7 265,440	1 928,665	-446,445
03-47727 **(SM27)**	PXPPL2004	Left side; 09:00; perpendicular to contact	7 265,390	1 928,564	-446,688
03-47723 **(SM23)**	PXPPL2002	Roof; 12:00; parallel to tunnel axis	7 268,272	1 929,140	-443,835
03-47722 **(SM22)**	PXPPL2005	Roof; 12:00; perpendicular to contact	7 268,174	1 929,031	-443,803
03-47724 **(SM24)**	PXPPL2003	Right side; 03:00; parallel to tunnel axis	7 271,107	1 929,478	-446,238
03-47725 **(SM25)**	PXPPL2006	Right side; 03:00; perpendicular to contact	7 271,205	1 929,409	-446,499

4.2 Embedment strain gages

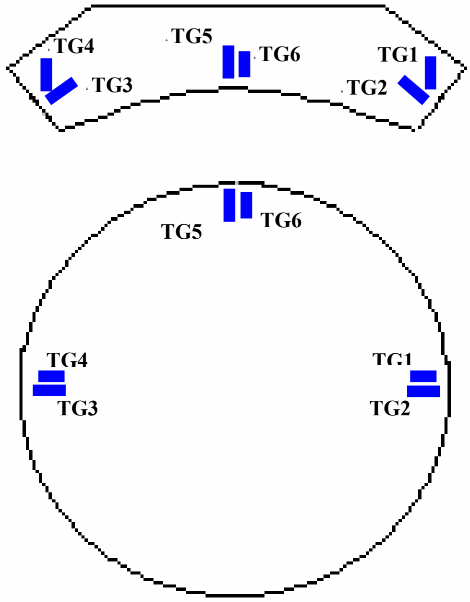


Figure 4-2. *Plan and elevation view of plug with embedment strain gage identification numbers*

Table 4-2. Summary of embedment strain gages

Cable marking	SICADA ID code	Location/orientation	x	y	z
TG 4	PXPPL2007	Left side; 09:00; parallel to tunnel axis	7 265,610	1 928,538	-446,445
TG 3	PXPPL2010	Left side; 09:00; perpendicular to contact	7 265,434	1 928,364	-446,688
TG 6	PXPPL2008	Roof; 12:00; parallel to tunnel axis	7 268,452	1 929,014	-443,863
TG 5	PXPPL2011	Roof; 12:00; perpendicular to contact	7 268,056	1 928,872	-443,875
TG 1	PXPPL2009	Right side; 03:00; parallel to tunnel axis	7 270,930	1 929,301	-446,238
TG 2	PXPPL2012	Right side; 03:00; perpendicular to contact	7 271,267	1 929,167	-446,499

4.3 Rebar strain meters

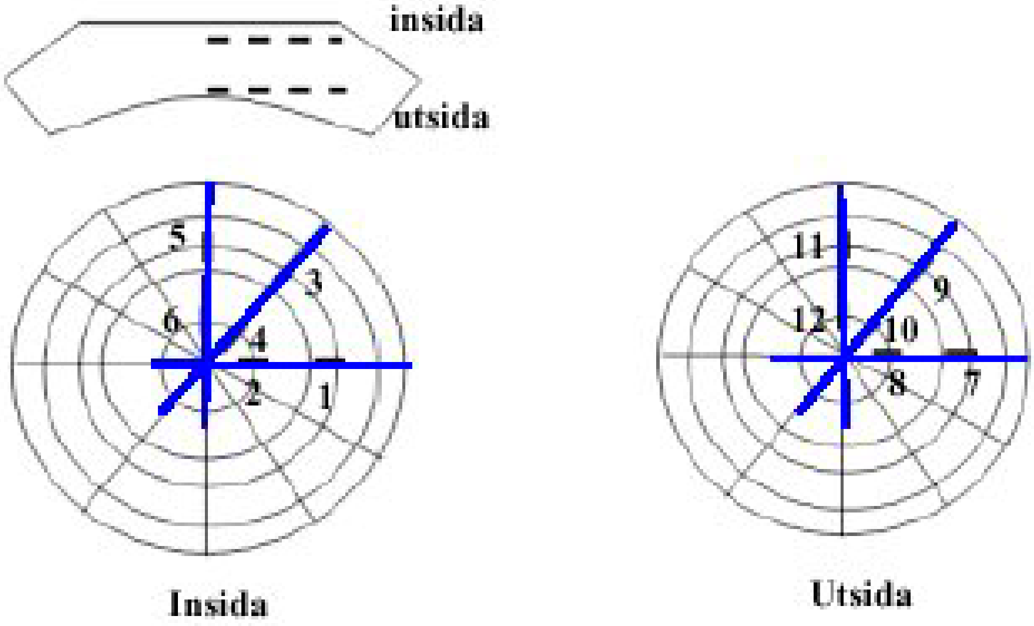


Figure 4-3. Plan and elevation view of plug with rebar strain meter identification numbers and dimensions

Table 4-3. Summary of embedment strain gages

Cable marking	Serial number	SICADA ID code	x	y	Z
AJ 1	25652	PXPPL2024	7 270,481	1 927,754	-446,703
AJ 2	25653	PXPPL2023	7 269,246	1 927,579	-446,697
AJ 3	25654	PXPPL2022	7 269,906	1 927,689	-445,284
AJ 4	25655	PXPPL2021	7 269,018	1 927,573	-446,166
AJ 5	25656	PXPPL2020	7268,465	1 927,509	-444,697
AJ 6	25657	PXPPL2019	7 268,478	1 927,499	-445,947
AJ 7	25658	PXPPL2018	7 270,364	1 928,652	-446,728
AJ 8	25659	PXPPL2017	7 269,148	1 928,411	-446,748
AJ 9	25660	PXPPL2016	7 269,731	1 928,562	-445,373
AJ 10	26046	PXPPL2015	7 268,828	1 928,344	-446,180
AJ 11	25662	PXPPL2014	7 268,404	1 928,303	-444,710
AJ 12	25663	PXPPL2013	7 268,389	1 928,279	-445,959

5 Data collection and future works

The instruments have been connected to the existing datalogger system already in use for the monitoring of stresses and strains in the rock mass. Two additional 16-channel multiplexers have been added to the system to accommodate the new plug sensors. The multiplexers (which are referred to as nos. DL2M4 and DL2M5) are then in turn connected to one of the two existing datalogger (referred to as datalogger no.2), which can be accessed remotely by telephone modem.

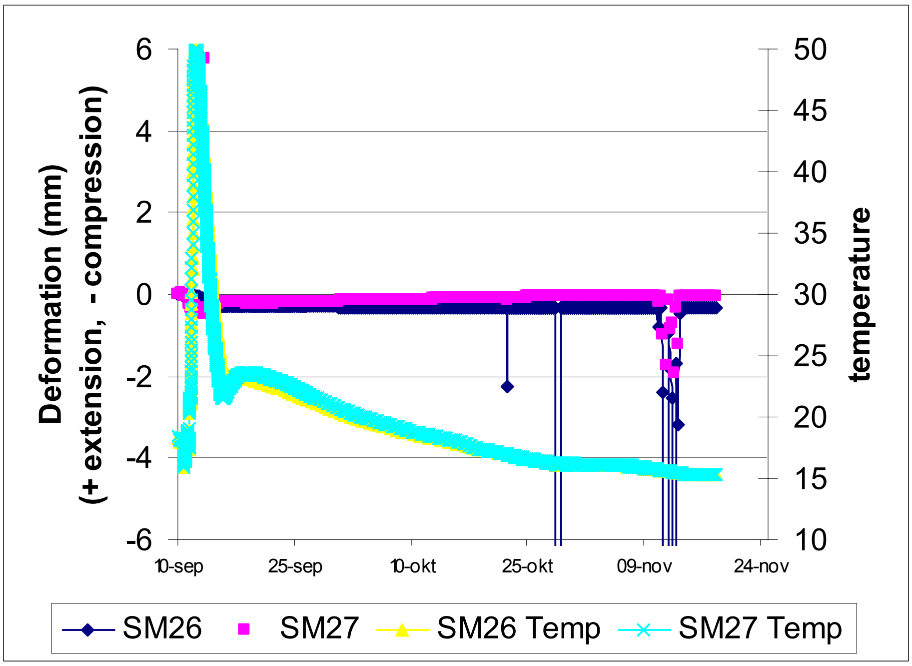
The multiplexers are Geokon model 8032 units which expand the number of channels that can be read by the dataloggers. The dataloggers is a Geokon MICRO-10 unit (without a digital signal processor) which is built around the Campbell Scientific CR 10 MCU which is a microcomputer, clock, multimeter, calibrator, scanner, frequency counter and controller.

Readings are typically recorded by the datalogger fours times each day, and then downloaded to a remote PC via a telephone modem. The data are collected in an ASCII file, and imported to a spreadsheet where the raw data is analysed.

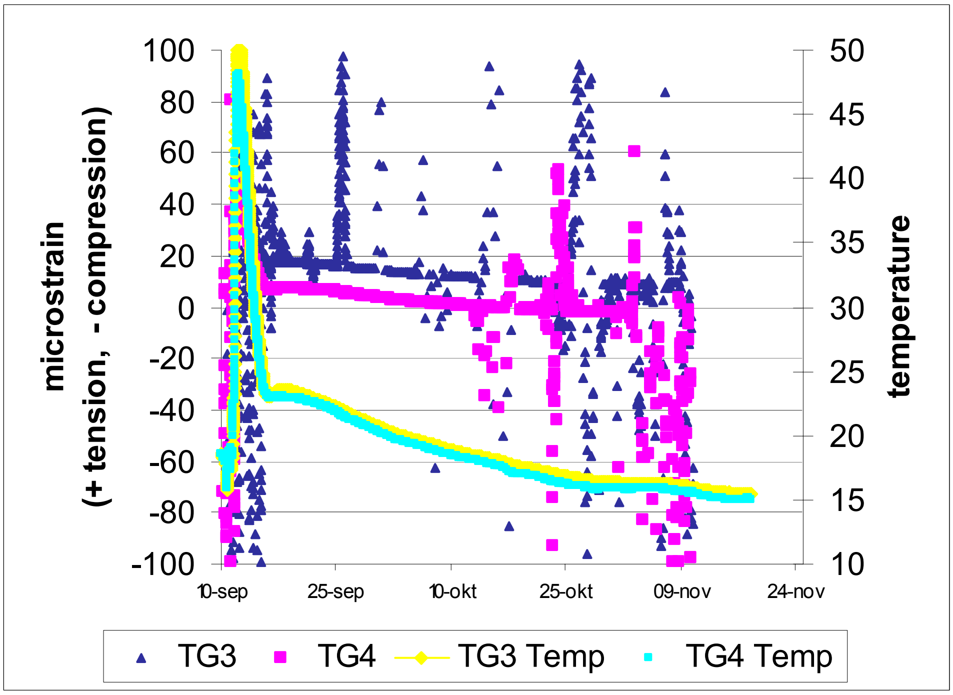
The most recent set of data is presented graphically in Appendix A.

Appendix A

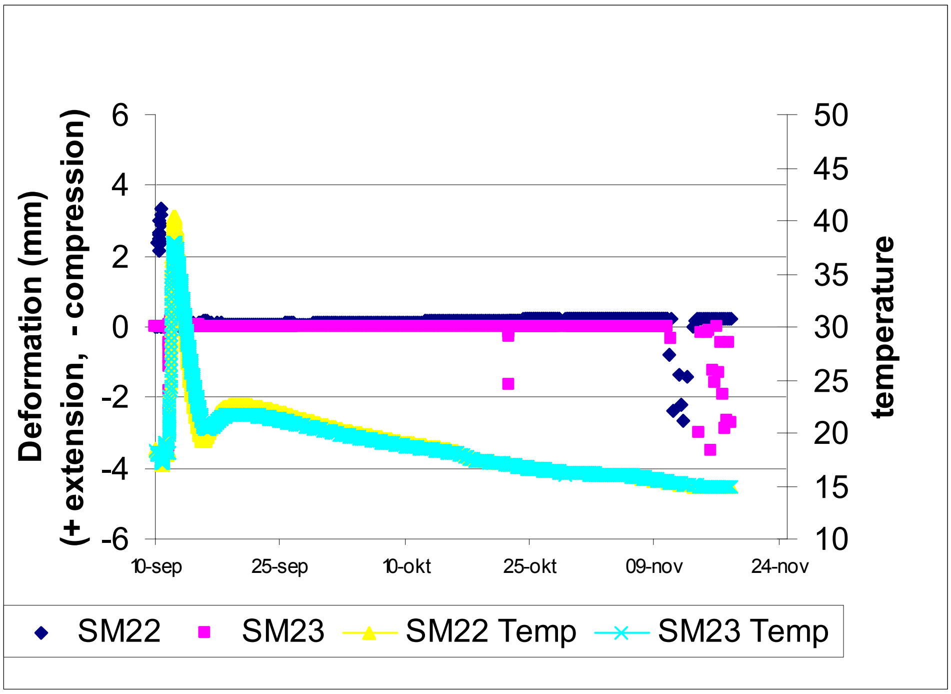
Joint meter data – Left side of tunnel (09:00)



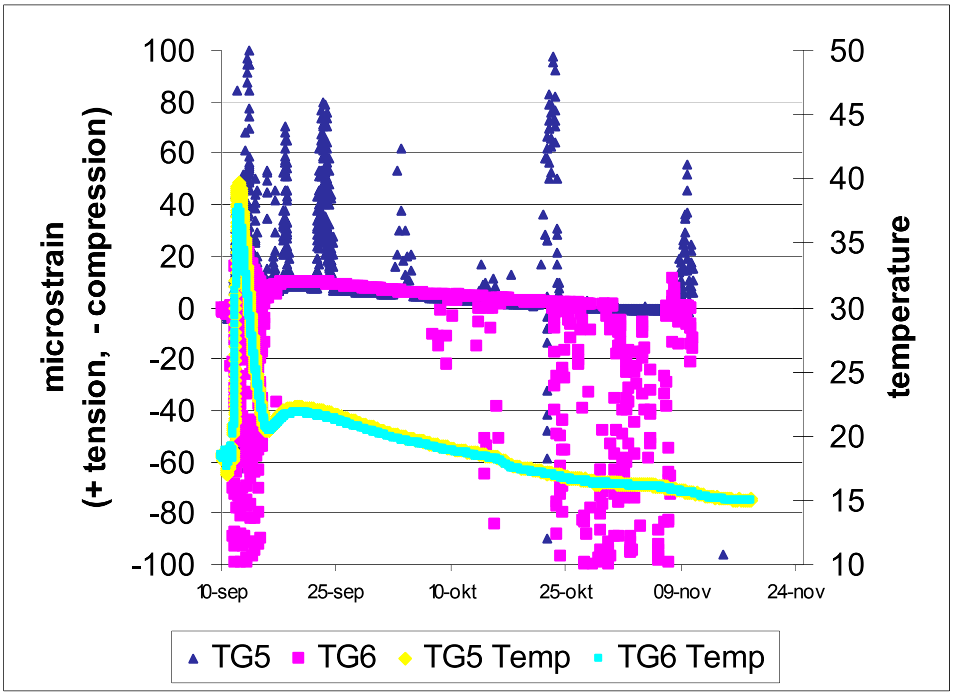
Strain gage data – Left side of tunnel (09:00)



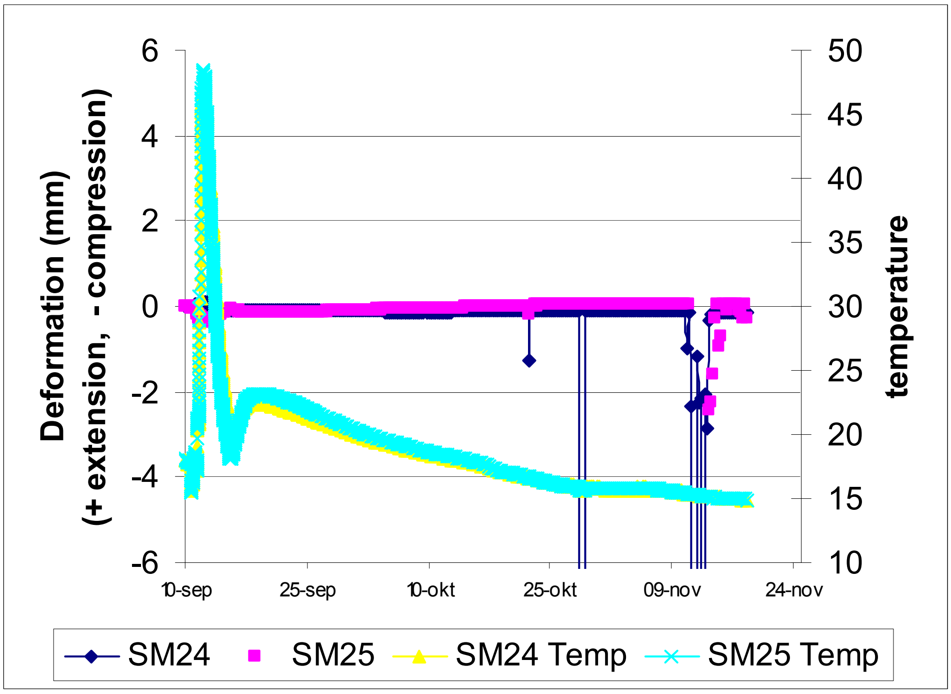
Joint meter data – Roof of tunnel (12:00)



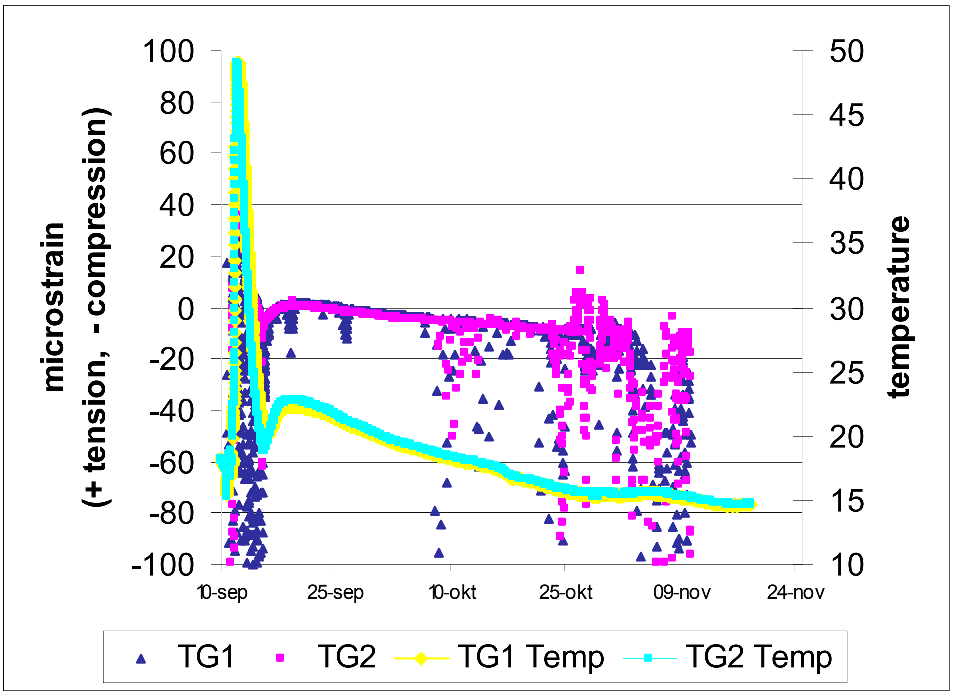
Strain gage data – Roof of tunnel (12:00)



Joint meter data – Right side of tunnel (03:00)



Strain gage data – Right side of tunnel (03:00)



Rebar strain meter data