University of Southern Queensland

Faculty of Health, Engineering and Sciences

Use of Wire Extensometers for Monitoring Pavement Performance in Areas of Slope Instability

A dissertation submitted by

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Courses ENG4111 and ENG4112 Research Project

Towards the degree of

Bachelor of Engineering (Civil)

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Foreword

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Abstract

In 1998, the Gregory Developmental Road was diverted around the western side of the Highway-Reward Mine to allow overburden stripping operations in the open cut. In 2005, mining operations concluded, but several months later cracking was detected in the pavement of the Gregory Developmental Road (Coffey Geotechnics 2011a). This cracking is thought to be the result of slope instability in the western wall of the open cut mine.

The Department of Transport and Main Roads, Queensland (TMR) were requested to provide an instrumentation and monitoring system for the site. The monitoring is required to provide data that can be used to analyse ground movements and to provide an early-warning system to notify TMR staff of any road surface deformations that may impose a risk to road users.

For the basis of the monitoring system, several types of instrumentation were considered. Case studies of instrumentation installations used to monitor slope instability were examined in an attempt to identify the most suitable system. Wire extensometers were eventually selected as the best solution for the site. A system of 3 wire extensometers and a weather station, connected to satellite telemetry was installed on the remote site, as the basis of the early-warning instrumentation system.

The wire extensometer system required the design and fabrication of unique hardware for the installation to be successful. A satellite telemetry system was selected to provide reliable communication of the collected data, and in order to prevent vandalism and threat from fire, the logging, power, telemetry and weather station systems were installed on a custom-designed 8-metre tall mid-hinged pole. Temperature sensors at each of the wire extensometer locations were also fitted in order to determine if the extreme temperature fluctuations have any effect on the operation of the extensometers.

Data from the instruments located on site is automatically sent to a web server, where it can be viewed by key personnel. The system will also provide automatic alerts in the

form of SMS messages if the devices detect movement or rainfall in excess of the pre-determined thresholds.

The wire extensometer system provides a unique solution to the requirement for a reliable early-warning system on the remote site. The proven success and reliability of the system has provided a cost effective alternative to traditional instrumentation systems for monitoring pavements in the vicinity of unstable slopes. In addition, the data provided by the weather station will be made available to the Bureau of Meteorology (BOM) for inclusion in its nationwide distribution network.

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Signature

Date: 24 October 2013

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Glossary of Terms

ABS	Acrylonitrile Butadiene Styrene
BGAN	Broadband Global Area Network
COM	Communications
DGSI	Durham Geo Slope Indicator
EL	Electronic Level
FBG	Fibre Brag Grating
FTP	File Transfer Protocol
GFRC	Glass Fibre Reinforced Composite cable
Hz	Hertz
IPI	In-place Inclinometer
mA	Milliamps
NSW	New South Wales
PHP	Hypertext Preprocessor
PVC	Polyvinyl Chloride
QLD	Queensland
RF	Radio Frequency
RL	Reduced Level
RTA	NSW Road Transport Authority
SEMP	Site Emergency Management Plan

SWTC	South West Transport Corridor
TMR	Department of Transport & Main Roads, QLD
V	Volts
VW	Vibrating Wire
VWP	Vibrating Wire Piezometer
WDM	Wavelength-Division Multiplexing
WE	Wire Extensometer

1. Introduction

1.1. Slope Instability and Instrumentation

Slope instability can be one of the major causes of premature road pavement failure. These instabilities have the potential to cause costly damage to pavements and property as well as injury or loss of life. Much research has been undertaken into suitable systems and methodologies for mitigating the risks associated with unstable slopes and road pavements. One such methodology is the installation of instrumentation in the vicinity of the slope or the pavement itself. These systems can provide an early warning to any imminent failures, so remedial action can be taken.

Kane and Beck (2000) state that slope stability monitoring involves selecting certain parameters and observing how they change with time. The two most important parameters are groundwater levels and displacements. Displacements may be characterised by depth of failure plane, direction magnitude and rate.

There are various types of instrumentation systems available for measuring the above parameters. These range from devices that measure surface movements such as simple survey monuments, to complex networks of strain gauges imbedded in the road pavement itself. Devices that measure groundwater levels also range from the very simple, such as observation bores, to complex, such as remotely monitored networks of vibrating wire piezometers.

Although there are many instrumentation options available, the difficulty lies in anticipating the mode and/or direction of failure. This will inevitably determine the type of instrumentation system used, so it is critical to have a solid understanding of the geological and site conditions present before a monitoring system is selected. This is often undertaken by geotechnical investigation and the application of knowledge and experience from similar scenarios where instrumentation has been successful.

Over the years, the advancement in telecommunications systems, particularly the mobile network has paved the way for new and innovative remote monitoring systems. It is now possible for the collection of near real-time data anywhere on the planet. This advancement means that instrumentation has become a feasible risk management strategy in managing road pavement safety and performance in areas of slope instability.

1.2. Project Background

The Gregory Developmental Road (or Gregory Highway) runs southward from outside Georgetown off the Gulf Developmental Road, via Lynd Junction and Charters Towers to Springsure, over 900 km away. The Gregory Developmental road was recently upgraded to a dual-lane bitumen sealed surface, and carries a large proportion of heavy vehicle traffic, including road trains.

The Highway-Reward Mine site is located approximately 30 km south of Charters Towers, and is positioned adjacent to the Gregory Developmental Road. At the closest point, the wall of the 220 m deep open cut mine is only 50 m from the roadway. A map of the location is shown in Figure 1.

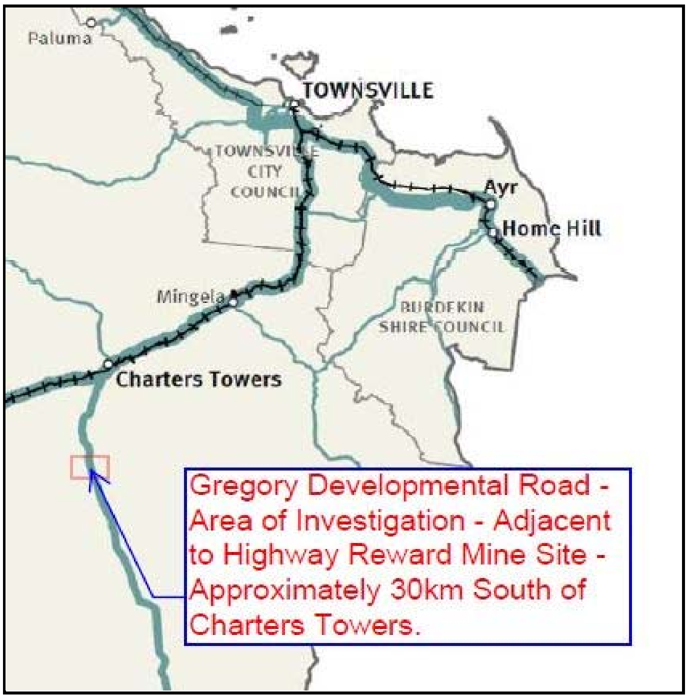


Figure 1 – Site location

In 1998, the Gregory Developmental Road was diverted around the western side of the Highway-Reward Mine to allow overburden stripping operations in the open cut. Open cut mining operations concluded in March 2005 (Coffey Geotechnics 2011a).

Several months later, cracking was detected in the pavement adjacent to the south-west wall (Coffey Geotechnics 2011a). Due to the presence of a large fault in the western wall of the mine, and several significant slip failures, it was hypothesized that the cracking in the pavement was most likely due to movement activity in the western pit wall of the mine due to the West Wall Fault.

A day after the cracks were discovered on the road pavement, a consultant was engaged and recommended the installation of 20 survey prisms between the highway and the mine pit, and also at locations west of the highway to allow the monitoring of any possible ground movements. Several more prisms have been added since this time and there are now a total of 36 prisms across the site.

The survey prisms have provided a simple cost effective method of monitoring ground movements in both the horizontal and vertical directions, but are not without their shortfalls. Due to the installation method used and the location of the prisms, the integrity of the data gathered has been questioned.

The survey prism system along with visual inspection has been the only system available to warn of a more serious pavement failure. Therefore, it was decided that another monitoring system should be selected and installed to take the place of the prisms to provide an early warning system to alert of any pavement cracking.

1.3. Research Objectives

The primary research objective is to select and evaluate a suitable monitoring system for monitoring pavement performance on the Gregory Developmental Road adjacent to the Highway Reward mine site.

In order to meet this primary objective, a number of secondary, project specific objectives have been identified:

1. Develop an understanding of typical slope instabilities and the various types of instrumentation monitoring systems that are installed to monitor pavement performance. To achieve this objective, a literature review on selected instrumentation systems used to monitor slope instabilities will be undertaken, from which several projects where these systems have been installed will be analysed.

2. Research other components of instrumentation systems including data logging systems, remote monitoring telemetry and specific installation requirements and techniques.

3. Select the most suitable instrumentation system from the identified systems after considering site specific requirements and client needs.

4. Customise the system to meet the above requirements and to minimise any probable sources of error.

5. Evaluate the data gathered and modify the system if required to improve integrity of the data and/or instrumentation system.

1.4. Project Scope

The project will focus on the selection, design and installation of the wire extensometer instrumentation system on the site, and will include a relatively brief explanation of the site geology. Complex numerical modelling of failure mechanisms or the role of hydrogeology in the failure mechanism will not be covered.

Analysis of the data captured to date will be undertaken in order to explain anomalies, and for the purpose of proving the integrity of the data and the instrumentation system as a whole.

The literature review will be conducted for the purpose of identifying the options available for instrumentation systems and data acquisition systems to monitor pavement performance and slope movement.

1.5. Organisation of Research Project

- Chapter 1 introduces the important role instrumentation has in monitoring slope instability and also includes the project background, research objectives and the scope of the project.

- Chapter 2 contains a literature review which presents several different types of instrumentation and data acquisition systems. For each system, the principles of operation and relevant theory and installation techniques are presented. Case studies are also included in order to give a better understanding of the applications of each type of instrument and their role in providing an early-warning system.

- Chapter 3 presents the site history, geology and postulated failure mechanism of the Highway-Reward Mine site.

- Chapter 4 presents the selection of the instrumentation system by presenting proposals based on the types of instrumentation as presented in the literature review. The proposals are then evaluated against specific criteria and the system is selected.

- Chapter 5 covers the design and installation of the instrumentation system.

- Chapter 6 outlines the processes in place for the data presentation to the end users. This includes the data retrieval process, application of calibration factors and corrections, and the final presentation on the web-based system. Chapter 6 also presents a section on the analysis of the data retrieved from the instrumentation system.

- Chapter 7 provides conclusions, recommendations and some suggestions for further work to be undertaken.

2. Literature Review

2.1. Introduction

Safety is an essential consideration in all construction projects. Instrumentation programs can provide the needed safeguards, by indicating behaviour with respect to threshold limits (Dunnicliff 1988). Ultimately, the data provided by instrumentation can be used to provide an early warning to structural failure. Kane and Beck (2000) state that the two most important parameters in slope instability monitoring are groundwater levels and ground displacement.

Measurement of ground displacements in areas of slope instability are traditionally undertaken with instruments designed to measure lateral deformation. Examples of instruments that can be used to measure lateral deformation are: electronic levels, inclinometers, strain gauges, displacement transducers, extensometers and crackmeters.

In this literature review, a selection of instruments used to measure lateral deformations will be discussed, and case studies will be identified to give a broad understanding of the practical applications of these instruments. Additionally, data acquisition and telemetry systems will be examined in order to provide a broad understanding of the devices currently in use within the industry that can be used to provide the basis of an early-warning monitoring system.

2.2. Instrumentation Systems

2.2.1. Piezometers

As explained previously, measurement of groundwater levels or pressures are a critical part of slope instability monitoring. Therefore, instrumentation used to determine groundwater levels form the basis of most successful instrumentation programs.

The piezometer is an instrument used to measure groundwater pressure. Piezometers differ to observation wells in that a piezometer is sealed within the ground so that it only responds to groundwater pressure around the device, whereas an observation well will respond to groundwater pressures at other elevations.

Observation wells have serious limitations. Dunnicliff (1988) explains that observation wells create a vertical connection between strata, so their application should be limited to continuously permeable ground, in which groundwater pressure increases uniformly with depth. Observation wells are inexpensive, so they are generally favoured in the place of piezometers, but as explained above, one must have a good knowledge of the groundwater conditions before an observation well is favoured over a piezometer. In reality, the exact groundwater regime is rarely known so piezometers should be installed in most cases to ensure accurate and reliable data is gathered.

There are many types of piezometers available, but the most common types used in today's industry are vibrating wire piezometers (VWPs), standpipe piezometers, and solid state piezometers. This literature review will be limited to the application of VWP and standpipe piezometers.

A standpipe piezometer requires sealing off a porous filter element so that the instrument responds only to groundwater pressure around the filter element and not to groundwater pressures at other elevations (Dunnicliff 1988). The VWP is installed in the same manner, with the VWP transducer taking the place of the standpipe piezometer.

Operating principle

The VWP consists of a transducer, usually encased in stainless steel, with a porous filter on one end, and a cable attached to the other end to power the device and to allow the instrument to be read.

Inside the VWP is a magnetic, high tensile strength stretched wire, one end which is anchored and the other end fixed to a diaphragm. The wire can be plucked by sending a signal through the piezometer cable which reaches a magnet beside the wire. When the wire is plucked it resonates at a certain frequency. The signal produces an alternating current in the magnet which is read as a frequency (in Hz) via the instrument's cable.

When a pressure is applied to the diaphragm by the surrounding water, the tension of the wire is reduced. Therefore, when the wire is plucked it resonates at a lower frequency. The calibration of the piezometer produces the relationship between resonant frequency and pressure in that the resonant frequency is directly proportional to the square root of the wire tension, and inversely proportional to the length of the wire (Applied Geomechanics 2008).

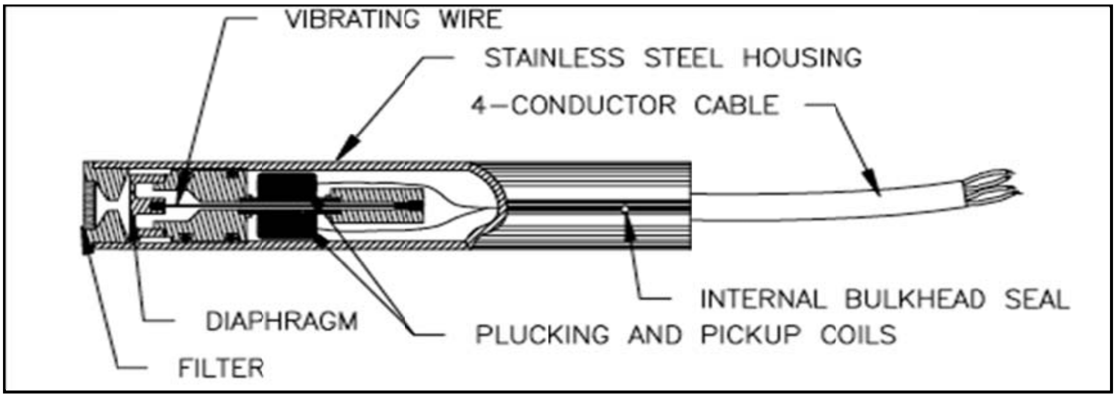


Figure 2 – VWP schematic (photo courtesy of Campbell Scientific).

Calibration factors are supplied with VWPs upon purchase, and are usually in the form of a cubic polynomial. Therefore, converting the raw data to pressure is a relatively simple process often undertaken in Microsoft Excel.

The standpipe piezometer, on the other hand, is a very simple device consisting of a porous tip attached to a riser pipe. The tip and riser pipe are usually manufactured from PVC, and are screwed or glued together depending on the type of coupling. Monitoring is undertaken by lowering an electronic water level meter through the pipe.

Installation

Piezometers can be installed by a number of methods. Applications of 'push-in' type VWPs are usually limited to installation in very soft clay (Dunnicliff 1988). The device is pushed from the ground surface by means of a threaded mandrel. The thread is used to attach the mandrel to a drilling rig. Once the device is installed, the mandrel is usually retrieved leaving the device at the desired depth. Extreme care must be taken when installing push-in VWPs as excess pressures generated during the pushing operation can exceed the rated pressure capacity of the instrument, causing permanent damage (Dunnicliff 1988). This can lead to erroneous results upon commissioning of the device.

Non push-in type piezometers are more common. If installation in fill is required, the device can usually be installed by excavating a trench and backfilling to the required level, otherwise a hole can be drilled and the piezometer can be positioned at any depth within the hole by attaching it to a piece of PVC pipe. Proper isolation of the piezometer sensor intake along the length of the borehole is necessary in order to obtain a correct pore water pressure measurement. To ensure this occurs, the piezometer must be sealed off from the surrounding layers.

The traditional method of correctly sealing the piezometer is described below:

First, a layer of filter sand is usually placed around the piezometer tip to form an intake zone following the sand layer, a layer of bentonite pellets. Finally, the borehole is backfilled with a grout mixture, which is usually a mixture of water, cement and bentonite. The function of the bentonite pellet layer is to prevent the grout from migrating into the sand filter layer.

Mikkelsen and Green (2003) argue that the traditional method described above is at best a laborious process and can in the worst case be so difficult that the installation becomes a total failure. Research by Mikkelsen and Green (2003) show that the traditional method can be abandoned in the place of sealing the piezometer along the entire depth using a special cement-bentonite grout. Figure 3 depicts the traditional installation method and the fully grouted method.

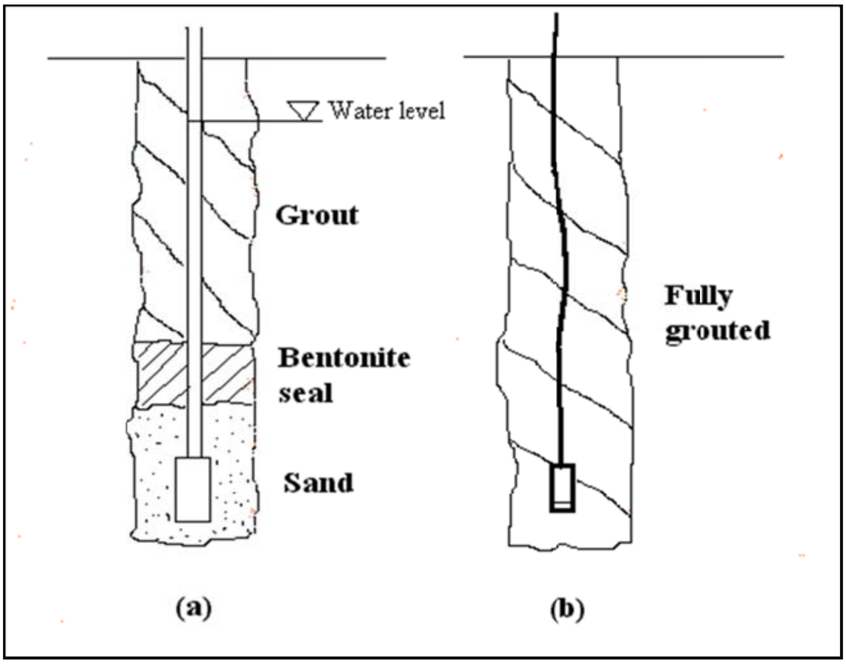


Figure 3 – Traditional installation method (a) & Fully Grouted Method (b)

(Mikkelsen and Green 2003)

Mikkelsen and Green (2003) also state that the fully grouted method is not only easier and faster, but has a much better chance of success in measuring the correct ground water pressure. The grout mixtures recommended by Mikkelsen and Green (2003) for installation of VWPs are shown in Table 1.

Table 1 – Grout mixtures for fully grouted VWPs (Mikkelsen & Green 2003)

Application	**Grout for Medium to Hard Soils**		**Grout for Soft Soils**	
Materials	Weight	Ratio by Weight	Weight	Ratio by Weight
Water	30 gallons	2.5	75 gallons	6.6
Portland Cement	94 lbs. (1 sack)	1	94 lbs. (1 sack)	1
Bentonite	25 lbs. (as required)	0.3	39 lbs. (as required)	0.4
Notes	The 28-day compressive strength of this mix is about 50 psi, similar to very stiff to hard clay. The modulus is about 10,000 psi.		The 28-day strength of this mix is about 4 psi, similar to very soft clay.	

Another advantage of the fully grouted method is that multiple piezometers can be installed at varying depths in the same borehole. This is useful in applications where the groundwater conditions are complex.

TMR has adopted the fully grouted method on many VWP installations with much success, and it is now the primary method adopted by TMR for installing VWPs. For open standpipe piezometers, the traditional method is still used.

2.2.2. Inclinometers

Inclinometers are instruments that are used to monitor subsurface movements or deformations. An inclinometer system consists of inclinometer casing and a measurement system. The measurement system consists of a traversing slope inclinometer probe, graduated electrical cable and a readout unit.

The inclinometer casing is a special purpose precision-made pipe. Inclinometer casing is typically installed in a near vertical borehole that passes through suspected zones of movement into stable ground (DGSI 1997). When the casing is installed, the inclinometer measurement system is used to survey the casing profile. This is undertaken by passing the traversing slope inclinometer probe through the length of the casing.

Dunnicliff (1988) lists the typical applications of inclinometers as:

1. Determining the zone of landslide movement.
2. Monitoring the extent and rate of horizontal movement of embankments, embankment dams, embankments on soft ground, and alongside open cut excavations or tunnels.
3. Monitoring the deflection of bulkheads, piles or retaining walls.

Operating principle

As mentioned in Section 2.2.2, the inclinometer casing is a special purpose precision-made pipe. A respected manufacturer of inclinometer systems, Durham Geo Slope Indicator (DGSI), manufactures it's casing from Acrylonitrile Butadiene Styrene (ABS) plastic. DGSI inclinometer casing contains spiral-free, machine broached guide groves. The purpose of these precision grooves is to allow repeatable tracking of the inclinometer probe through the casing (DGSI 1997).

The inclinometer probe body contains a gravity sensing transducers or accelerometers. The accelerometers measure any inclination with respect to the vertical direction. The inclinometer probe manufactured by DGSI uses two force-balanced servo accelerometers. One accelerometer measures tilt in the plane of the inclinometer wheels, which track the longitudinal grooves of the casing while the other accelerometer measures tilt in the plane perpendicular to the wheels (DGSI 2009). Inclinations measured by the inclinometer probe are converted to lateral deviations as shown in Figure 4.

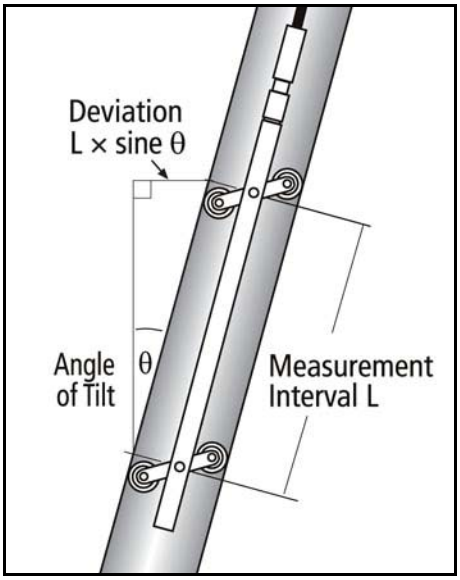


Figure 4 – Inclinometer probe angle measurement (DGSI 2009)

During a survey, the probe is attached to the cable and the data readout unit. The probe is then pulled upwards from the bottom of the casing to the top. At half-metre intervals, the probe is halted in its travel and data is recorded on the readout unit.

As seen in Figure 5, the cable is marked at half-metre graduations with a yellow marker and at metre graduations with a red marker. In addition, every 5 metres the cable is labelled with the corresponding metreage.

Figure 5 – Probe, cable and Datamate set up for reading inclinometer

When the inclinometer casing is initially installed, an initial survey is undertaken. This survey establishes the ‘as installed’ profile of the casing. Subsequent surveys will reveal any deformation to the inclinometer casing due to ground movement by comparison with the initial survey (DGSI 2009). Figure 6 shows a typical plot of an inclinometer survey showing ground displacement. Note the distinct failure plane between 60 and 70 metres elevation.

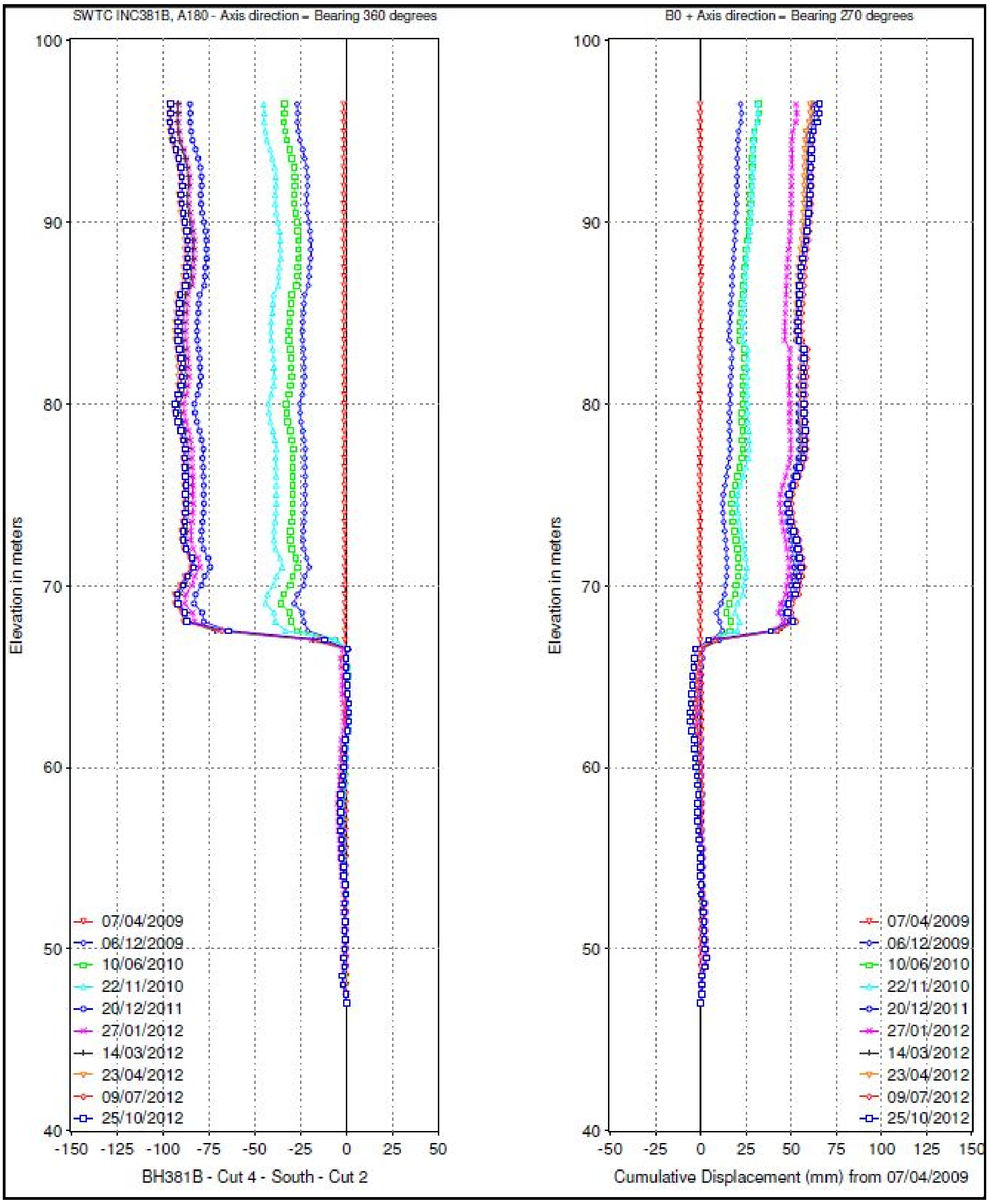


Figure 6 – Typical inclinometer plot displaying ground movement

<u>In-place inclinometers</u>

A major disadvantage of the traditional traversing slope inclinometer probe is that it requires that an operator manually traverses the probe throughout the length of the casing for readings to be undertaken. An alternative to this system are in-place inclinometers (IPIs).

The IPI employs a fixed chain of sensors that is permanently suspended in the inclinometer casing. The positioning of the chain of IPI sensors is critical, as if possible ground displacements are to be detected, the IPI chain must span the suspected failure zone. For this reason, manual monitoring using a traversing slope inclinometer probe is usually undertaken first so the failure zone can be identified. With reference to the inclinometer plot shown Figure 6, the IPIs must adequately span the failure zone identified (between RL 60 and RL 70 m).

IPIs are usually connected to a data acquisition system, which will power the system and will automatically log the readings from the IPI, thus abolishing the requirement for an operator to be present on site to undertake readings.

Installation

Inclinometer installation and monitoring is one of the most labour and data-intensive geotechnical instrumentation activities, and the accuracy of the data provided by the inclinometer system is highly dependent on the installation process of the casing itself (Green & Mikkelsen 1988). Because of this, a summary of some of the important installation considerations will be presented here.

Inclinometer casing is usually manufactured in 10 foot (3.05 m) lengths. The casing lengths are installed progressively into a borehole, and joined to subsequent lengths either by a glued coupling or snap-on bayonet type fitting, depending on which type of casing is used. After installation, the void between the inclinometer casing and the borehole is filled with grout. Figure 7 shows the process of a typical inclinometer installation.

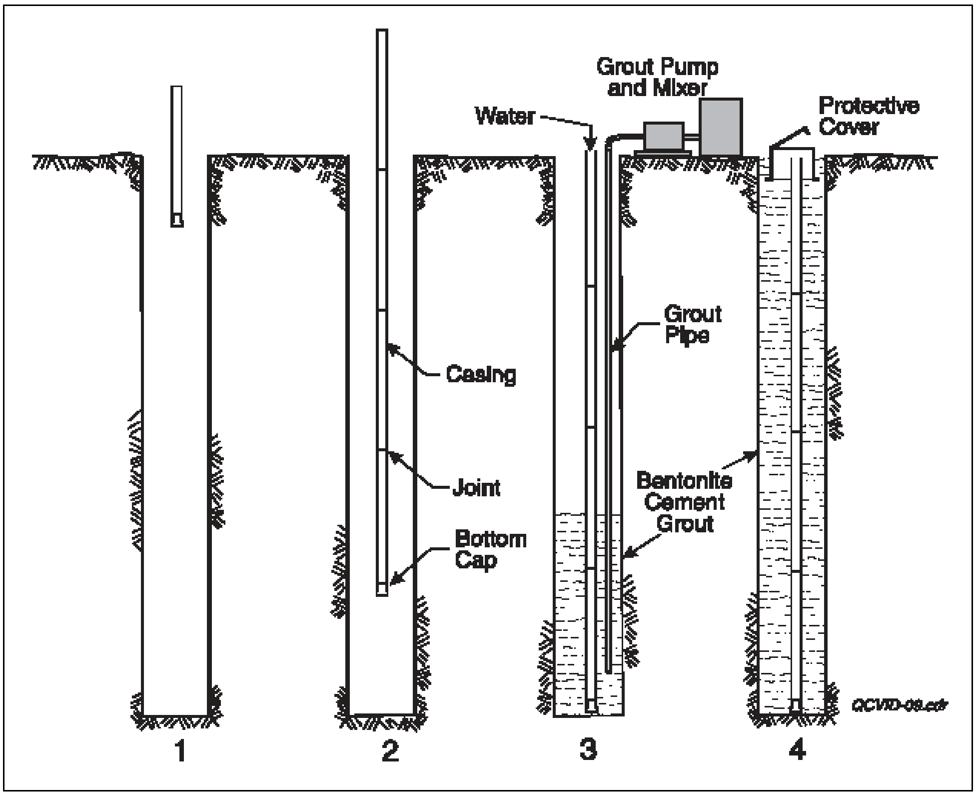


Figure 7 – Inclinometer casing installation steps (DGSI 1997).

Although the above may sound like a relatively simple procedure, there are a number of important steps that must be followed for the device to function correctly. This section outlines some of the basic procedures and important considerations regarding inclinometer installation.

Because an inclinometer allows ground displacement to be measured with respect to a reference datum, it is *critical* that the device is anchored into competent material below the zone of failure. If this does not occur, the entire inclinometer will be displaced above the failure plane, and no movement will be detected by the device.

Bassett (2012) states that the process of formation of the borehole throughout the full depth of soil and the installation of the inclinometer casing must ensure that the reference is correctly orientated and acts with the soil. This involves not only the formation of the borehole but also casing insertion and grouting.

The method of grouting adopted must ensure that the entire instrument is encased in grout. Voids between the inclinometer casing and the borehole will cause the readings taken with the inclinometer probe to be unstable, and may introduce errors into the data sets.

To ensure complete grouting of the inclinometer casing, a method of grout delivery must be provided. Upon drilling a borehole for inclinometer installation, the borehole is sometimes filled with water or drilling fluids. In this case, grout must be delivered from the bottom of the borehole in order to purge the fluids from the borehole. This is usually done by lowering a delivery hose or 'tremmie' with the inclinometer casing. Once the casing is in place, the grout mixture is pumped through the tremmie until the void between the inclinometer casing and borehole is filled.

The type of grout mixture used is also an important consideration. The objective is to use a grout mixture that does not alter the local soil response to the ground that is being monitored (Bassett 2012). Bassett (2012) also states that there have been cases where a series of inclinometers have been grouted and perform like micro-piles, with gross movements occurring around the instruments, with little or no movements being detected in the inclinometers themselves. In addition, a grout mix that contains too much water will shrink excessively, leaving the upper portion of the inclinometer un-grouted (DGSI 1997).

TMR has used the inclinometer system for monitoring a number of slope instabilities that have had a serious impact on major roads. A recent project where several inclinometers and piezometers have been installed will be discussed in order to provide a sound understanding of the usefulness of the inclinometer system as a monitoring tool.

Installation case study: Centenary Motorway extension (South West Transport Corridor)

The South West Transport Corridor (SWTC) is a major transport corridor in south-east Queensland which extends the Centenary Highway to the Cunningham Highway via Ripley.

During the advanced stages of earthworks construction of the Springfield to Yamanto section, large scale landslide activity was detected in the vicinity of road cuts 3 and 4. The landslide activity is believed to be a result of the reactivation of a deep seated slow movement along shear planes associated with an ancient land surface (Starr et al. 2010). Figure 8 shows the severity of the observed shearing in the pavement and batter. This evidence of slope instability was discovered only days before the road was scheduled to be opened to the public.

Figure 8 – Shear cracking in pavement and batter at Cut 3 after heavy rainfall (Starr et al. 2010)

In the period between 2007 and 2009 a comprehensive drilling programme was undertaken in order to build the geological model of the site. Nearly 5000 m of core was recovered across approximately 80 boreholes. In selected boreholes, a total of 54 inclinometers and over 80 VWPs with data loggers were installed along cuts 3 and 4 (Starr et al. 2010).

A typical inclinometer profile from Cut 3 shown in Figure 9 clearly demonstrates the deep seated shear boundary that was revealed during the comprehensive investigation. In Figure 9, it can be seen that the shear boundary is located more than 20 m below the road surface. Also note the magnitude of the displacement, which is in excess of 150 mm.

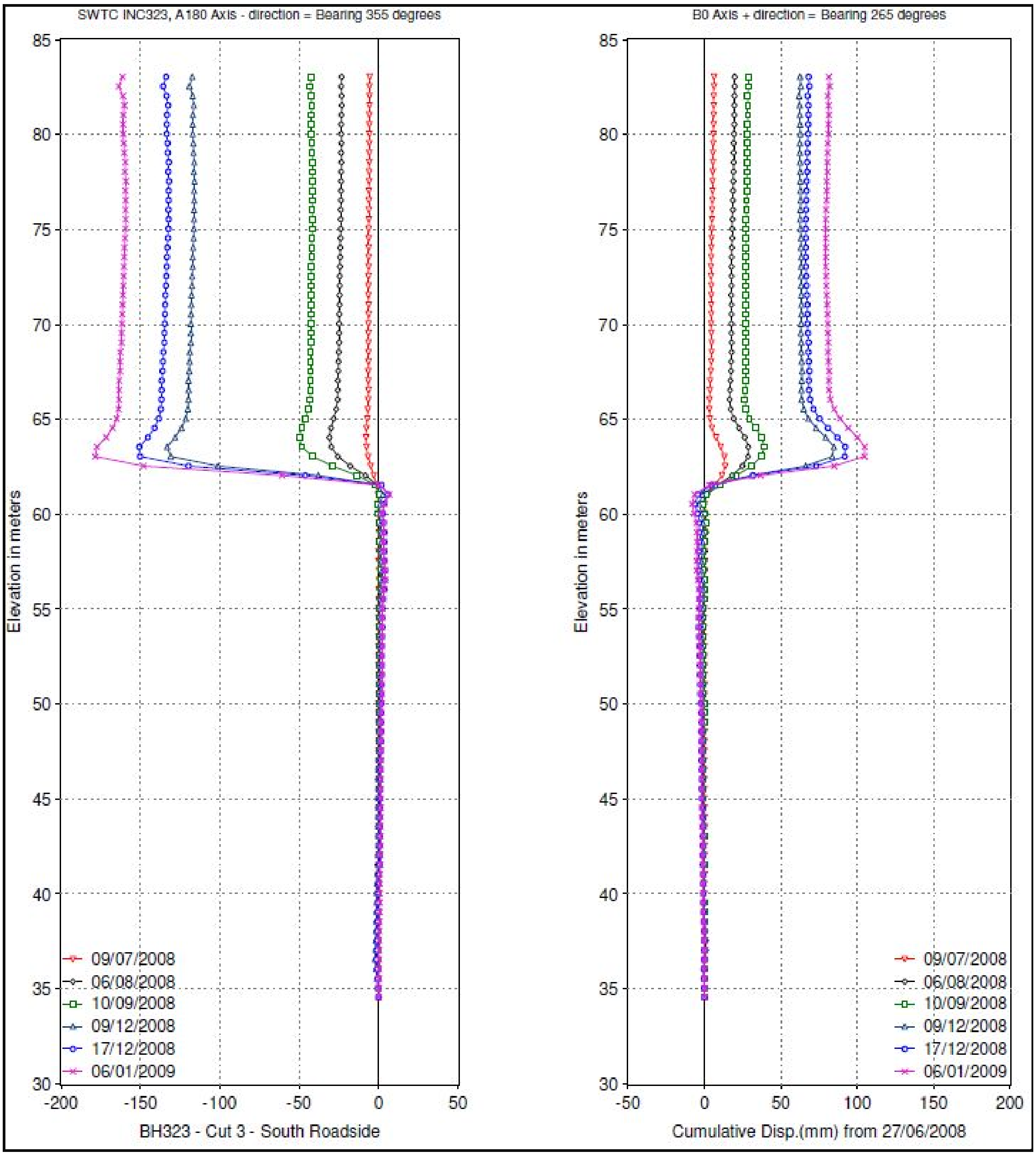


Figure 9 – Inclinometer plot showing severe shear deformation below pavement

The data gathered from the network of inclinometers and piezometers revealed a relationship between ground movement and the groundwater levels. This relationship is shown in Figure 10. This figure shows that both the surface movement rate as recorded by ground survey and the movement recorded in the inclinometers both increase significantly when groundwater levels rise less than 2 m.

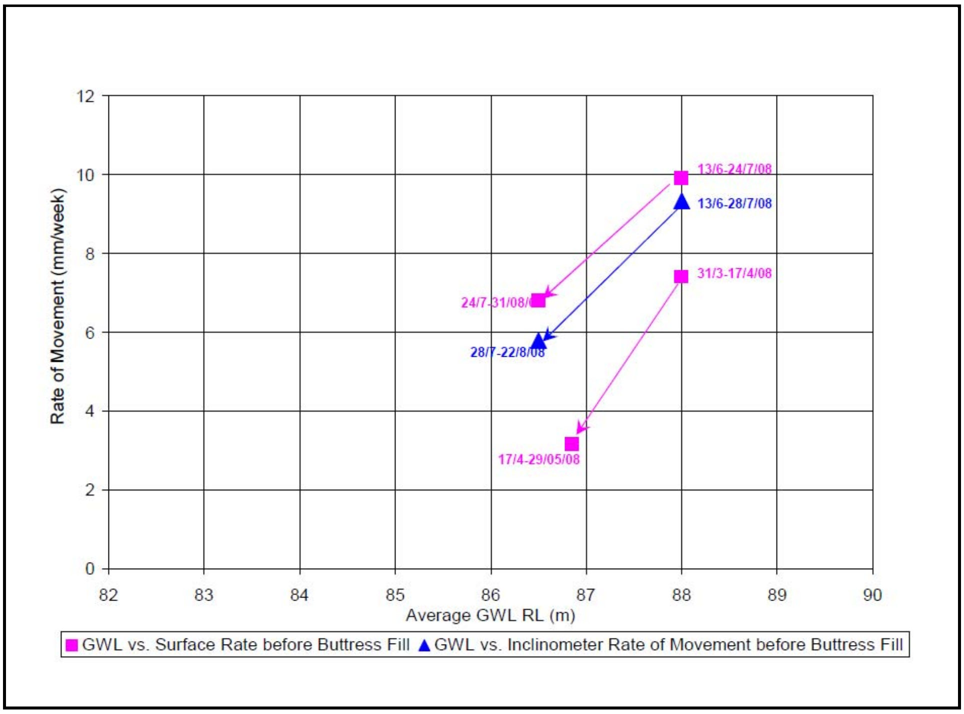


Figure 10 – Plot of rate of movement against groundwater level

Additional modelling enabled a relationship between the groundwater level and factor of safety to be reached. This is shown in Figure 11.

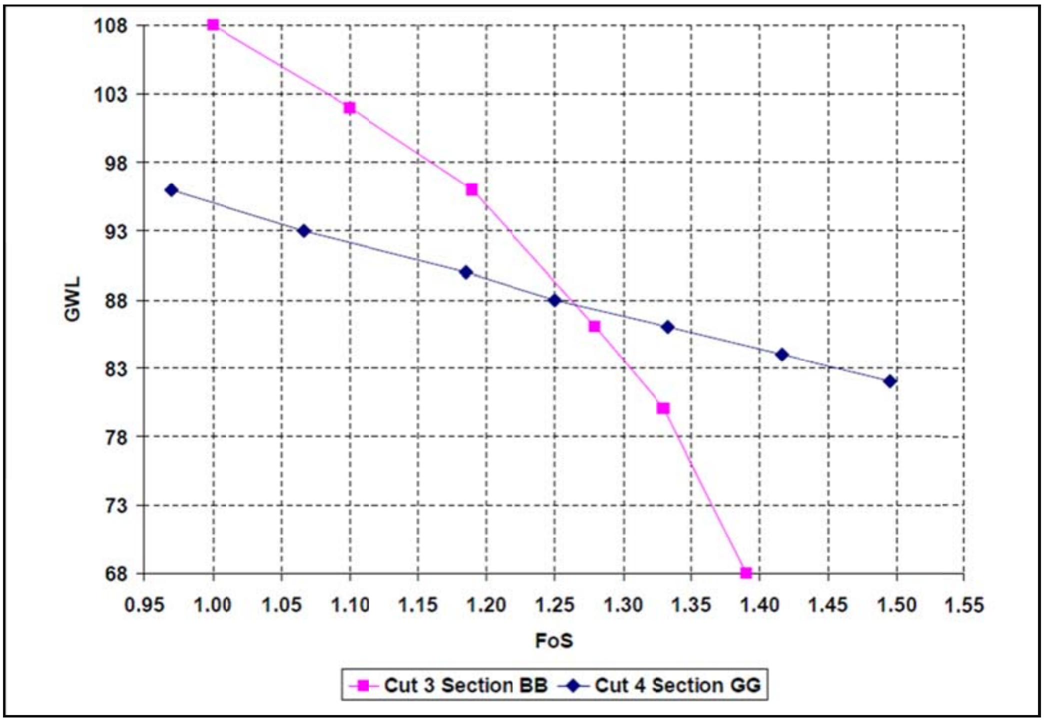


Figure 11 – Plot showing influence of groundwater level on factor of safety

The relationship between groundwater levels and accelerated landslide movement led to remediation options being undertaken, such as the removal of close to one million cubic metres of material from the top of Cuts 3 and 4. A large portion of this excavated material was used to provide a buttress fill at the toe of the cuts, raising the level of the roadway. In addition, pumping wells have been installed in selected locations. These pumps are connected to piezometers and automatically engage when the groundwater levels reach a critical level. The pumps enable the groundwater level to be reduced, and hence the risk of accelerated ground movement is also lessened.

The final part of the remediation was the implementation of an early-warning system on the site. The network of VWPs form a critical part of this system, as they can automatically detect and record any change in groundwater levels.

The piezometers are linked to data loggers which can transmit data via radio frequency (RF). For data download to occur, each logger creates a RF link to a base station. The base station logger is connected to a wireless broadband modem, which allows all data to be uploaded to a web server at scheduled intervals.

If groundwater levels or rainfall above a certain threshold are detected, alerts will be automatically issued to the appropriate staff. These alerts are provided in the form of SMS and email messages. Table 2 shows the trigger levels defined for the SWTC site, as well as the actions to be undertaken for each trigger level. Note that rainfall has also been included. This data is acquired from the Australian Bureau of Meteorology web site.

Table 2 – SWTC trigger levels and action plan

Condition	Assessed Factor of Safety	Cut	Trigger Levels		Supplementary Trigger Levels			Action to be Taken
			Measured Groundwater Level [m AHD]	Proxy Lead Indicator: Significant Rainfall (3 day cumulative rainfall) [mm]	Pavement Condition – Gradual Distortion (Hump) [mm]	Pavement Condition – Sudden Distortion (Step) [mm]	Landslide Rate of Movement [mm/week]	
"Green"	> 1.30	Cut 3	<RL85	<200	<25	<5	<3	No specific action necessary - continue monitoring at established frequency
		Cut 4						
"Amber"	1.10 to 1.30	Cut 3	RL85 to RL103	200 to 300 (or 100mm in 24 hours)	25 to 50	5 to 10	3 to 20	Steps are to be taken to prepare for more severe actions including greater monitoring vigilance and frequency. Visual observations of movement in the slope and road pavement from structured inspections by suitably trained and qualified staff are recommended. Speed restrictions are likely to be required pending the finding of visual observations and whether potentially problematic pavement distortion has developed
		Cut 4	RL85 to RL94					
"Red"	<1.10	Cut 3	>RL103	>300	>50	>10	>20	Close the road pending further investigation and assessment
		Cut 4	>RL94					

2.2.3. Wire Extensometers

The wire extensometer, also known as a linear displacement transducer, is an instrument which enables the monitoring of a change in distance between two points. In this literature review, the wire extensometer manufactured by SISGEO will be considered.

Typical applications of the wire extensometer include measurements of large displacements associated with landslides, monitoring rock-masses and surveying earth faults (SISGEO 2011).

The device consists of an enclosure, in which a displacement transducer is housed. A long cable or wire is attached to the transducer at one end, and is placed under tension spanning the desired area. The end of the cable is attached to an anchor. Any movement between the anchor and the transducer unit will alter the output signal from the transducer, from which the displacement can be determined.

Figure 12 – SISGEO wire extensometer in typical below ground installation (Geotesta 2012)

Operating principle

The wire extensometer relies on a type of linear displacement transducer known as a rotary potentiometer to undertake measurements. Todd (1975) states that one of the basic potentiometer applications is that of converting mechanical linear motion to rotary motion and utilizing the resultant output signal.

The rotary potentiometer is a device with a movable slider, usually called a wiper, that makes electrical contact along a fixed resistance strip to which a regulated DC voltage is fed to both ends. As the wiper moves, the voltage varies. The measured voltage is directly proportional to the displacement of the wiper. In the rotary potentiometer, any displacement of the steel cable causes a rotation of the potentiometer, and the displacement can be determined from the signal produced.

In the SISGEO wire extensometer, one turn of the potentiometer corresponds to 240 mm of displacement. The device is designed to re-zero after each rotation (SISGEO 2011).

The SISGEO wire extensometer can span a distance of up to 30 m. To keep the steel cable loaded a tensioning device (balancer) is used. The stroke of the balancer is 2 metres and to enable a reasonable amount of tension on the cable, a loading capacity of up to 8kg is possible (SISGEO 2011). SISGEO (2011) also state that the device has a sensitivity of 0.03 mm, an accuracy of +/- 1 mm and a measurement repeatibility of +/- 0.03 mm.

Figure 13 shows the internal components of the SISGEO wire extensometer. The tensioning device is the large drum on the left and the rotary potentiometer transducer is on the right.

Figure 13 – Wire extensometer internal components

Installation case study: Princes Highway, Morwell

The SISGEO wire extensometer has been successfully installed as the basis for a remote early warning monitoring system on the Princes Highway, at Morwell in Victoria.

In early February 2011, a significant rainfall event was associated with a movement event on the northern wall of the Hazelwood Coal Mine. As a result of the movement, cracks appeared across the mine batter, the surface of the Princes Highway and at the end of Hazelwood Road (Sceney & Bignell 2011). A large sinkhole also appeared at the top of the mine batter.

According to Sceney and Bignell (2011), the ground movement was caused by water entering underground coal joints in the mine. The mine consists of brown coal, which is sensitive to water pressure due to its low bulk density.

It is suspected that the source of the water flow was caused by the large rainfall event in combination with a defect in a large drainage system known as the Morwell Main Drain. The Morwell Main Drain carries flows from industrial areas north-east of the mine, and the Hazelwood mine itself (Sceney & Bignell 2011).

Due to the safety concern for road users, diversions were put in place for approximately 9 months so investigation and remediation could be undertaken (Sceney & Bignell 2011). Figure 14 depicts the location of the large sinkhole and cracking extending from the Hazelwood Mine to the Princes Highway.

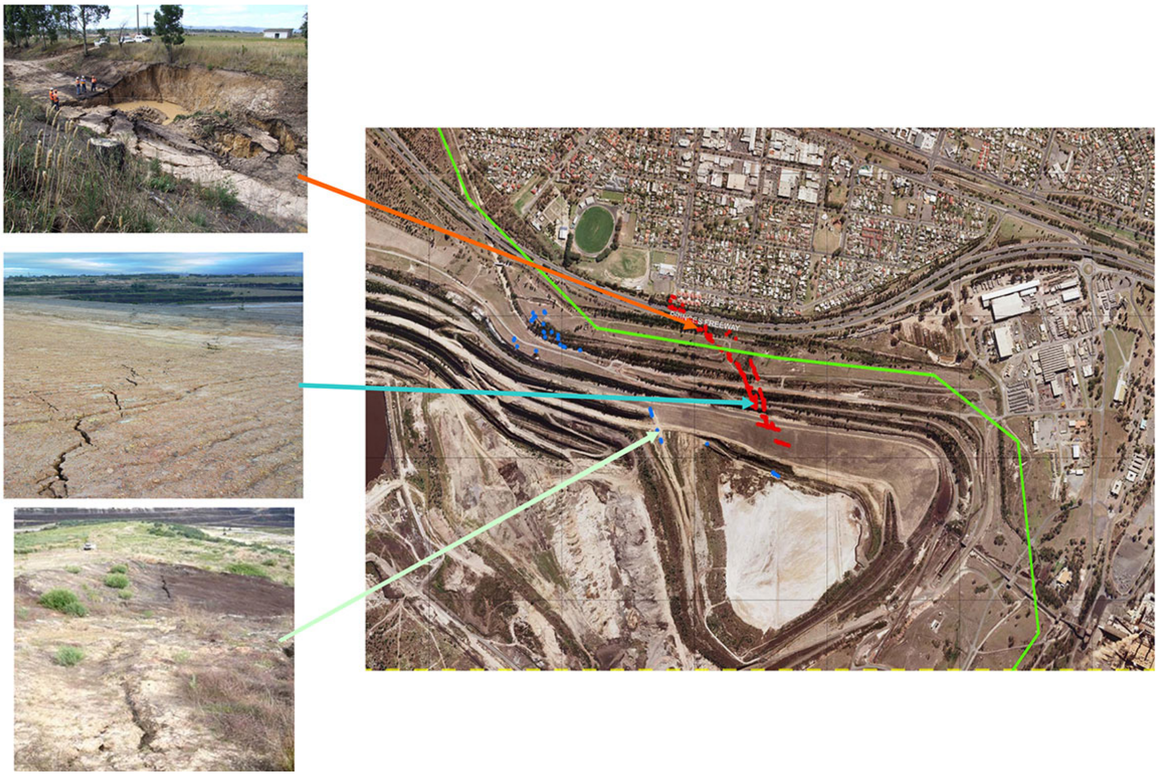


Figure 14 – Sinkhole and cracking at the Princes Highway/Hazlewood Mine site, Morwell (Sceney & Bignell 2011)

VicRoads engaged the specialist geotechnical engineering company to install an instrumentation monitoring system with remote monitoring capability utilising mobile network communications. This was done in order to provide a near real time monitoring solution in order to mitigate risks associated with possible further ground movements to road users. In addition, remedial measures included the drilling of 50 horizontal drain holes to remove water from the area of instability (Sceney & Bignell 2011).

The specialist contractor engaged by VicRoads proposed a wire extensometer monitoring system, and this was accepted. Four wire extensometers were installed on the site, along with a VWP in an existing monitoring bore. Installation of the wire extensometers was undertaken by means of directional boring. 50 mm conduits spanning 40 m were installed 1 m below the road surface at each site (Geotesta 2012).

The transducer units on the live end were then installed in concrete pits, and anchored to the sides and base of each pit using threaded bar and brackets. The anchor end was secured by means of a concrete filled steel bollard attached to the base of a concrete pit. These arrangements are shown in Figure 15 and Figure 16.

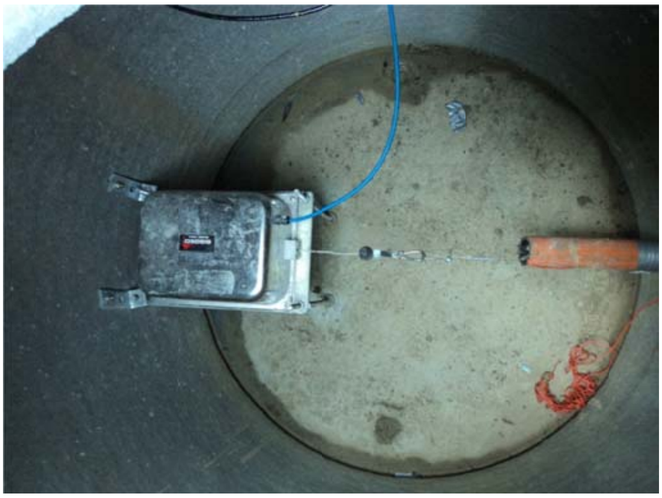


Figure 15 – Live end of wire extensometer on the Morwell site (Geotesta 2012)

Figure 16 – Anchor end of the wire extensometer on the Morwell site (Geotesta 2012)

Each wire extensometer is logged by means of a Campbell Scientific CR1000 data logger, which is installed in a secure traffic signal type enclosure. A solar panel is attached to charge the battery system. Data is sent via a 3G data modem, and is automatically uploaded to a web based server so that data is able to be accessed 24/7 by VicRoads emergency staff.

Figure 17 – Logger enclosure and solar panel on the Morwell site (Geotesta 2012)

In addition to the wire extensometers, a weather station has also been installed on-site, and is connected to the data logger. The weather station also forms part of the alert system. Alerts will be sent to emergency staff if rainfall over a certain threshold is detected.

The sensors are currently logged every 5 minutes, and the data is uploaded daily to the web based server (Geotesta 2012). Once the data reaches the server, it is compared to 'trigger levels' which define the amount of movement required for an alert to be issued. If displacements at or in excess of the trigger levels are recorded, VicRoads emergency staff will be immediately notified by SMS and email.

2.2.4. Soil Strainmeters

Soil strainmeters are a type of fixed embankment extensometer. They are defined by Dunnicliff (1988) as devices that are buried in fill material for the purpose of monitoring the changing distance between two or more points along a common axis without the use of a movable probe. They are used for measuring settlement, horizontal deformation and strain.

This instrument is normally installed horizontally in trenches, and has the advantage that several can be linked together in series to measure the deformation over a long profile. The applications for the soil strainmeter include: monitoring horizontal strain in embankment dams, monitoring tension cracks in earth structures, and monitoring rock fill dam walls (DGSI 2013) .

The soil strainmeter consists of two anchors connected by a rod and a displacement sensor. In the soil strainmeter manufactured by SISGEO, the gauge length (the distance between the anchors) may be as long as 6 metres (SISGEO 2010).

<u>Operating principle</u>

A typical soil strainmeter system consists of several measuring units connected by an extension rod to circular anchor plates. The measuring unit is a telescopic section equipped with a displacement transducer which is usually a vibrating wire sensor or a linear potentiometer. A signal cable attached to the sensor links the sensor to a readout at the surface. Figure 18 shows a soil strainmeters manufactured by SISGEO.

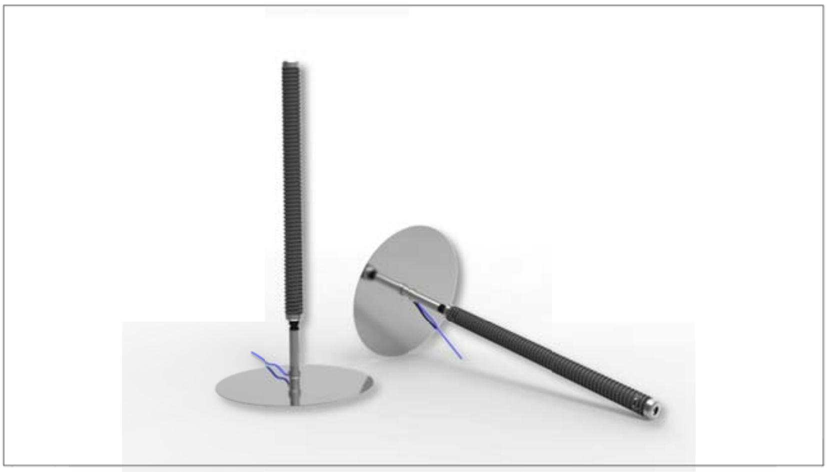


Figure 18 – SISGEO soil strainmeters (SISGEO 2010)

The soil strainmeter can be assembled in a series by using threaded rods to provide a bolted connection between the flanges. These components are linked together so that movement of one anchor relative to the other causes a change in the output of the potentiometer (DGSI 2013). The initial reading of the strainmeter is used as a datum. Subsequent readings are compared to the datum to calculate the magnitude, rate, and acceleration of movement (DGSI 2013). Figure 19 depicts SISGEO soil strainmeters in a typical installation. Note the large circular flanges which anchor the instruments in place when fill is placed around them.

Figure 19 – Soil strainmeter installation (SISGEO 2010)

The installation of soil strainmeters as the basis for an early warning monitoring system is described in the following case study undertaken by Husaini and Ratnasamy (2001).

<u>Installation case study: North-South Expressway, Malaysia</u>

In January 1996, a soil slope collapsed on the North South Expressway (one of the major highways in Malaysia) at Gunung Tempurung. According to Husaini and Ratnasamy (2001), a temporary diversion lane was constructed in order to minimise the disruption to traffic. It was then proposed that a complete realignment of the highway in the vicinity of the landslide should be undertaken.

It was decided that a monitoring system be installed to provide the basis of an early warning system to ensure the safety of workers and road users during the remediation of the collapsed slope. The instrumentation selected was soil strainmeters. This would enable ground movements to be measured with respect to pre-determined threshold limits.

Installation

The soil strainmeters in this site were selected to monitor existing tension cracks behind the unstable slope. Two soil strainmeters were installed perpendicular to tension cracks on both sides of the failed slope where movement was expected to occur, and eight soil strainmeters were installed at positions where no indication of tension cracks existed (Husaini & Ratnasamy 2001). A site plan and the installation locations are shown in Figure 20.

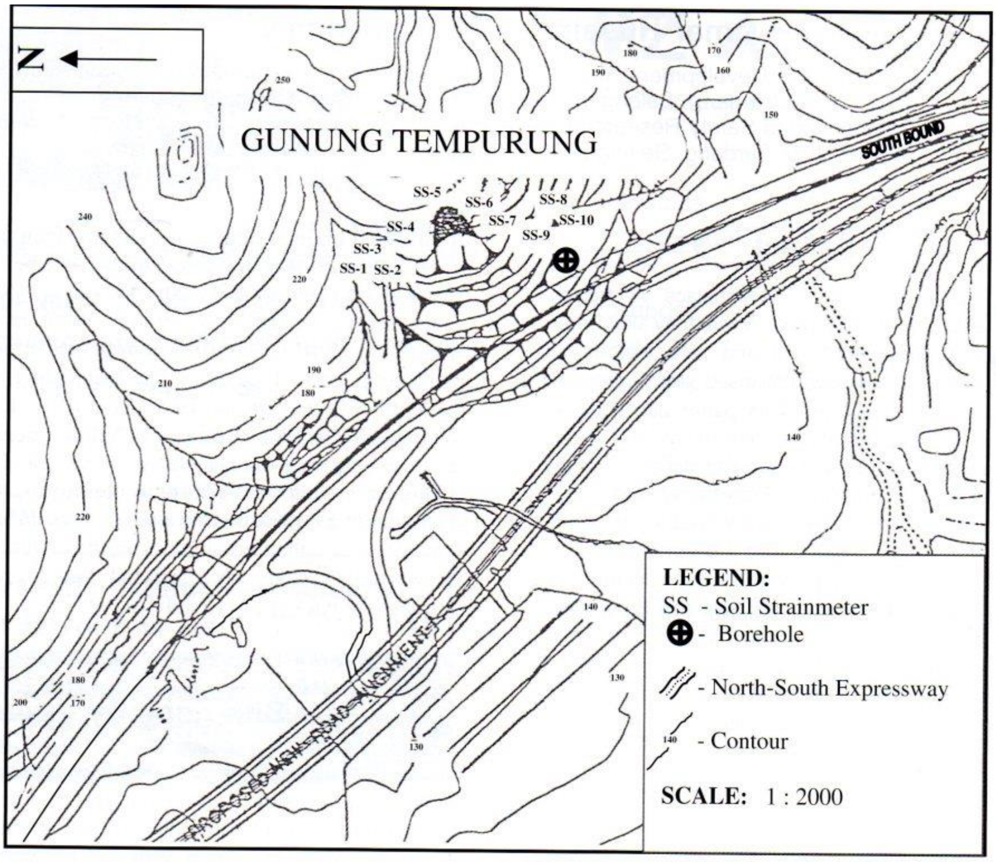


Figure 20 – Site plan showing slope failure and location of soil strainmeters (Husaini & Ratnasamy 2001)

The soil strainmeters were connected to a datalogger through a multiplexer. An early-warning system was also installed, and this consists of an array of flashing lights and sirens to alert workers of an imminent failure. The flashing lights and sirens were installed at the toe of the slope and on the slope itself (Husaini & Ratnasamy 2001). Pre-determined trigger values are programmed in the data logger, and if the recorded readings exceed these values, the flashing lights and sirens are activated. Figure 21 shows the flashing light warning sign installed on the slope near the roadway.

Figure 21 – Flashing light warning sign installed on slope (Husaini & Ratnasamy 2001)

2.2.5. Fibre Bragg Grating Sensors

Conventional strain gauges operate on electrical resistance of a fine wire or foil to measure strains. These electrical strain gauges have a significant disadvantage in that they do not continue to operate over a long period, due to the deterioration of the fine wire or foil in the instrument.

Optical fibre sensors do not suffer from this disadvantage, as they do not require electrical power for them to operate. One type of optical fibre based sensor is the Fibre Bragg Grating (FBG) sensor.

FBG sensors are a popular alternative to conventional strain gauges for monitoring civil structures such tunnels, retaining walls, buildings, foundations and tanks. They can be mounted outside or embedded within the components themselves, allowing the monitoring of structural parameter directly inside the components. This makes them an ideal choice for monitoring strains within road pavements (Nosenzo et al. 2013).

Other than longevity and versatility, the FBG sensor has a number of additional advantages over conventional strain gauges as described below:

1. Remote capability

   Because the sensor relies on the transmission of light rather than electricity, the sensing cable can run many kilometres without suffering signal degradation for which conventional sensors are prone.

2. Multiplexing

   Many FBGs can be included on one optical fibre, and several hundred can be read with one interrogation instrument. This provides a low cost option of providing many sensors on a single structure or location.

3. Electrical immunity

   They do not suffer from electrical interference from electrostatic, electromagnetic or radio frequency sources. Because of this, they are not susceptible to surge or lightning strikes.

4. Ease of installation

   Conventional strain gauges must be bonded to the structure being monitored, and the sensor needs to be connected to the transmission cable. Because the FBG sensors are written to the cable itself, the sensor and transmission cable are one unit, so installation is streamlined.

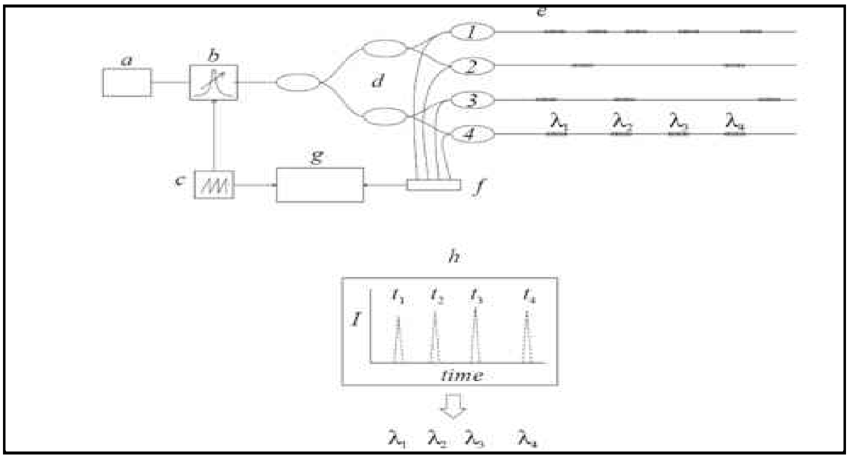
<u>Operating principle</u>

FBGs are produced by using a UV laser to modify the refractive index of the glass in the core of an optical fibre to form an interference pattern. This interference pattern will allow most wavelengths of light to travel freely down the optical fibre whilst strongly reflecting one particular wavelength. This wavelength is equivalent to twice the pitch of the interference pattern so that any strain induced in the optical fibre will increase the pitch of the interference pattern, and thus the wavelength of the reflected light. In this way, the FBG provides a direct means of measuring strain (Epsillon Optics 2013).

To use a FBG as a sensor, it is illuminated by a light source with a broad spectrum and the reflected wavelength is measured and related to the local measurands of interest. This task is normally undertaken by an instrument known as an interrogation unit. A widely-employed approach of interrogating a FBG is to illuminate it with a narrowband tuneable light source. This is known as Wavelength-Division Multiplexing (WDM) (Smart Fibres 2013).

The principle behind WDM is simple: many gratings can be combined on a single fibre and addressed simultaneously provided that each has a different Bragg wavelength. The explanation of the process has been taken from Smart Fibres (2013) and the process is explained below with reference to Figure 22:

The scan generator (c) tunes the light source, sweeping it back and forth across its range such that at any given instant the wavelength of light being transmitted down the fibres is known. When this wavelength coincides with the Bragg wavelength of an FBG, light is reflected back down the fibre to a photo detector (f). The scan generator also supplies a timing signal to the processor (g), allowing it to convert the intensity vs. time information into a spectrum. Further processing is performed to identify peaks in this spectrum, find their peak positions and convert these to strain or temperature.



Key: a) light source, b) scanning filter, c) scan generator, d) coupler network for channels 1-4, e) FBG arrays, f) photo-detectors, g) processor and h) time varying output of the detector on channel 4 showing times converted into Bragg wavelengths $\lambda\lambda i$.

Figure 22 – Schematic of WDM interrogation equipment (Smart Fibres 2013)

From here, the data from the interrogator is sent to a processing unit which converts the wavelengths gathered by the interrogation unit into the data format of choice (strain, temperature etc.). Figure 23 shows an example of a complete FBG instrumentation system.

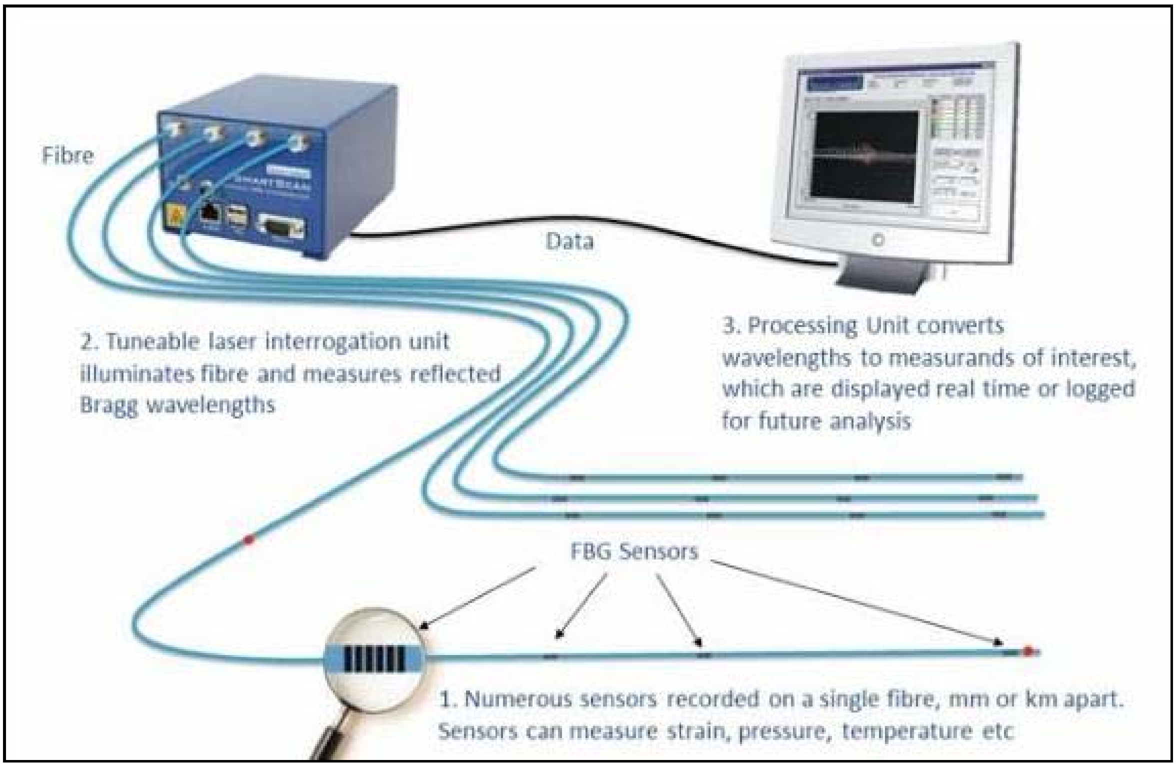


Figure 23 – FBG monitoring system (Smart Fibres 2013)

The following case study demonstrates the use of FBG sensors as an alternative for measuring pavement performance through an early warning system. Although in this case study the cause of the pavement failure is not due to slope instability, the application could be easily extended to monitoring pavements due to slope instability.

<u>Installation case study: Hume Highway, New South Wales</u>

The Hume Highway in New South Wales was constructed in the 1970's. The pavement structure consists of an asphaltic surface, with a slag road base and sandstone sub-base. The pavement is in the vicinity of a coal mine, operated by BHP Billiton. In 2009, underground mining commenced beneath the section of the Hume Highway using the longwall method. When underground coal is extracted using the longwall mining method, the ground immediately above the coal seam is allowed to collapse into the void that is created as extraction proceeds, resulting in subsidence of the ground surface (Nosenzo et al. 2013).

Nosenzo et al. (2013) state that experience has shown that when longwall mining has been conducted underneath pavements of a similar structure to that of the Hume Highway, damage caused by subsidence usually consists of cracking of the pavement and drainage structures.

However, this was not the case on the Hume Highway. Shear/compression steps, 40 to 80 mm high occurred at two locations. Both steps occurred where irregular subsidence was observed in the form of elevated compressive ground strain (Nosenzo et al. 2013).

Figure 24 – Stepping in pavement surface caused by compressive strains (Nosenzo et al. 2013)

A technical committee consisting of the Road Transport Authority (RTA), BHP Billiton and other experts from various fields was formed, and it was decided that as part of the management strategy, a total of 840 FBG strain and temperature sensors would be installed to provide continuous strain measurements in the pavement to enable ongoing monitoring of the pavement to be conducted during the continued mining operations (Nosenzo et al. 2013). The instrumentation system would also provide an early warning system to ensure the safety of road users.

The monitoring system commenced logging in January 2009, and over 21 million data points have been logged (Nosenzo et al. 2013). The success of the monitoring technique has allowed the exploitation of rich mining areas while guaranteeing the safety of the road users.

The key to the FBG monitoring system is a special glass fibre reinforced composite cable (GFRC) which is embedded with optical fibres containing the FBGs. This technology was developed by Monitor Optics Systems, and allows FBG sensors to be deployed in GFRC cable which can be several kilometres in length while providing excellent protection to the FBGs without reducing their sensitivity to changes of temperature and strain (Micron Optics 2009).

To install the sensing cables, it was decided that slots be cut in the 100 mm deep asphalt layer, and the sensing cables installed at a depth of 40 - 50 mm as shown in Figure 25:

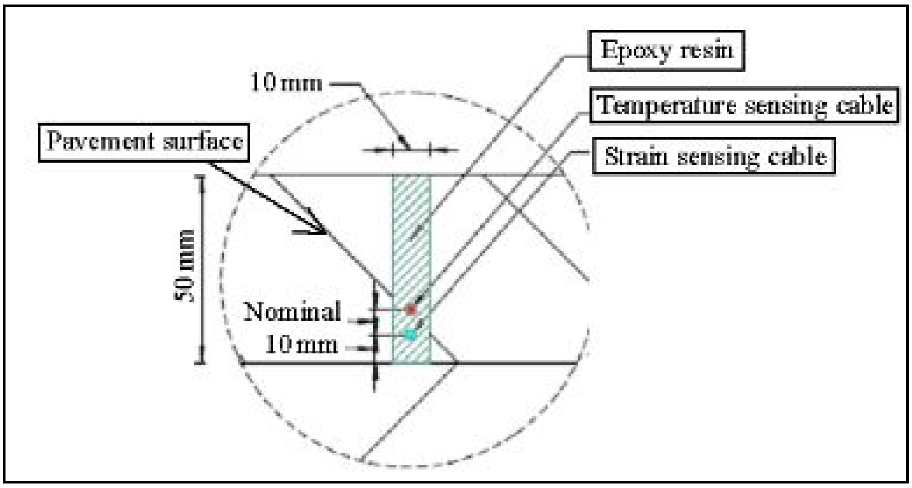


Figure 25 – Embedment of the sensing cables in the asphalt layer (Nosenzo et al. 2013)

The installation of the GFRC is outlined by Nosenzo et al. (2013) and comprise of the following steps which are also shown in Figure 26:

1. Slot was cut in the pavement and cleaned with compressed air
2. A bed of 2 part epoxy resin was poured into the slot
3. Strain sensing cable was installed with a layer of epoxy resin poured on top.
4. Temperature sensing cables were installed and a final layer of epoxy resin was poured on top.
5. Cable ends were terminated through conduits running to below-ground communication pits. Both ends of each sensing cable are terminated with

standard fibre connectors for serial multiplexing or connection to signal transmission cables.

Figure 26 – Installation steps (Nosenzo et al. 2013)

Sensing cables were serially multiplexed into strings of up to 20 FBGs inside the communication pits. From here, signal transmission cables connected the sensor strings to an onsite hut containing the demodulation equipment. The demodulation equipment consists of Micron Optics interrogators, multiplexers and processors and is shown in Figure 27.

Each FBG is interrogated every 4 seconds, and converted to strain and temperature measurements by the Micron Optics processor. This strain and temperature data is uploaded every 15 minutes to a master control computer which uploads the data to a web based server so the data can be viewed in near real time. Then, the data is automatically compared with the trigger level thresholds, and if the trigger levels are reached, a mobile text message alert is sent to key personnel through an SMS gateway (Micron Optics 2009).

Figure 27 – Micron Optics interrogators, multiplexers and processors located in the site hut (Micron Optics 2009)

2.3. Data Acquisition Systems

2.3.1. Introduction

The data acquisition system is the process of gathering the data from the instrument and presenting it to the end user. A complete data acquisition system consists of data logger components, data retrieval components and associated software (Dunnicliff 1988).

All of the instruments discussed in the previous section rely on electrically powered transducers in order for monitoring of the instruments to be undertaken. As discussed previously, the traversing slope inclinometer and standpipe piezometer require manual readings to be taken by an operator using a portable readout unit. Other instruments such as the fill extensometer and vibrating wire piezometer can also be monitored with portable readout units, but due to the instruments being permanently installed, data logging systems are commonly installed on site with these devices. Data loggers also provide the power required for the instruments which contain electrical transducers.

The main advantage of the data logger is that data from the instrument can be logged continuously at a user-defined interval. This is a significant improvement over a manual data acquisition system in that the manual monitoring process may fail to capture data that reflects a significant change in site conditions at a certain point in time.

Several instruments can usually be connected to one data logger depending on the type of instrument and site conditions. For example, the SWTC project, (which was discussed in Section 2.2.2) uses SIGRA data loggers. These loggers contain multiple channels that allow several different instruments to be powered and monitored by a single logger. They will be discussed further in the next section.

The process of data retrieval has undergone a revolution in the past 20 years (Marr 2013). Traditionally, a technician was required to attend site to read the instrument, and if there are a large amount of instruments located on site, or if the location is remote, this is a costly and labour intensive process. Presently, low cost, highly reliable wireless communication technologies coupled with web-based connections mean that instruments can be monitored from anywhere across the globe.

2.3.2. Data Loggers

Dunnicliff (1988) state that data loggers can be separated into two categories: dedicated loggers and flexible loggers. A dedicated logger is a device designed for connection to one or two types of transducer, while flexible loggers are designed to operate with a wide range of sensors.

<u>VW Mini Logger</u>

A type of dedicated data logger is the VW Mini Logger manufactured by DGSI. The VW Mini Logger is a compact data logger designed to monitor a single VW sensor, such as a VWP or soil strainmeter. This logger is powered by two alkaline ‘D’ size batteries. This is sufficient to power the logger for several months at one hour reading intervals. At the specified interval, the logger will power up the vibrating wire sensor, and save the data which will be a frequency in Hertz, and a temperature in Degrees Celsius.

The logger can be programmed to read thermistor or RTD temperature sensors, and the temperature calculation is undertaken within the logger itself. This logger also has the option of being fitted with a RF communications lid which operates over a spread spectrum of the 2.4 GHz range (DGSI 2012). This allows data to be downloaded remotely over a short range by using a 2.4 GHz RF modem.

Figure 28 – DGSI VW Mini Loggers in standard configeration (left) and with optional RF transmission lid (right) (DGSI 2012)

The VW Mini Logger is programmed and downloaded via proprietary DGSI software called VW Manager. The logger is programmed by specifying the sensor identification, reading frequency, type of temperature sensor, calibration factors and time (DGSI 2012). When the data within the logger is ready to be downloaded, the logger is connected to a computer using the cable supplied. The data is stored as an ASCII file, which is easily opened with Microsoft Excel. The file contains two data values for each reading: a value in Hz and a value in engineering units. Therefore, calibration factors need not be applied in the spreadsheet (DGSI 2012). A VW Mini Logger in a typical installation is shown in Figure 29.

Figure 29 – VW Mini Logger connected to PC for data retrieval

The VW Mini Logger has several advantages over conventional full size loggers. Firstly, they are relatively inexpensive compared to full sized loggers such as the Campbell Scientific CR1000, which will be discussed shortly. Also, they are robust and simple to use. The logger can also survive being inundated in several metres of water as the circuitry within the logger is fully sealed. Finally, they can be fitted with an optional radio receiver lid which allows the logger to be read wirelessly using a radio modem, although this option is very power intensive and significantly reduces battery life.

SIGRA data logger

The SIGRA logger is a type of flexible data logger and can be programmed to monitor sensors that output frequency, voltage, resistance and pulses (such as reed switches). The logger is designed and sold by the local company Sigra which is located in Acacia Ridge, Queensland. The logger is managed using Sigra's DOS based software.

The logger contains 8 channels, and is able to transmit data over the 433 MHz frequency up to a range of 800 m (Sigra 2009). In addition to the wireless capability, the logger is easily programmed to operate with most commercially available modems which allow wireless transmission of data over the mobile network. The logger is powered by a rechargeable battery pack which contains an on-board charging regulator and fuse to allow direct connection to a solar panel.

Data recorded by the logger is stored in the logger’s memory until it can be downloaded to a PC. The logger can store at least 18000 – 45000 data samples, depending on the number of channels being recorded (Sigra 2009). An added advantage of this logger is the unit’s liquid crystal display (LCD). This allows the current state of the instruments connected to the logger to be viewed in real time by use of the 4 buttons on the face panel of the logger. This can be seen in Figure 30. In this Figure, note the solar panel installed on the side of the cabinet. This 1-watt, 6-volt solar panel is sufficient to ensure the battery pack continuously remains at operational voltage provided the solar panel receives sufficient radiation.

Figure 30 – Sigra logger data retrieval with a PC

SIGRA loggers form a critical part of the early-warning monitoring system at the South West Transport Corridor (SWTC) site, where over 30 of these loggers have been installed to monitor a network of 80 VWPs and several rain gauges.

Campbell Scientific CR1000 data logger

The Campbell Scientific CR1000 logger is one of the more powerful data loggers on the market. It is a type of flexible data logger and can be programmed to monitor a diverse range of sensors.

The CR1000 can undertake many tasks, such as measurement of sensors, data storage and processing. It also has the ability to control external devices and drive direct communications and telecommunications. The electronics are RF shielded and glitch protected by the sealed, stainless steel canister (Campbell Scientific 2013). A battery-backed temperature compensated clock assures accurate time-keeping. The module can simultaneously provide measurement and communication functions. The on-board, BASIC-like programming language supports data processing and analysis (Campbell Scientific 2013).

The logger will support up to 16 sensors through its single ended analogue channels but can be easily expanded by connecting a multiplexer. A CR1000 logger with optional Multiplexer is shown in Figure 31. This logger is used to control and monitor 8 electronic level (EL) beams which are used to monitor movements on a bridge.

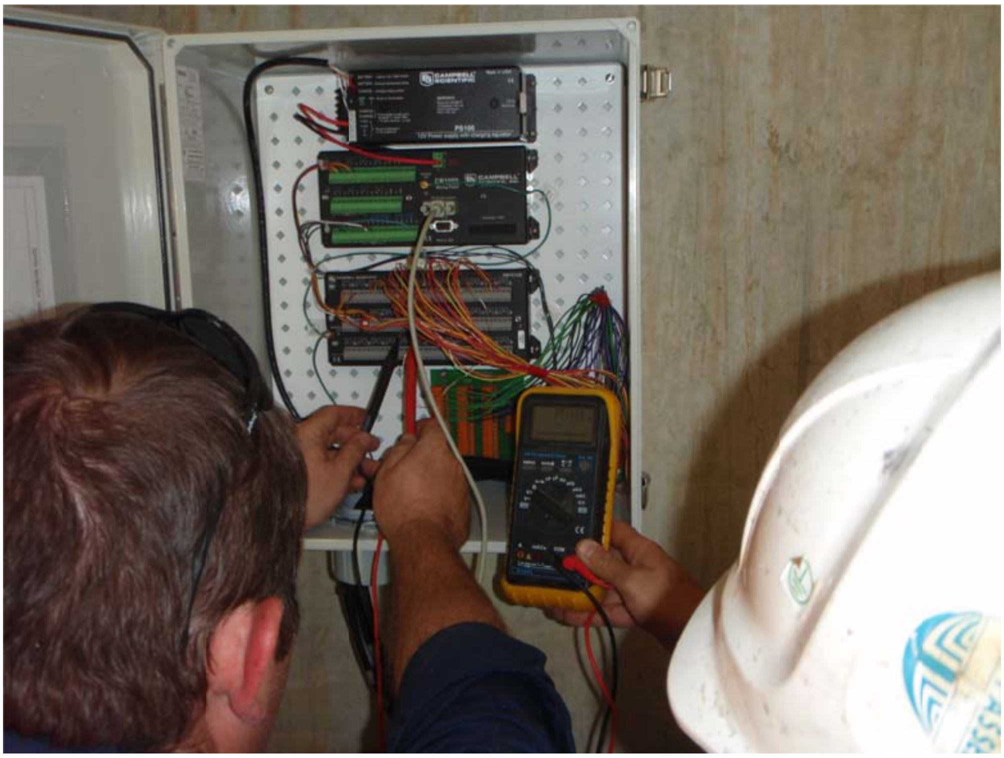


Figure 31– Campbell Scientific CR1000 logger (centre), connected to Multiplexer (bottom) and battery box (top)

A peripheral port is also included on the logger. This allows additional devices to be connected such as the Campbell Scientific NL120 Ethernet module. It allows the data logger to communicate over a local network or over an internet connection through a data modem by using the common networking and communication protocol- TCP/IP (Campbell Scientific 2013).

2.3.3. Remote Data Retrieval Systems

On remote sites, or sites which have difficult access, it is usually an economical option to employ some form of remote data retrieval system. Both the Sigra and DGSI loggers have radio frequency data transfer capability. This is a basic form of remote data retrieval, but this still requires that a technician be present on site to download the data through a radio modem due to the limited range.

As the mobile communication network continues to improve, network access is now available on sites in very remote locations. In this case, a compatible data logger can be connected to a mobile data modem and data can be retrieved through connection with a web server or by using a dial-up modem on a fixed telephone line.

A demonstration of how radio and mobile communication technology can be used in conjunction is shown in Figure 32. This Figure shows a chain of Sigra loggers in a network configuration that use radio frequency communication to transmit data to the base station logger. From here, the data is sent to a web server by a data modem over the mobile network. This is the data acquisition procedure used on the South West Transport Corridor project which was previously discussed.

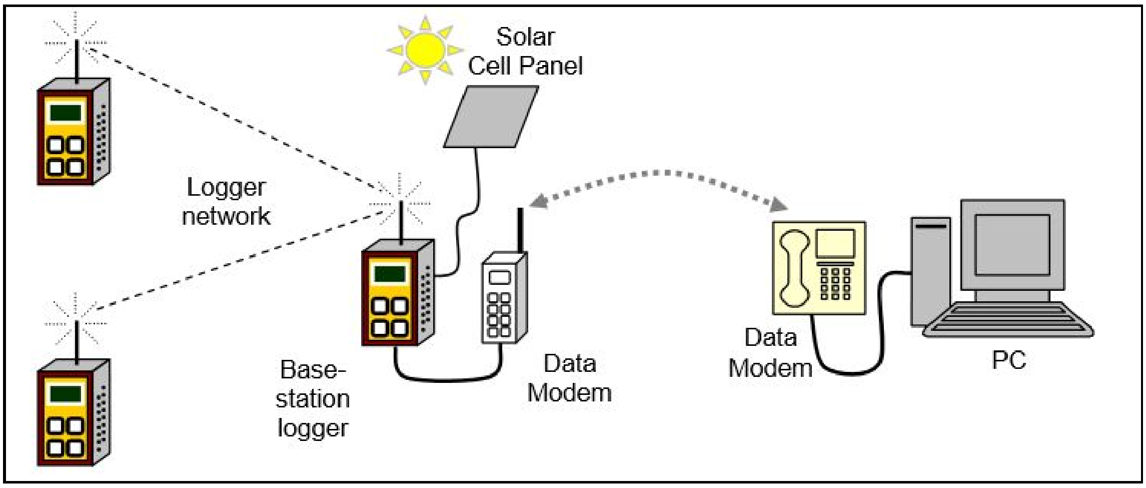


Figure 32 – SIGRA logger data retrieval via radio link and data modem (Sigra 2009).

Although there are many makes and models of data modems available, one that is commonly used is the Maxon Mod Max data modem. This modem is a rugged, full duplex data and SMS modem designed to operate on Third Generation (3G) 850 MHz mobile networks (Maxon 2009). 3G is an efficient and secure mobile wireless technology that compliments fixed line or mobile applications (Maxon 2009).

Figure 33 – Maxon Mod Max 3G data modem (Maxon 2009)

An example of the application of this modem is shown in Figure 34. This shows an Environdata automatic logging rain gauge connected to a Maxon Mod Max data modem. To download the data, a dial-up modem is connected to a fixed phone line and the rain gauge is dialled using the rain gauge software on a PC. In Figure 34, note the small solar panel (top) which is used to charge the rain gauge battery, and the large solar panel (bottom) for charging the battery which powers the modem. Modems are generally power intensive so they require a larger solar panel to meet this demand.

Figure 34 – Environdata automatic rain gauge with Maxon ModMax 3G modem

In situations where there is poor or no mobile network coverage and no access to fixed phone lines, a technician may be required to attend site to download the data, or a satellite communications system may be considered.

A reliable satellite modem that delivers end-to-end internet protocol (IP) connectivity is the Hughes 9502 Broadband Global Area Network (BGAN) data modem. The modem operates over the dedicated Immersat BGAN network, and it’s IP data connectivity makes it suitable for use in monitoring applications (Hughes 2013).

An advantage of using IP connectivity is that there are no connection charges. The user only pays for the data that they download. This is ideal for monitoring instruments, as the data files are normally small, therefore operating costs are kept to a minimum.

However, the Hughes 9502 does require to be connected via an Ethernet (RJ45) or USB to the logger, making it unsuitable for use with Sigra loggers, but it can be connected to a Campbell Scientific CR1000 by using the optional NL120 Ethernet module.

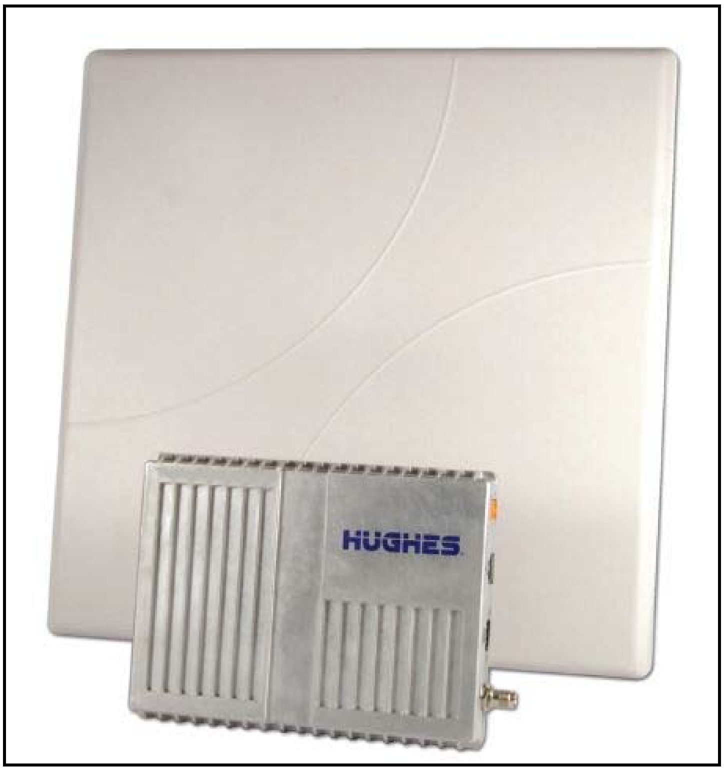


Figure 35 – Hughes 9502 BGAN modem with satellite antenna (Hughes 2013)

2.4. Summary

This literature review has presented several different types of geotechnical instrumentation that can be used for monitoring performance of road pavements and slopes. Although each type of instrumentation presented is unique, they all provide a means of measuring water levels or pressures, or displacements and deformations within the ground surface. When combined with an automatic data acquisition system, the measurements from these instruments can be viewed from the comfort of the home or office. Most importantly, remote data retrieval opens the possibility for the implementation of an early warning system, which allows alerts to be issued if excessive ground displacement or deformation is detected.

3. Site Description and Geology

3.1. Introduction

The Highway-Reward copper and gold deposit is located approximately 35 km southwest of Charters Towers, Queensland, adjacent to the Gregory Developmental Road (see Figure 1). The Gregory Developmental Road runs southward from Georgetown, via Lynd Junction and Charters Towers to Springsure, about 900 km away. This Highway serves the major mining centres of Central Queensland, and is subject to use by a large proportion of heavy and oversize vehicles.

Charters Towers is within a subtropical region, with distinct dry and wet seasons. The average annual rainfall amounts to 650 mm and much of the precipitation occurs as high intensity rainfall events between November and April.

The Highway-Reward Mine was in operation from 1997-2005 and was operated by Mount Windsor Joint Venture. This joint venture was comprised of 70 per cent Thalanga Copper Mines and 30 per cent Grange Resources (Houlahan, Ramsay & Povey 2003).

3.2. Geology

The Highway-Reward copper and gold deposits are hosted within the Trooper Creek Formation, which is one of four formations within the Seventy Mile Range Group (Beams & Dronseika 1995). The Trooper Creek Formation comprises of a complex mix of rhyolitic, dacitic and andesitic lavas, sin-sedimentary intrusions , volcaniclastic rocks and volcanic and non-volcanic siltstone (Beams & Dronseika 1995).

According to Beams and Dronseika (1995), the deposit comprises of two main ore bodies in the form of pyrite-chalcopyrite pipes: Highway and Reward. Reward is a ‘blind’ orebody and was discovered in 1987 after a long history of exploration by various companies in the area. The highway pipe was discovered 1990 and is located approximately 200m NNW of the reward orebody beneath the abandoned Highway open pit (the Highway pit was host to a small open-cut gold operation in the late 1970's).

The total expected yield of the Highway orebody is approximately 1.2 million tonnes of 5% copper, while the Reward orebody's yield has been calculated as 0.75 million tonnes of 8.7% copper. In addition, an oxide resource of 0.17 million tonnes overlies the Reward orebody. This is estimated to yield 3.7g of gold per tonne of ore (Beams & Dronseika 1995).

Overburden removal of the Highway open pit commenced in October 1998 with open cut mining continuing up until December 2001. To permit this operation, the Gregory Developmental Road was diverted around the western side of the site. From 2001, the underground mining operation commenced using up-hole benching and sublevel caving techniques by accessing a portal located in the south wall of the open pit (Houlahan, Ramsay & Povey 2003). Mining activities concluded on 8 July 2005 after the ore reserves were exhausted. Rehabilitation of the site commenced in September 2005, and an environmental monitoring program has been established (Houlahan, Ramsay & Povey 2003).

3.3. Slope Instability and Pavement Failure

Coffey Geotechnics has provided an in-depth analysis of the site geology and postulated failure mechanism.

Subsurface conditions in the southwest pitwall area of the Highway open pit generally consist of extremely weathered sediments, in the form of stiff sandy clays, overlying the volcanic rocks which host the orebody pipes. The volcanics vary from highly weathered to fresh, with depth of weathering being approximately 40 m in the Highway pit western wall (Coffey Geotechnics 2011a).

The southwest pit wall is host to a large fault known as the West Wall Fault. This fault consists of up to 8 m thickness of sheared rock and dips SE at an angle of 50 to 65° (Coffey Geotechnics 2011a). Figure 36 shows the extent of the large West Wall Fault.

Figure 36 – North west view of the West Wall Fault, July 2013

In addition to the West Wall Fault, another fault line known as the Conviction Fault, cuts across the West Wall Fault. According to Coffey Geotechnics (2011a) there is no information regarding the character or thickness of the Conviction Fault.

During open cut mining operations on the western wall of the mine, small to large slips have occurred. The largest being in September 2000, and another in December 1999. Coffey Geotechnics (2011a) state that the September 2000 failure appears to have occurred by slipping down the low strength West Wall Fault, with sub-horizontal shearing through approximately 40 m thickness of rock at the toe of the excavation. Coffey Geotechnics (2011a) go on to say that the major factors in the development of the rock slide were considered to be the presence and low strength of material contained in the zone of the West Wall Fault, and the elevated groundwater pressures in the fault zone. Additional pressure relief drain holes were drilled in the lower west wall as a consequence of the September 2000 failure, and the mine was forced to cut back operations in this area (Coffey Geotechnics 2011a). It is also a point of interest that the September 2000 failure was preceded by cracking in the Highway Pit haul road.

The mine geometry and location of the December 1999 and September 2000 slips are shown in Appendix B.

According to Coffey Geotechnics (2011a), on the evening of 18 July 2005, Thalanga staff reported cracking in the pavement of the Gregory Developmental Road, adjacent to the south-west wall. The total length of this cracking now extends over 100 m of the roadway, and at the closest point, the crack is only 50 m from the crest of the mine open cut pit (see Figure 37 & Figure 38). Geotechnical specialists were engaged, and recommendations were made to immediately seal the cracking and install survey monitoring prisms in this area in order to monitor possible ground movements.

Figure 37 – Marked location of pavement cracking (image courtesy of Google Earth)

Figure 38 – Repaired pavement cracking, July 2013

Subsequent site visits by Coffey Geotechnical staff also discovered cracking adjacent to the ground surface in the vicinity of the West Wall Fault. Images of these observed cracks are shown in Figure 39. However, it is noted that these cracks are no longer visible due to infilling over time.

Figure 39 – Observed cracking in the vacinity of the West Wall Fault (Coffey Geotechnics 2011a)

3.4. Postulated Failure Mechanism

Coffey Geotechnics has provided ongoing advice to TMR regarding the Highway-Reward site, and they have developed a postulated slope failure mechanism that may associate cracking observed in the Gregory Developmental Road with slope instability in the south western wall of the open cut pit.

As explained in Section 3.3, historical failure of the south-west wall has been associated with the West Wall Fault, and elevated ground water pressures in this vicinity. The first failure mechanism that was investigated was a slip failure in line with the West Wall Fault. Coffey Geotechnics (2011a) explains that this is not kinematically feasible as it involves sliding normal to the dip direction of the strata. The failure direction in line with the West Wall Fault is shown in Figure 40, and is represented by the arrow indicating 'B' direction. A detailed cross-section is shown in Figure 41.

Coffey Geotechnics (2011a) states that a more realistic scenario involves shear occurring in line with the dip direction, and is represented by the arrow indicating 'A' direction shown in Figure 40. This postulated failure mechanism is consistent with the observed cracking in the pavement surface and natural ground, which has been shown in Section 3.3.

One problem with this model is that complete failure requires shearing to continue through relatively intact rock below the West Wall Fault, and in addition, shear must occur through rock of the same condition on the southern wall to complete the release surface (Coffey Geotechnics 2011a). These areas have also been indicated on Figure 40, and the cross-section of the inferred release surface can be seen in Figure 41.

Slope stability analysis of the postulated failure mechanism was undertaken by Coffey Geotechnics using Sarma's method with non-vertical slices. This analysis yielded a factor of safety for long-term conditions of 1.35 (Coffey Geotechnics 2011a).

To summarise the overall stability concern, Coffey Geotechnics (2011a) state that 'while catastrophic failure is probably not imminent for the pit wall in its present condition, conditions are not as stable as would usually be required for long-term pit slopes. Significant long term creep movements are likely to occur' (Coffey Geotechnics 2011a).

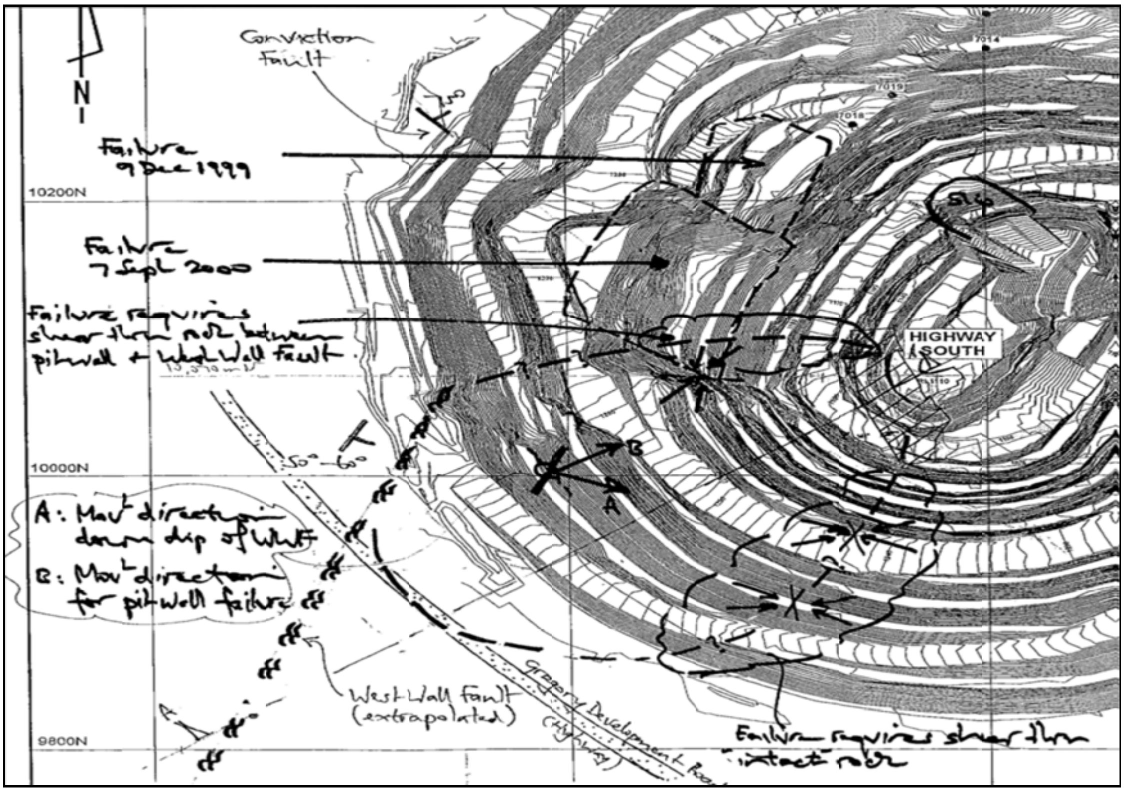


Figure 40 – Predicted failure mechanism (Coffey Geotechnics 2011a)

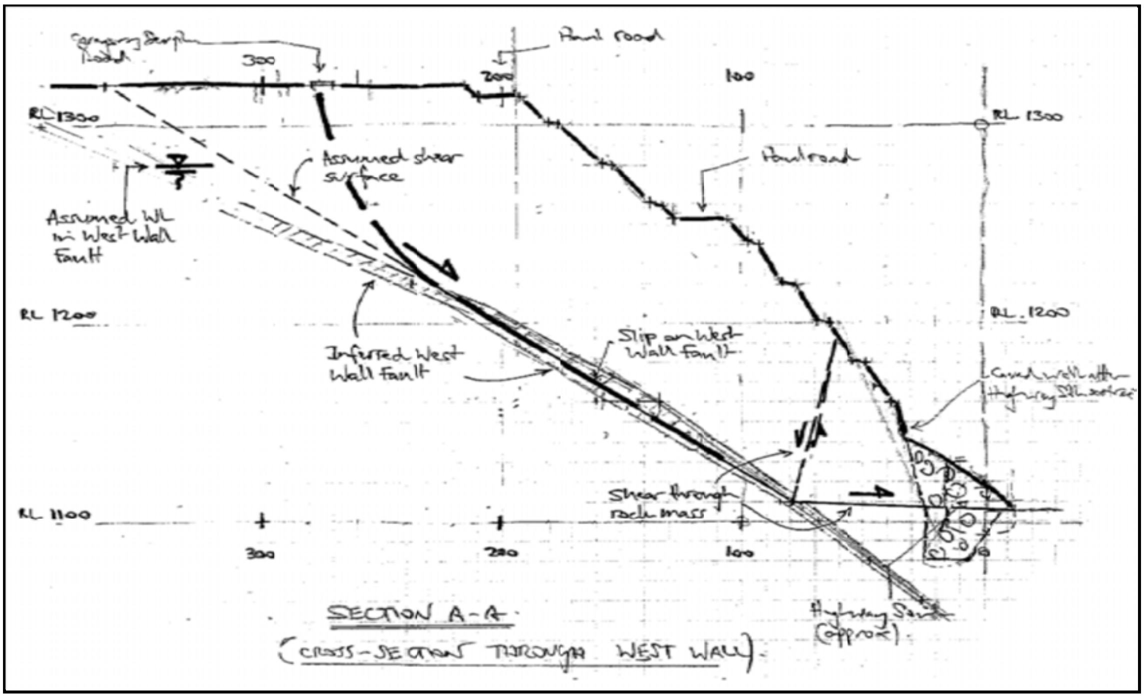


Figure 41 – Cross section of predicted failure mechanism through the West Wall Fault (section A-A from Figure 13) (Coffey Geotechnics 2011a)

3.5. Survey Prism Monitoring History

As mentioned in Section 3.3, one of the initial recommendations was to install an array of survey prisms to monitor any possible ground movement. To date, a total of 36 survey prisms have been installed within the mine site and road reserve, with a survey base station included on the western side of the highway. Appendix C depicts the location of these prisms.

The prisms monitoring have been ongoing since 2005, but Coffey Geotechnics (2011a) state that the survey prisms on the pit walls have not been monitored for some time as it is believed that they do not contribute useful data.

Prism movement trends have been detailed by Coffey Geotechnics (2011a), and the observations contained within this report are summarised in part below:

1. Recorded movements during 2005 to 2006 showed response heavy rainfall events followed by dry periods with no recorded creep movements – in some cases apparent reversal of movement was recorded.

2. Since 2009 there has been no significant horizontal movements

3. Since 2009, relatively insignificant vertical movements have been recorded. Prior to mid-2009, it was thought that these movements could have been influenced by seasonal shrink-swell of ground materials.

4. Following wet seasons during 2009/2010 and 2010/2011; no significant sustained movements have been recorded.

5. Overall, horizontal movements have increased by a factor of 3 since 2005, however, the prism movements have not been accompanied by highway cracking and the observed movements do not indicate accelerated movements.

Finally to summarise the results of the prism survey, Coffey Geotechnics (2011a) states 'it is suggested that recorded movements confirm overall area instability and residual risk' (Coffey Geotechnics 2011a).

Although the survey data gathered from the prisms has provided some evidence that significant horizontal ground movement may be occurring, a site visit by TMR personnel highlighted some serious deficiencies in the installation of the prisms themselves, which could possibly compromise the integrity of the data. These observations are noted below:

1. The prisms are mounted on a metal star picket driven into the ground surface with the prism housing bracket welded to the top of the picket. This type of mounting is questionable and can lead to erroneous data capture. The pickets are susceptible to being knocked or vandalized, especially those close to the roadway and therefore the datum for that prism will be in error.

2. It was noted that some of the prisms had suffered damage due to a recent fire. The current mounting arrangement makes them especially susceptible to damage from fire.

3. The prisms mounted on the mine bund would be very susceptible to unrelated subsidence movements due to the disturbed, uncompacted nature of the soil. This could lead to erroneous data readings.

Coffey Geotechnics (2011b) also highlight the shortfalls of the prism survey, and states that to date they have displayed a number of deficiencies, including occasional anomalous readings, significant gaps between readings (when instruments require repair) and finally, the display of erratic variations (+/- 5 to 10 mm).

In summary, the survey prisms had shown some insight into the possible mechanism and magnitude of surface movements due to the unstable mine slope, and this was enough to warrant further and ongoing investigation as there is a significant risk to road users. However, the prism survey is a somewhat unreliable method of monitoring in its current condition, so this was a major motivation for TMR to investigate more reliable and accurate methods of monitoring the site.

4. Selection of the Instrumentation System

4.1. Instrumentation System Proposals

The several types of instrumentation discussed in the literature review were considered as the basis of an early-warning monitoring system. The type of instrument and the installation arrangement with respect to data acquisition and ongoing monitoring were critical factors in the selection of an appropriate system.

Several proposals were undertaken by other contractors other than TMR. TMR also considered these proposals along with monitoring systems that are currently in place on other TMR projects. Each instrumentation system proposed will be discussed in turn.

4.1.1. FBG Based Monitoring

An FBG based monitoring system was one of the instrumentation system proposals seriously considered by TMR. Coffey Geotechnics engaged a specialist contractor, Monitor Optics Systems, to draft a proposed FBG based monitoring system for the Highway-Reward site. Fundamentals of FBG sensor monitoring was explained previously in Section 2.2.5

The following is a summary of the monitoring system proposal drafted by Monitor Optics Systems:

For the FBG instrumentation, a total of 3 sensor locations were proposed: two locations spanning the Gregory Developmental Road, and one perpendicular to the existing West Wall Fault. It was proposed that each location would be connected to a secured monitoring station, at which an interrogation unit, logger, modem and battery would be housed. A solar panel would provide power, with sufficient battery capacity for four days. In addition, an automatic rain gauge would be included at the monitoring station.

This arrangement would provide a robust early warning system in the case of excessive ground movements, with the ability to automatically notify key personnel upon the detection of pavement movement in excess of the pre-determined trigger levels.

Monitoring Optics Systems outlined the following requirements for each sensor location:

1. A distributed sensing cable with four FBGs located at a 10 metre spacing
2. The FBG cable to be anchored in soil at 10 metre intervals
3. The FBG cable to be decoupled from matrix except at anchor points
4. FBGs to measure up to 150 mm of displacement between anchor points (15,000 microstrain for 10 metre gauge length)
5. The FBG cable to accommodate to movements in the ground
6. FBGs to be appropriately temperature compensated

For temperature compensation, another array of FBGs (four FBGs located at 10 m spacing) would be provided at each location. In addition, the FBG strain sensing cable would be isolated from contact with soil to eliminate the possibility of the sensor and cable causing local reinforcement of the ground at the location.

Both the FBG strain and temperature sensing cables would be interrogated using a Micron Optics SM125-500 interrogation unit. According to Micron Optics Systems, this unit is capable of interrogating four channels simultaneously at an acquisition frequency of 2 Hz, and has the required bandwidth to measure the expected displacements between sensing cables.

4.1.2. Inclinometers

An inclinometer based monitoring system was briefly considered. For the system to meet the requirements, IPIs would have to be used once the failure plane was located by means of manual monitoring.

An immediate sign that inclinometers would not be suitable for the basis of the system is the nature of the West Wall Fault. The depth of the West Wall Fault is considered to be too excessive to enable inclinometers to be a feasible option.

Because the failure mechanism is only postulated, a fair amount of uncertainty associated with the extent and nature of the mechanism, it was finally decided that inclinometers would not be suitable, so they were not considered further.

4.1.3. Piezometers

It was recognised that no matter which instrumentation system was selected, it would be important to install some form of groundwater monitoring system in order to provide useful information about the nature of the groundwater conditions, so possible relationships between groundwater levels and displacements could be determined.

4.1.4. Soil Strainmeters

Coffey Geotechnics proposed a soil strainmeter based monitoring system. Coffey Geotechnics (2011b) provided a detailed proposal of this system and it is presented here:

The monitoring locations would be identical to that of the FBG system explained previously; namely 3 sensor locations in total, with two locations spanning the Gregory Developmental Road, and one perpendicular to the existing West Wall Fault. An automatic logging rain gauge would also be installed on the site.

The following are requirements specified by Coffey Geotechnics (2011b) for each of the three sensor locations:

1. Four 6 metre long DGSI soil strainmeters (each line spanning 24 or 30 m).
2. Sensors installed in trenches approximately 1.2 m deep and 0.6 m wide.
3. Each sensor to have a measurement range of 150 mm.
4. Resolution and precision of sensors to exceed that of the current prism monitoring system.

For the data acquisition and monitoring system, it was proposed that a Campbell Scientific CR1000 logger be used. At an interval of 20 minutes to 1 hour, readings from the instruments would be taken by the CR1000 logger and the data stored. A satellite modem would be installed to send the stored data at pre-determined intervals to a dedicated web server.

It was proposed that the ATLAS web monitoring system provided by DGSI would be used for the web server. From the server, email alerts and SMS alerts could be distributed to key personnel upon the detection of excessive ground movements.

Coffey Geotechnics (2011b) also mention the possibility of inclusion of an audible and visible warning system to warn motorists of danger, but he states that the significance of such alarms may not be clear to motorists, and the consequences of false alarms would need to be carefully considered.

4.1.5. Wire Extensometers

TMR proposed a wire extensometer system. It was proposed that the instrumentation would be installed in three locations, two locations spanning the Gregory Developmental Road, and one location spanning the projected failure zone extended from the West Wall Fault location. Each instrument would span around 35 metres, so this would easily enable the full width of the pavement to be monitored.

The instruments spanning the road pavement would be installed by means of horizontal boring under the road pavement, terminating at pits at either end for the anchor and wire extensometer transducer. The instrument spanning the cracking in the mine area could be installed by excavating a trench terminating at pits at either end.

Due to the similarities between case studies, it was proposed that the installation method developed by Geotesta for the Morwell site be used as a basis for the installation at the Highway-Reward site.

4.2. System Selection

4.2.1. System Requirements

A number of requirements for the system were identified by the client and provided to TMR within the contract documentation. These requirements are listed below:

1. The system has to be able to operate in an isolated area without continued maintenance.
2. Data has to be provided at near real time in order to provide an early warning in the event of pavement failure.
3. The system must operate reliably for a minimum service life of 5 years (with a view to 10 years).
4. The selected system needs to be vandal proof due to the isolated nature of the site and its proximity to the carriageway.
5. It must be cost effective both initially and in the long term (infrastructure cost, data collection and maintenance).
6. It has to have the ability to be installed without major plant and equipment due to the isolated nature of the site.
7. The system needs to operate and remain functional in extreme weather conditions such as extreme fluctuations in temperature and flash flooding.

8. The system must be able to operate without the provision of a mains power source.

4.2.2. Evaluation of Options

The instrumentation system options discussed in Chapter 4 were evaluated against the criteria (Section 4.2.1). Although FBG sensors and soil strainmeters met most of the requirements, there was one major disadvantage that they both had over the wire extensometer system. This major disadvantage is that both soil strainmeters and FBG sensors require excavation of the road pavement in order to install them.

Excavation of the pavement was considered to be a serious problem as the existing cracking in the road is considered to be an important feature from a visual monitoring perspective, and excavation would destroy this feature. Secondly, excavation would require a temporary road closure which would result in major traffic disruptions.

After careful consideration, the wire extensometer system was selected on the basis that it required no pavement excavation for the installation to be undertaken, in addition, the system had a recent proven success as the basis of an early-warning remote system on the Morwell site in Victoria. The Highway-Reward and Morwell sites also had the identified similarity in that they are both large open-cut mines which are in close proximity to major roads which are displaying signs of failure due to pitwall instability. This fact, coupled with the ease of installation and proven success was enough to convince the client that the TMR wire extensometer proposal was the most attractive option.

5. Design and Installation

5.1. Introduction

The system design process started with a site visit so the proposed location of the wire extensometers could be identified. In addition, a secure location for the data acquisition system was also selected.

The design of the wire extensometer system was based on that of Geotesta's wire extensometer system at Morwell. However, a number of deficiencies were identified with the Morwell installation. Because of this, critical elements of the system were redesigned in order to rectify the identified faults.

After the system was designed, the required components were selected and working drawings of the system and components were drafted. Finally, due to the remote nature of the site, the system installation was undertaken in 2 stages.

5.2. Selection and Design of System Components

5.2.1. Location Selection

A site visit was conducted in order to confirm the locations of the three instruments: WE1, WE2 and WE3, as well as the location of the communications pole and cable trenching. The locations of these components were marked with survey pegs and the approximate locations were recorded on a handheld GPS device. The location plans can be seen in Appendix D.

The location of existing services was also important, as it was known that a fibre optic communications cable lay within the site. The directional boring contractor is also a licensed service locator so they were able to confirm the location of the fibre optic cable.

At this stage, an existing water monitoring well was located approximately 200 m north of the WE3 location. Note that the position of this well has not been marked on the location plan shown in Appendix D, and no information regarding the installation of this well was able to be obtained.

The well cover is a steel pipe, approximately 850 mm high. The depth of the well was measured, and was found to be approximately 45.26 m (RL 276.37 m) in depth, with a water level of 19.16 m (RL 302.47 m). A VWP was installed in this monitoring well by lowering it into the open well to a depth of 45.0 m (RL 276.63 m) and attaching the cable to the lid. A DGSI VW Mini Logger was then attached.

Although the well was located a fair distance from the site, the VWP installed in the well would give some indication of the ground water levels present, which would assist in later stages of data interpretation. The VW Mini Logger was programmed to take readings at 1 hour intervals in order to capture any changes in groundwater level accurately. Figure 42 shows the installation of the VWP and logger.

Figure 42 – Installation of VWP and logger in existing monitoring well

5.2.2. Component Design: Adjustable Brackets and Bollards

At the Morwell site, Geotesta had used brackets to attach the wire extensometer unit to the base and side of the concrete pit enclosure. It was identified that any movement or settlement in the concrete pit would result in tension on the wire, and possible movement in the transducer, which would ultimately result in false readings. Because of this, it was decided that this method of attaching the wire extensometer transducer could not be used.

Another problem was that the installation pits at the Morwell site had been subjected to flooding and inundation due to stormwater runoff flowing into the pits. This problem had been overcome by providing a water level alarm which was in the form of a transducer wired to a channel on the Campbell Scientific logger. When the water level reached a certain height the alarm was triggered and notified personnel who would attend site and pump the water from the pits. This system could not be implemented on the Highway-Reward site, due to the remote location, so an alternate design was needed.

To overcome the above problems, it was decided that the wire extensometer transducer would be installed on top of a steel bollard that was firmly anchored into the existing ground. This bollard would not be attached to the installation pit. The theory is that the transducer could then be placed as near as possible to the ground surface, and any stormwater runoff entering the pit would be drained away before reaching the height of the transducer. Also, as the bollard would be firmly anchored and independent of the installation pit, any settlement of the pit would not have any impact on the wire extensometers.

To mount the wire extensometers on the steel bollards, angle-adjustable brackets were designed. These adjustable brackets help to overcome the problem of the wire extensometer transducers being mounted higher than the conduit entrance. The angle is adjusted during installation in order to minimise fouling of the cable on the conduit entrance. Appendix E contains detail of the wire extensometer mounting arrangement.

A sketch of the bracket concept was provided to a local steel fabricator, who fabricated three adjustable-angle brackets, as well as adjustable anchor points. The heights of the brackets are adjusted by means of 20 mm threaded bars.

Figure 43 shows the live end and anchor end brackets before installation. Note the nuts and steel plate at the surface of the bollard. These allow the correct height to be set before they are set in concrete inside the bollard.

Figure 43 – Adjustable brackets: live end (left) and anchor end (right)

5.2.3. Communications Pits

The wire extensometer transducer and anchor are required to be housed in pits. As mentioned in Section 2.2.3, on the Morwell site concrete pits were used. Concrete pits were deemed to be too heavy and expensive so plastic pits were investigated. Plastic pits would also allow a hole to be easily cut in the base so the pit would not interfere with the installation of the bollards.

5.2.4. Working Drawings

Once the location selection was finalised, and configuration of the brackets, bollards and pits had been selected, working drawings were produced showing the detail of the installations. These detailed drawings are shown in Appendix E.

5.2.5. Communications Pole

The next major component of the system to be designed was the communication base station. In their soil strainmeter proposal, Coffey Geotechnics had suggested a secure enclosure in which the communication and logging devices would be located. Upon visiting the site, it was realised that this enclosure would have to be located on the western side of the road which is exposed and in open view to road users. This location was considered to be undesirable, as it would be highly likely that the monitoring station would be the target of vandals. Therefore, it was decided that the monitoring station would have to be installed on the eastern side, which is less exposed due to the presence of vegetation.

The possibility of using a mid-hinged pole similar to the type which is used to position traffic monitoring cameras was investigated. The general operation of these poles can be seen in Figure 44. The hinged pole has the advantage that all of the hardware could be mounted well clear of the ground, while making it easily accessible for service and maintenance. Having the hardware mounted in an elevated position would reduce the risk of damage from fire and vandalism, while allowing the solar panel and weather station to be mounted above the tree line.

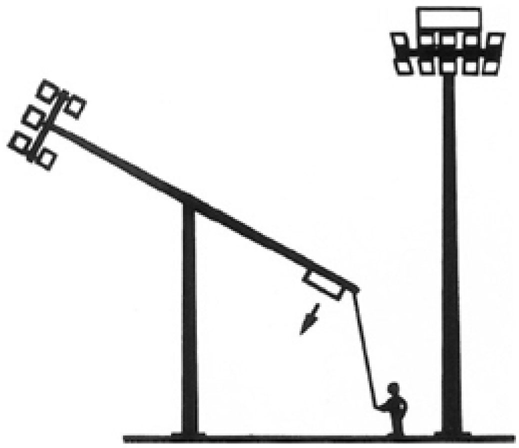


Figure 44 – Operation of mid hinged pole (Wooson Singapore 2013)

A company that could supply and manufacture a custom designed pole was engaged to fabricate an 8 m hinged galvanised communications pole. Specifications of each item to be mounted on the pole were given to the manufacturer so the required brackets could be manufactured and attached. The general arrangement of the hinged communications pole is shown in Appendix F.

5.2.6. Instruments and Data Acquisition System

For the wire extensometers, SISGEO units were selected. It was decided that temperature sensors would also be installed in the wire extensometer pits in order to monitor possible effects of thermally induced strains on the extensometer wires.

It was decided that a weather station would also be included in the installation so accurate rainfall measurements could be undertaken. This could be easily connected to the chosen data acquisition system, therefore it would provide an important part of the early-warning monitoring system. The weather station selected was the Vaisala WXT520 weather station.

The Vaisala WXT520 is a compact and lightweight multi-sensor instrument that measures the most essential weather parameters. It can measure wind speed and direction, liquid precipitation, barometric pressure, temperature and relative humidity all in one transmitter (Envco 2009).

A unique feature of the WXT520 is its RAINCAP sensor which measures precipitation. Instead of relying on the volume of precipitation entering the sensor, the RAINCAP sensor measures the impact of the individual rain drops. This gives the WXT520 a major advantage, as the RAINCAP sensor is totally maintenance-free.

To handle the data acquisition task, a Campbell Scientific CR1000 logger was selected along with a Hughes 9502 satellite modem. The poor mobile reception in the area meant that satellite communications were the only option for data acquisition. The Hughes 9502 is connected to the CR1000 through the NL120 Ethernet module which is mounted on the logger.

To power the logger and modem, two 12-volt batteries were selected in conjunction with a 60-watt solar panel. The logger, modem, batteries and associated power control hardware were pre-wired inside an IP65 rated cabinet. For added protection, the logger was also mounted inside an IP66 rated sealed box (see Figure 45). The wiring diagram is shown in Appendix G.

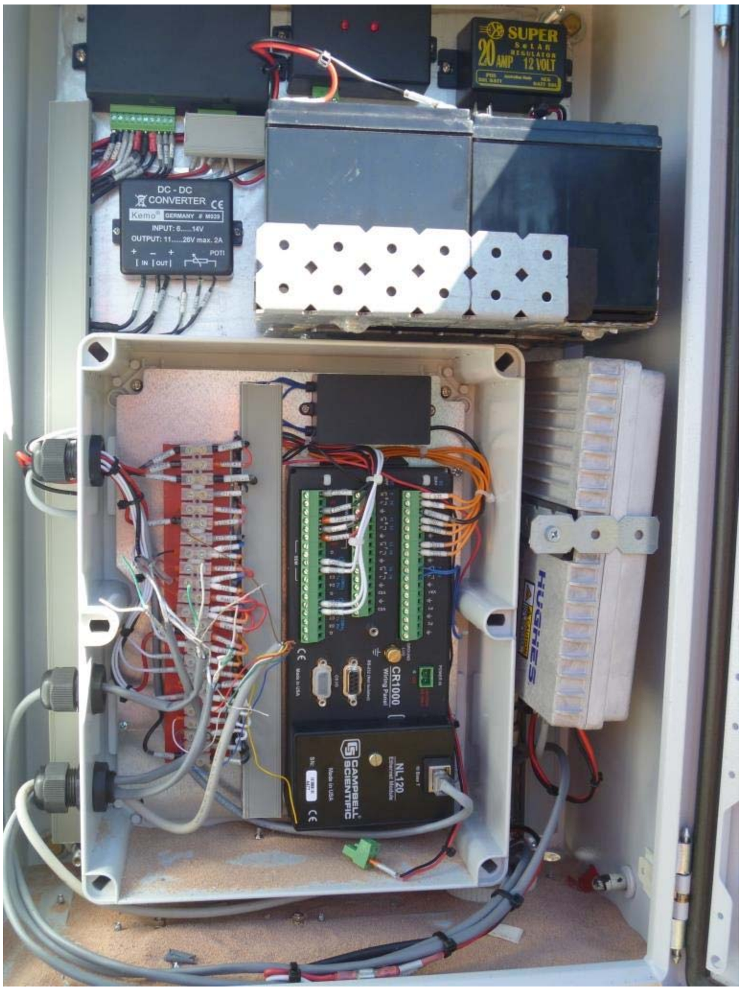


Figure 45 – Mounting arrangement of logger, modem and batteries

5.3. System Installation

The various components of the system were installed in two stages. The first stage involved the ground works, including excavation and directional boring, as well as the installation of bollards, brackets and communications pits. The final part of this stage was the installation of the footing cage for the hinged pole foundation.

The second stage of the installation involved the installation of the wire extensometers, weather station and associated hardware and wiring. The hinged pole was also installed along with the associated logging and data transmission hardware.

5.3.1. Installation: Stage 1

Marking out, excavation and directional boring

Stage 1 of the installation involved travelling to the site with the directional boring contractors. It was at this stage that the majority of the ground work for the instrumentation system would be completed.

The first task undertaken was to accurately mark out the positions using string lines and marking paint. This process is shown in Figure 46. Note the survey pegs which indicate the required position of the bollards within the pits.

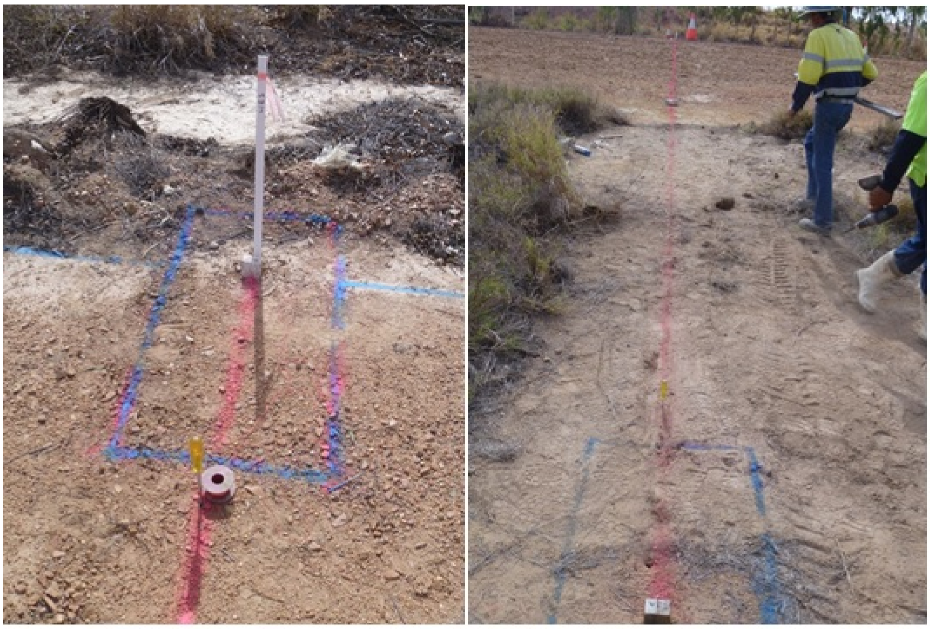


Figure 46 – Marking out for directional boring and pit excavation

For directional boring to commence for instruments WE1 and WE2, it was required to first dig the pits for these devices. The pits were dug to dimensions slightly larger than the plastic communications pits. This would allow the pits to be backfilled with sand around the edges, thus ensuring that the pits were level and secured into position.

Figure 47 – Excavation of pit

The directional boring commenced for devices WE1 and WE2. The directional boring machine was set up behind the dead end pit, firstly at the WE2 location.

The face of the pit was marked where the boring bit was to enter, exactly 500 mm from the ground surface. Directional boring then commenced while a vacuum excavator disposed of excess cuttings and drilling mud as it entered. Figure 48 shows the process of guiding the drill into the correct position.

Figure 48 – Centeralising drill through pit

The directional boring drill bit contains a location device that sends a signature to the ground surface. This signature is able to be picked up by a handheld device which displays the current alignment and depth of the drill bit, and the anticipated direction.

The operator can then signal the drill rig operator to alter the direction or depth in order to maintain the correct location. Figure 49 shows the location device being used to direct the drill across the roadway.

Figure 49 – Controlling drill position with location device

During the directional boring process, the depths at critical points were recorded with the location device. For WE2, which was drilled first, a depth of 1.49 m was recorded as the drill passed below the road edge line on the western side, 1.18 m at the centre line and 0.9 m at the opposite edge line on the eastern side. The difference in depth between at the edges is due to the western side being at a higher elevation than the eastern side of the road. Tracking of depths during the boring of WE1 revealed that the depths achieved along the width of the pavement were nearly identical to that of WE2.

The final step of the directional boring was to pull the 65 mm conduit through the completed hole. This was done by attaching the rod train to the conduit with an adaptor, and carefully withdrawing the rod train while guiding the conduit into the hole. The attachment of the conduit to the drill rods is shown in Figure 50.

Figure 50 – Attaching conduit to drill for pulling through borehole

After the completion of the directional boring for WE1 and WE2, the excavator was used to dig the pits for WE3 which is located on the mine site (See Appendix D). A 500 mm deep trench was also dug between the pits for the conduit to be laid.

Installation of pits, bollards and brackets

Before the pits were installed, a section was cut out of the bottom of each pit to allow adequate clearance of the 165 mm bollard on the dead and live ends. This process is shown in Figure 51.

Figure 51 – Cutting base from bottom of pits

A 200 mm diameter auger was then used to drill a hole in the base of each pit in order to accommodate the steel bollards. Each hole was drilled to a depth of approximately 1000 mm from the base of each pit. The bollard position was then checked using a string line and tape measure, and the bollards were concreted in place. This process is shown in Figure 52.

Figure 52 – Augering and installation of bollard

The pits were then installed by positioning them in each trench and filling the voids with crusher dust. Formwork was then set up and the pit surrounds were concreted. Concreting of the pit surrounds is shown in Figure 53.

Figure 53 – Concreting pit surrounds

The next step was to install the brackets for the wire extensometers. The bollards on the live end and anchor end were filled with concrete. The brackets were then adjusted by using the nuts and plates provided on the threaded bars. This enabled the brackets to be positioned at the correct height while the concrete set. Figure 54 shows the live end and anchor end brackets concreted in position.

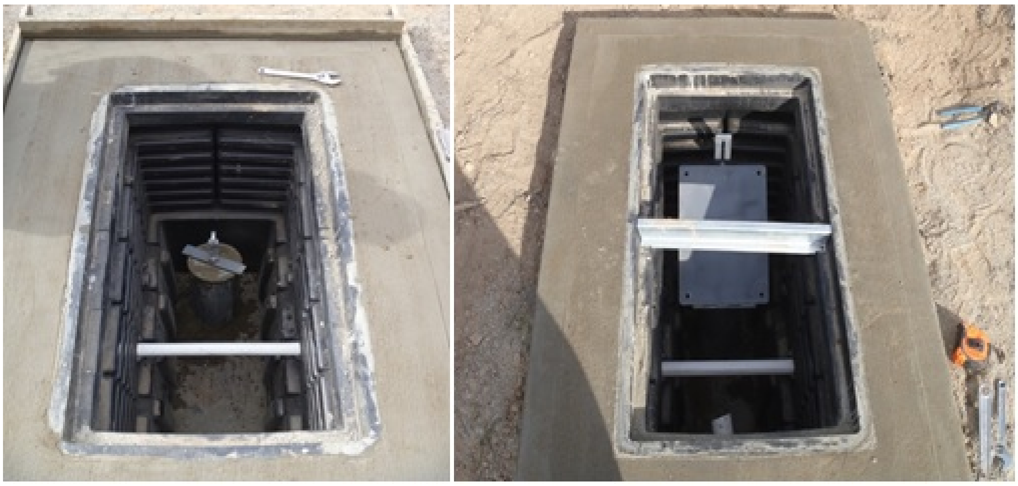


Figure 54 – Brackets concreted into bollards for anchor end (left) and live end (right)

To mark the locations of the pits, and also to prevent them being damaged by vehicles, steel barriers fabricated from 50 mm pipe were installed beside each pit. A completed installation with the yellow barrier is shown in Figure 55.

Figure 55 – Completed installation with marker barrier

The final part of the first stage of the installation was to construct the drainage for the live end pits. The drainage consists of an excavated trench with subsoil drainage pipe, backfilled with gravel. Because the ground relief on the eastern side of the site is relatively level, a drainage sump was dug at the end of the trench to a depth lower than that of the pit. The drainage pipe was terminated at the sump, and the sump was also filled with gravel. Excavation of one of the drainage trenches is shown in Figure 56.

Figure 56 – Drainage trench for live end of pit

<u>Communications pole foundation</u>

Road-Tek staff were engaged to construct the foundation for the mid-hinged communications pole. An excavator was used to auger a hole for the foundation reinforcement cage. A communications pit was also provided adjacent to the pole footing in order to provide a lead-in location for the instrument wiring at a later stage. Figure 57 shows the construction of the foundations for the reinforcement cage and communications pit.

Figure 57 – Foundation formwork and reinforcement cage for communications pole

5.3.2. Installation: Stage 2

The second stage of the installation involved the installation of the wire extensometers, weather station and associated hardware and wiring. The hinged pole was also installed along with the associated logging and data transmission hardware. Finally, surveyors were engaged to provide accurate locations for each installation.

Each process undertaken during this stage will now be explained in detail.

<u>Installation of communications pole</u>

The mid-hinged pole arrived and was installed onto the footing by using a truck mounted crane. The pole was then bolted to the studs at the face of the foundation. This process is shown in Figure 58.

Figure 58 – Lifting hinged pole into place with truck mounted crane

Installation of wire extensometers

Each wire extensometer was attached to the adjustable bracket base plate with four M8 sized bolts. After this was complete, the draw rope was attached to the stainless steel wire and pulled through the conduit, along with an additional piece of rope. The additional draw ropes were provided in the event of a wire cable breakage, another cable could be easily installed.

On the anchor end of the installations a turnbuckle was provided so adjustments could be made to the extensometers. Snap hooks was used to attach the turnbuckles to the anchor eyelet. Before the wire was attached, the turnbuckle was adjusted to maximum extension to give ample length of cable for calibration adjustments.

Wire rope clamps were then used to attach the stainless steel wire on each end. Heat shrink tubing was used to contain the tails of the wire in order to provide a neat finish. Final live end and anchor end configurations are shown in Figure 59 and Figure 60.

Figure 59 – Wire attachment configeration at live end

Figure 60 – Wire attachment configeration at anchor end

The SISGEO wire extensometers are a 4 – 20 milliamp (mA) sensor. Upon extension of the wire, the rotary potentiometer turns and provides a reading in milliamps depending on the amount of revolution experienced by the potentiometer. In the SISGEO unit, a displacement of 240 mm will cause one full turn of the potentiometer. Theoretically, a zero displacement will result in a reading of 20 mA and a displacement of 240 mm will result in a reading of 4 mA. Additionally, the potentiometer has a limitless rotation range, so if it was continually rotated the readings would range through 4 - 20 mA during each full rotation of the rotary potentiometer. This was a critically important factor when calibration was undertaken in the field, as the amount of displacement available needed to be maximised in order to provide adequate range of the instrumentation system.

To achieve this, a SISGEO CRD400 Digital Readout Unit was wired directly to the extensometer. This unit powers and displays the raw output signal of the device in milliamps. The displacement on each device was then carefully adjusted by rotating the turnbuckle on the anchor end until an output of approximately 17 mA was reached on the readout unit.

An initial output of 17 mA would allow adequate range in the positive direction, while still allowing some room in the negative direction in the event that the instrument experienced negative displacements due to relaxation of the cable.

Installation of pit temperature sensors

The selected temperature sensors were a TT420 temperature sensor manufactured by Electro Sensors. The TT420 temperature sensors combine a temperature sensor, signal conditioning and a 2 wire loop-powered 4-20mA transmitter into a single unit (Electro Sensors 2012). The sensor has an ambient operating range of -20 to 80℃, and an accuracy of ± 1℃ (at 25℃). The TT420 sensor is shown in Figure 61.

Figure 61 – 4 to 20 mA temperature sensor

The temperature sensors were installed in each pit on the live end, on the bottom of the junction box. This location was selected as a more representative temperature would be achieved as the sensor would not be subject to direct heat radiation from the steel pit lid To attach each sensor, a hole was drilled in the bottom of the junction box and a single nut and bolt was used to attach it to the bottom of the plastic box.

Connection to communications pole

Cable trenches were dug from the live end wire extensometer pits and terminated at the pit at the base of the communications pole. 40 mm electrical conduits were then laid with draw ropes inside. The cable layout can be seen in Appendix D.

Next, 2 pair instrumentation cable was run through the conduits from the pit at the communications pole to the junction boxes in each live end pit. The cable was joined at the junction boxes to the wire extensometers and temperature sensors through terminal blocks. The join inside a junction box can be seen in Figure 62.

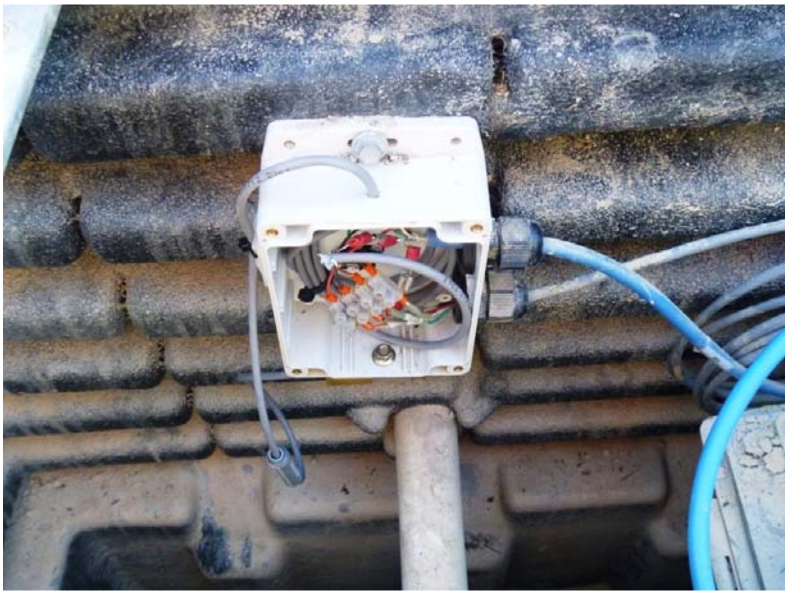


Figure 62 – Temperature sensor bolted to bottom of junction box

Communications setup

Setting up the communications first required that the logger enclosure, which contains the data logger, modem, battery and associated hardware to be connected to the communications pole. Once this had been done, the solar panel was connected to the bracket provided at the top of the pole, along with the weather station and the satellite antenna. The antenna and the solar panel were then connected to the charging system and modem respectively.

A lightning protection system was also connected. This consists of a spike attached to the 90 mm spigot at the top of the communications pole. Heavy-gauge earth wire completes the connection to a copper earth stake in the communications pit at the base of the pole.

Figure 63 – Connection of satellite antenna to bracket

The instruments were then connected to the Campbell Scientific logger. The weather station was wired directly into 2 of the communications (COM) ports, while the temperature sensors and the wire extensometers were connected to the single-ended channels provided on the logger through a converter. The wiring diagram for the logger is shown in Appendix G.

The converter is required as the Campbell Scientific CR1000 monitors voltage only on the single-ended channels, while the temperature sensors and wire extensometers are 4 - 20 mA sensors, so their output is current. The converter consists of 120 Ohm resistors wired to a junction block. This is connected to the negative terminal of the logger. By knowing the resistance, the voltage from the sensor input current can be directly calculated through Ohm's law which states that voltage is equal to the product of the current and resistance. The converter used for the temperature sensors is shown below in Figure 64.

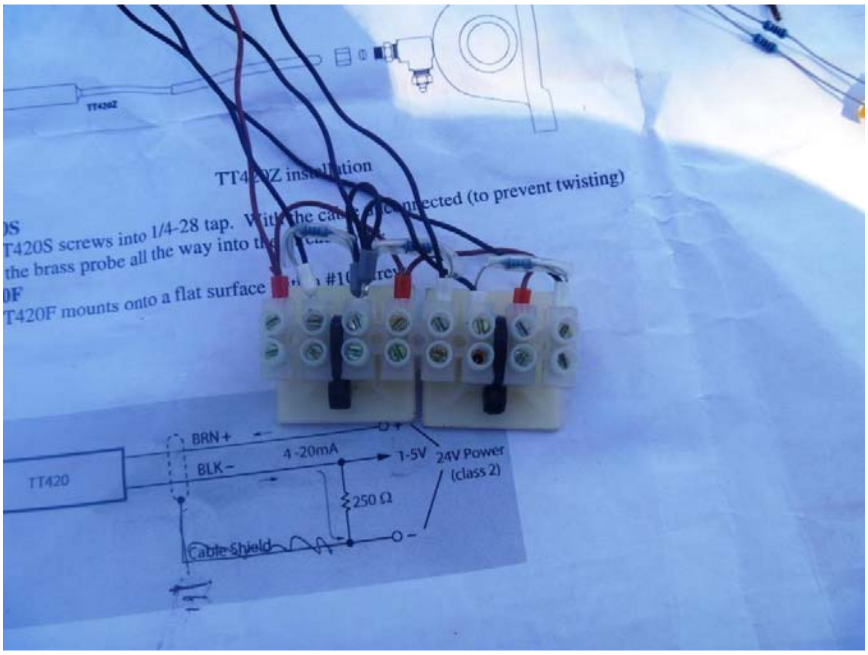


Figure 64 – 120 Ohm resistor converter and wiring diagram

The next part of the installation was to position the satellite antenna and test the communications system. A program that was provided with the modem allowed the antenna to be positioned so optimal signal strength could be achieved.

Finally, the system was tested and the recorded readings from the instruments were checked against the initial calibration readings. Figure 65 shows the completed installation of the communications pole.

Figure 65 – Completed installation showing logger box (bottom), satellite antenna (mid), weather station and solar panel (top)

Surveying

Surveying of the site was undertaken by TMR surveyors. The wire extensometer concrete pit surrounds and the communications pole foundation were all marked with survey nails and their locations surveyed using a Leicia Total Station. The survey data of the wire extensometer pit surrounds would be used in the future to verify the results recorded by the extensometers.

The Details of the survey and recorded locations are included in Appendix H.

6. Data Presentation and Analysis

6.1. Introduction

The design and installation of the hardware was covered in the previous chapter (Chapter 5). In this chapter, the data presentation process will be explained in detail. This process begins with the initial generation of the raw data by the instrument. From here, the data is transmitted and is uploaded to Geotesta's secure web server where a PHP program processes the data and issues the required alerts according to the defined trigger levels.

Since the installation of the system, the site has experienced a severe weather event. This weather event resulted in damage to the installations, and also triggered movements which were recorded by the wire extensometers. The later part of this chapter deals with the analysis of the data recorded by the instruments to date, including a detailed analysis of the data captured during the severe weather event.

6.2. Data Presentation

6.2.1. Process Overview

The following section explains the processes involved in transferring the data from the instrument to the end user. This process is illustrated in Figure 66.

1. Data logging

The Campbell Scientific CR1000 logger is programmed to collect data from the wire extensometers, weather station and temperature sensors every hour. The data is stored in the logger's memory until an upload is triggered.

2. Data transmission

Every 3 hours, a relay is triggered to power the Hughes 9502 satellite modem. The satellite modem is connected to the CR1000 by a Campbell Scientific NL120 mounted on the CR1000 peripheral port. The satellite modem then makes a connection to the server and transfers data to the server through a File Transfer Protocol (FTP).

3. Web server

In the web server, the software utility 'Cron' is running every minute to check for files that have been sent to the server. Cron is a software utility used to schedule activities at certain times.

If a file is found, the Cron utility will execute a PHP script on the server. The PHP script will extract the file and compare the raw data values with the pre-defined trigger levels.

4. Triggers and alerts

If any trigger values are found, an email will be sent via the SMS Gateway. SMS Gateway will then convert the email to SMS message. All data will then be saved to the server.

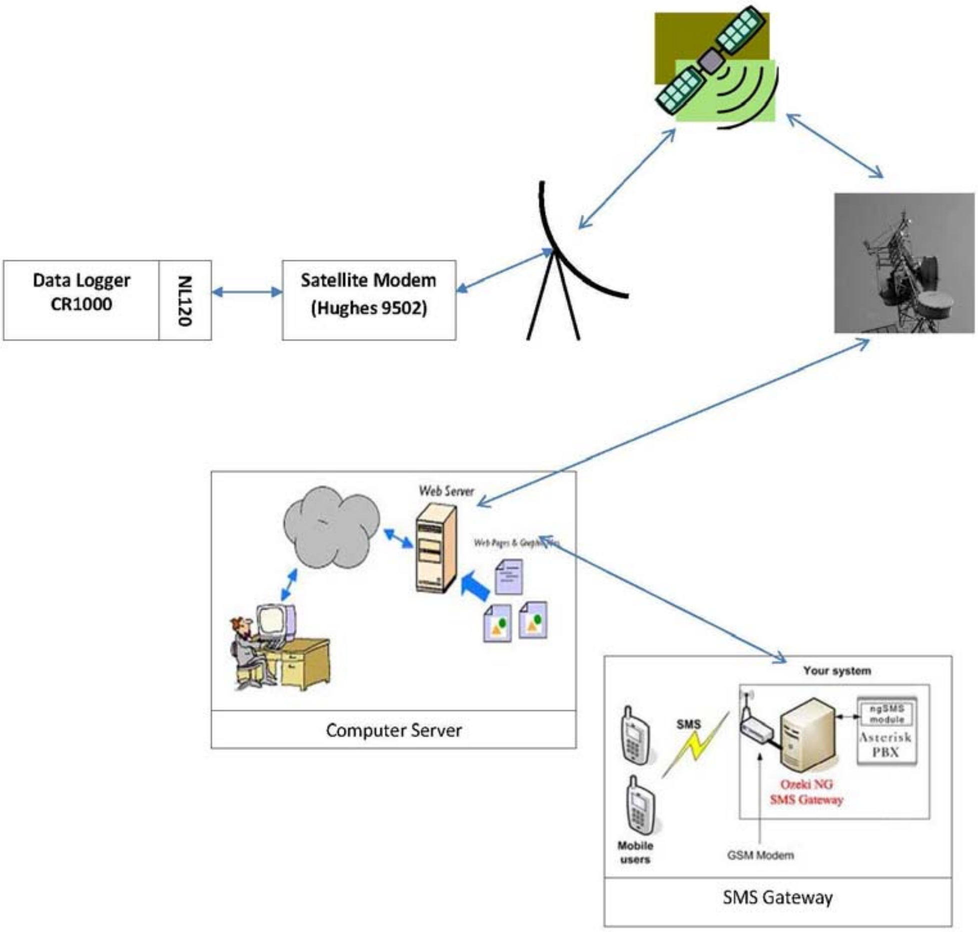


Figure 66 – Data transfer process from CR1000 logger to end user

6.2.2. Trigger Levels and Alerts

The thresholds for the trigger levels and alerts for the devices have been defined in the Site Emergency Management Plan (SEMP). The SEMP defines the trigger levels for both movement recorded by the wire extensometers and total daily rainfall. It also details the persons to be notified when a trigger level is reached, and the actions to be undertaken in response. The SEMP trigger level and response matrix has been included in Appendix I.

The trigger levels for movement recorded by the wire extensometers have been set at 25 mm or greater for the amber alert, and 100 mm or greater for the red alert. For rainfall trigger levels, these have been set at 50 mm or greater and 125 mm or greater for the amber and red alerts respectively. The SEMP flow chart contains the actions to be undertaken when a red or amber alert alarm notification is reached. This is shown in Figure 67.

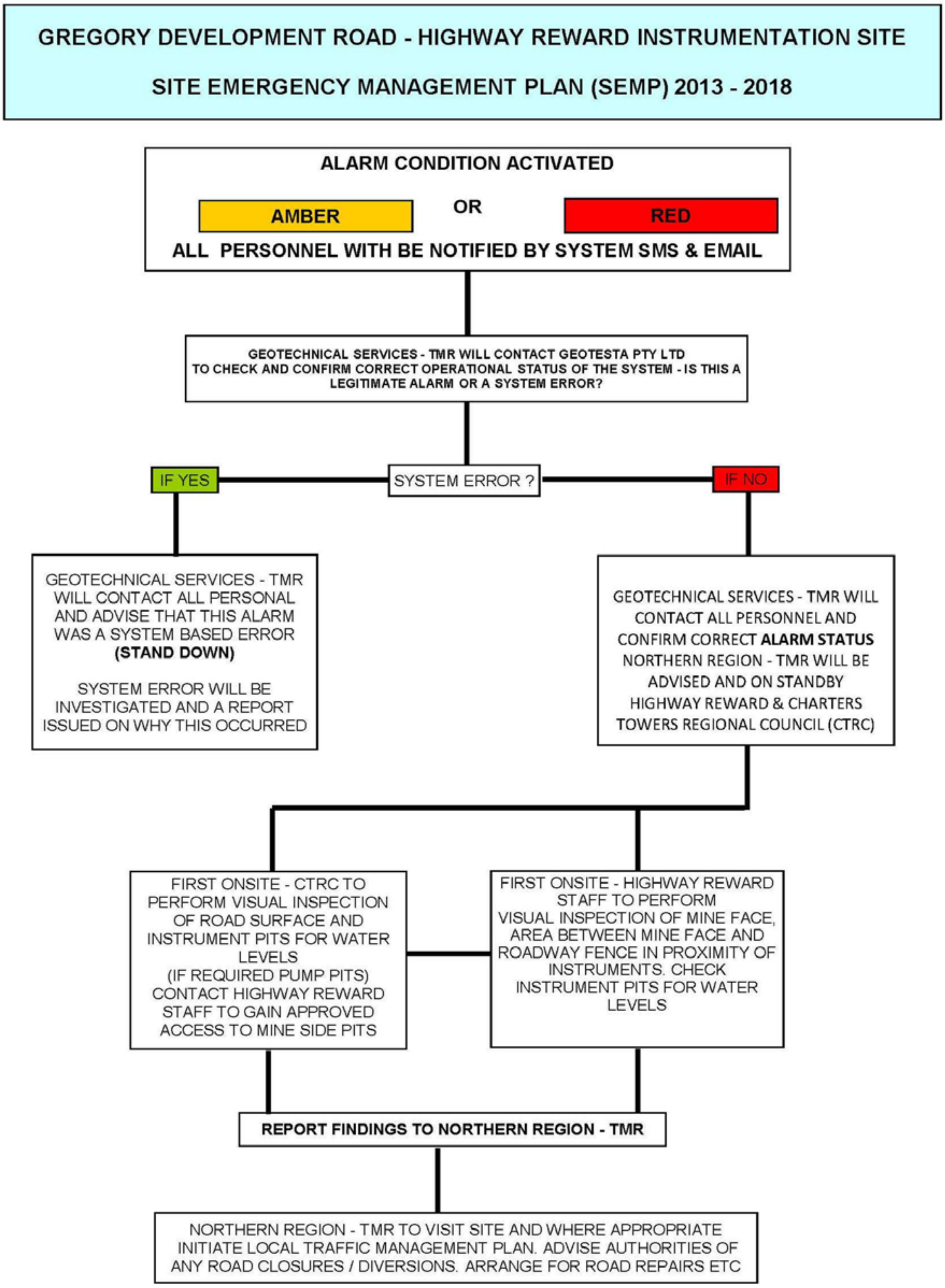


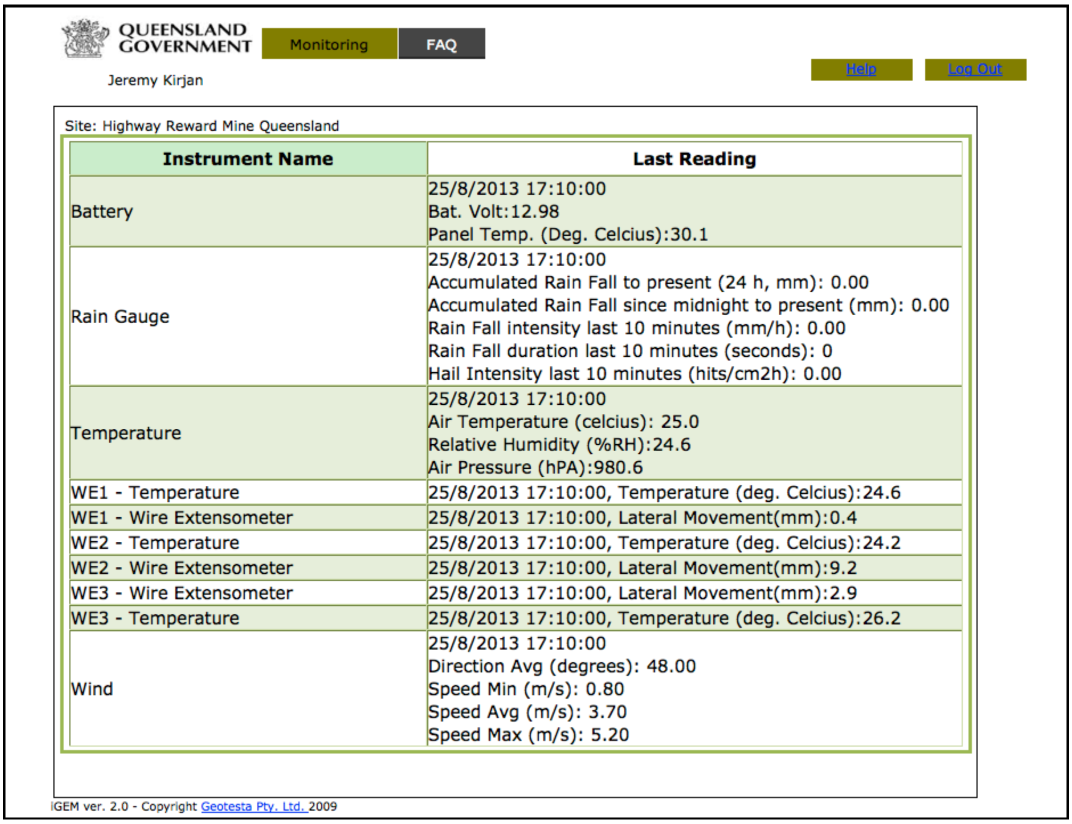
Figure 67 – Site Emergency Management Plan (SEMP) flow chart

6.2.3. Access, Calibration and Processing

The data is accessed by the secure web server hosted by Geotesta. The server is found on the following address: http://www.geotesta.com/reward/ufLogin.php. The user is then presented with a log-in screen as seen in Figure 68.

Figure 68 – Server access page: Highway-Reward Mine data monitoring

Upon successful log-in, the user is presented with a page which displays the most recent data from the wire extensometers, temperature sensors and weather station. This page is shown in Figure 69.



QUEENSLAND GOVERNMENT Monitoring FAQ

Help Log Out

Jeremy Kirjan

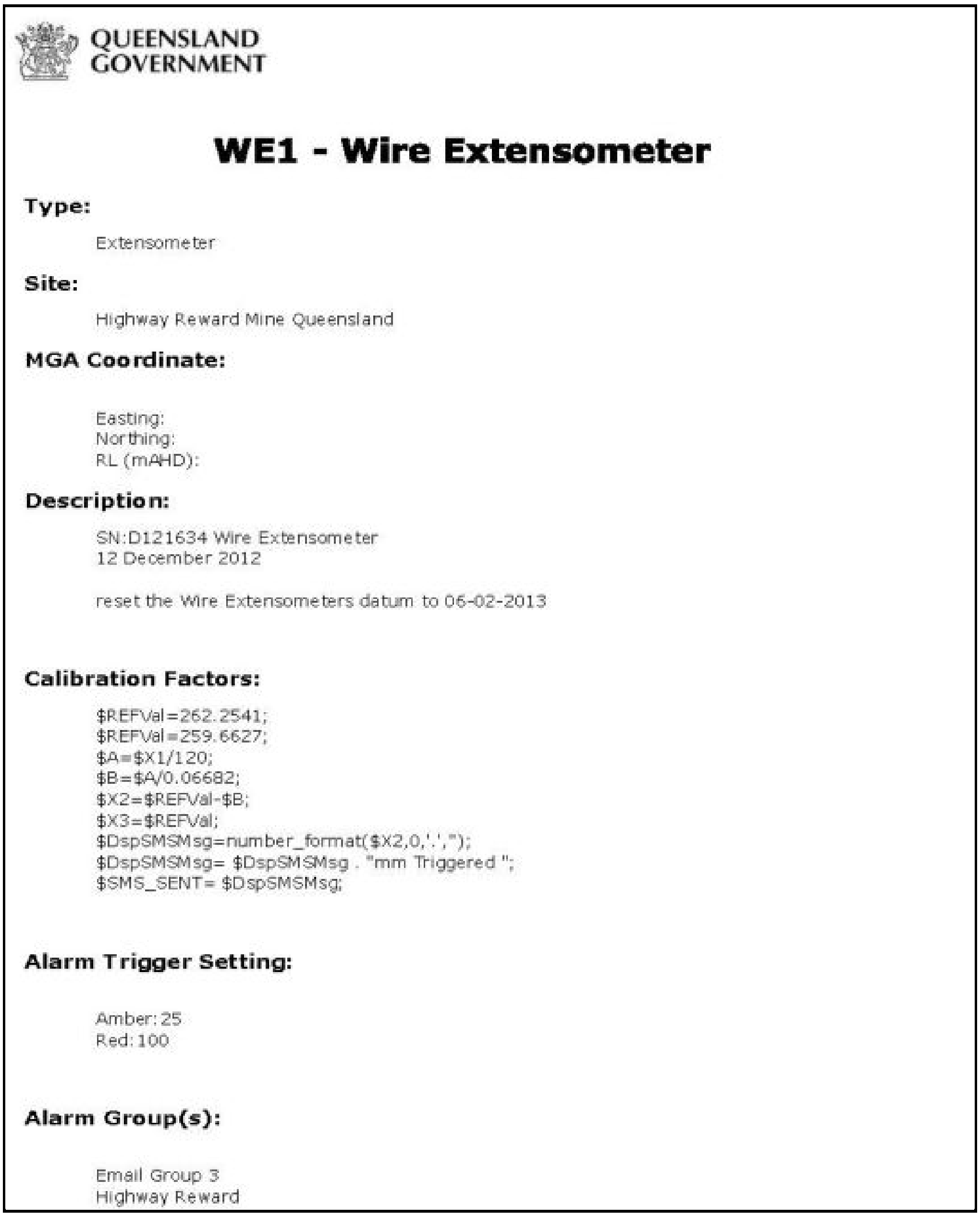
Site: Highway Reward Mine Queensland

Instrument Name	Last Reading
Battery	25/8/2013 17:10:00 Bat. Volt:12.98 Panel Temp. (Deg. Celcius):30.1
Rain Gauge	25/8/2013 17:10:00 Accumulated Rain Fall to present (24 h, mm): 0.00 Accumulated Rain Fall since midnight to present (mm): 0.00 Rain Fall intensity last 10 minutes (mm/h): 0.00 Rain Fall duration last 10 minutes (seconds): 0 Hail Intensity last 10 minutes (hits/cm2h): 0.00
Temperature	25/8/2013 17:10:00 Air Temperature (celcius): 25.0 Relative Humidity (%RH):24.6 Air Pressure (hPA):980.6
WE1 - Temperature	25/8/2013 17:10:00, Temperature (deg. Celcius):24.6
WE1 - Wire Extensometer	25/8/2013 17:10:00, Lateral Movement(mm):0.4
WE2 - Temperature	25/8/2013 17:10:00, Temperature (deg. Celcius):24.2
WE2 - Wire Extensometer	25/8/2013 17:10:00, Lateral Movement(mm):9.2
WE3 - Wire Extensometer	25/8/2013 17:10:00, Lateral Movement(mm):2.9
WE3 - Temperature	25/8/2013 17:10:00, Temperature (deg. Celcius):26.2
Wind	25/8/2013 17:10:00 Direction Avg (degrees): 48.00 Speed Min (m/s): 0.80 Speed Avg (m/s): 3.70 Speed Max (m/s): 5.20

iGEM ver. 2.0 - Copyright Geotesta Pty. Ltd. 2009

Figure 69 – Web server page showing most recent data for all devices

In order to view each device in more detail, the user selects the relevant instrument name which brings up a detailed summary for each device. This summary contains information such as: the type of instrument, site name, instrument geographical location, description, instrument calibration factors, alarm trigger settings and alarm groups. The device summary for WE1 is shown in Figure 70.



QUEENSLAND GOVERNMENT

WE1 - Wire Extensometer

Type:

Extensometer

Site:

Highway Reward Mine Queensland

MGA Coordinate:

Easting:
Northing:
RL (mAHD):

Description:

SN:D121634 Wire Extensometer
12 December 2012

reset the Wire Extensometers datum to 06-02-2013

Calibration Factors:

```
$REFVal=262.2541;
$REFVal=259.6627;
$A=$X1/120;
$B=$A/0.06682;
$X2=$REFVal-$B;
$X3=$REFVal;
$DspSMSMsg=number_format($X2,0,'.','');
$DspSMSMsg= $DspSMSMsg . "mm Triggered ";
$SMS_SENT= $DspSMSMsg;
```

Alarm Trigger Setting:

Amber: 25
Red: 100

Alarm Group(s):

Email Group 3
Highway Reward

Figure 70 – Device summary page for WE1

The information for each device as shown in the summary page can be modified by System Administrators. The screen shown in Figure 71 shows the instrument management panel which allows all parameters of the instrument to be set. Most importantly, this is where the calibration factors and the alarm trigger levels are set.

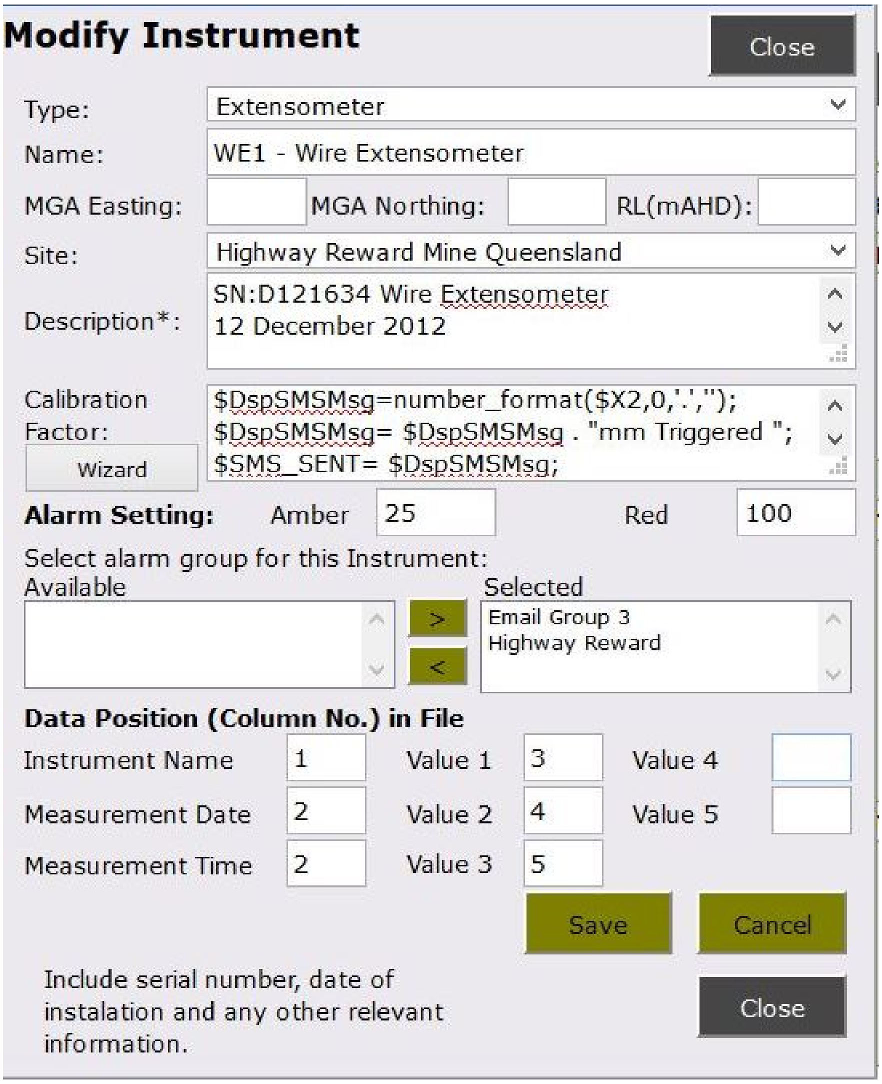


Figure 71 – Instrument management panel

6.2.4. Calibration of Wire Extensometers

The calibration script is required to convert the raw data uploaded to the web server to displacement. It also enables alerts to be sent if any of the values exceed the trigger levels. The complete calibration script for WE1 as entered in the instrument management panel is shown in Figure 72. Note the format of the variables assigned to the calculations. The elements of this script will now be explained in detail.

```
Calibration Factors:
        $REFVal=262.2541;
        $REFVal=259.6627;
        $A=$X1/120;
        $B=$A/0.06682;
        $X2=$REFVal-$B;
        $X3=$REFVal;
        $DspSMSMsg=number_format($X2,0,'.','');
        $DspSMSMsg= $DspSMSMsg . "mm Triggered ";
        $SMS_SENT= $DspSMSMsg;
```

Figure 72 – Calibration script for WE1

The raw data downloaded from the wire extensometers is in units of millivolts (mV) as recorded by the Campbell Scientific CR1000. A sample of raw data downloaded from WE1 is shown in Table 3. This data can be accessed by selecting the ‘view data’ button at the bottom of the device summary page. From here, the required date range can be specified.

Note that the values in the table correspond to the information in the header, and the units of the ‘Current Reading’ value are millivolts (mV).

Table 3 – Raw data output from WE1

ID,Date Time,CurrentReading,Lateral Movement (mm),,,,,,,,
WE1 - Wire Extensometer,2013-09-18 14:10:00,2075.3,0.8,,,,,,,,
WE1 - Wire Extensometer,2013-09-18 15:10:00,2078.0,0.5,,,,,,,,
WE1 - Wire Extensometer,2013-09-18 16:10:00,2076.0,0.8,,,,,,,,
WE1 - Wire Extensometer,2013-09-18 17:10:00,2076.0,0.8,,,,,,,,
WE1 - Wire Extensometer,2013-09-18 18:10:00,2076.0,0.8,,,,,,,,
WE1 - Wire Extensometer,2013-09-18 19:10:00,2086.8,-0.6,,,,,,,,
WE1 - Wire Extensometer,2013-09-18 20:10:00,2076.4,0.7,,,,,,,,
WE1 - Wire Extensometer,2013-09-18 21:10:00,2076.1,0.7,,,,,,,,
WE1 - Wire Extensometer,2013-09-18 22:10:00,2077.4,0.6,,,,,,,,
WE1 - Wire Extensometer,2013-09-18 23:10:00,2076.7,0.7,,,,,,,,

In order to convert this data from mV to mA, Ohm's law is used. This is undertaken in the third line of the calibration script (Figure 72). Note that the value of the resistor used is 120 Ohms.

The next step in the calibration is to convert the amperage value to displacement. This calculation is undertaken by using the 'Sensitivity Factors' provided on the calibration sheets for the wire extensometers. The Sensitivity factor is based on linear interpolation of the calibration data. Also provided on the calibration sheet are the more accurate calibration factors which are based on a polynomial interpolation, however, the linear interpolation provide sufficient accuracy in this case. The calibration sheets for the wire extensometers are included in Appendix K. Note that the instrument serial numbers for WE1, WE2 and WE3 are D121634, D121633 and D121632 respectively.

For instrument WE1 the Sensitivity factor from the calibration sheet is 0.06682 mm. The displacement in mm is given by:

$$D = L / S$$

where

D = displacement, in mm,

L = output reading, in mA,

S = Sensitivity Factor, in mm,

This calculation is represented in the fourth line of the calibration script.

As explained in the previous chapter (see Section 5.3.2), during calibration of the wire extensometers, each instrument was adjusted until a raw output of around 17 mA was achieved. In the case of WE1, the exact output was 17.351 mA. By substituting this value along with the Sensitivity Factor for WE1 into the formula given above, the raw output of 17.35066 mA corresponds to a displacement of 259.6627 mm. This value is known as the reference value. The reference value is displayed in the second line of script in Figure 72. Since the initial calibration, this value has been replaced with the value shown in the first line of the script due to re-zeroing of the instruments. This will be explained further in Section 6.3.

The displacement is calculated by taking the difference between the reference value and the calculated displacement value. This calculation is represented in the fifth line of the calibration script.

A sample calculation for the first line of data in Table 3 is as follows:

$A = 2075.3 / 120

$A = 17.2942 mA

$B = 17.2942 / 0.06682

$B = 258.817mm

$X2 = 259.6627 – 258.817

$X2 = 0.8457mm ≈ 0.8mm

The remaining lines of script enable an SMS text message to be sent to the subscribed persons if the calculated values exceed the defined trigger levels. Note that these trigger levels can be altered at any time by a system administrator using the instrument panel (Figure 71).

6.2.5. Calibration of pit temperature sensors

The temperature sensors are of the same sensor type as the wire extensometers (4 - 20 mA sensors) and rely on a linear calibration. Therefore, the process for undertaking the calibration for data presentation is identical to that of the wire extensometers. They only differ in that they do not require a reference value, and they are not included as an alarm triggering device.

The calibration for the temperature sensors were applied through the formula on the data sheet. The calibration for the sensors is a linear relationship and is as follows:

$$\text{Temperature}\ (°C) = (I - 8\text{mA}) \times 10,$$

where I is the current in mA

This calibration factor was entered into the script on the web server.

6.2.6. Data Plots

Data plots for all devices can be accessed by selecting the appropriate date range through the device summary page. As an example, a plot for device WE1 is shown in Figure 73. Note the trigger levels displayed in red and amber, and the specified date range of the plot shown in the top left hand corner. Plots of all devices over the entire operational duration are shown in Appendix J. Note that plots can only be produced for rainfall, windspeed and temperature. Barometric pressure and relative humidity can be only viewed from the device summary page.

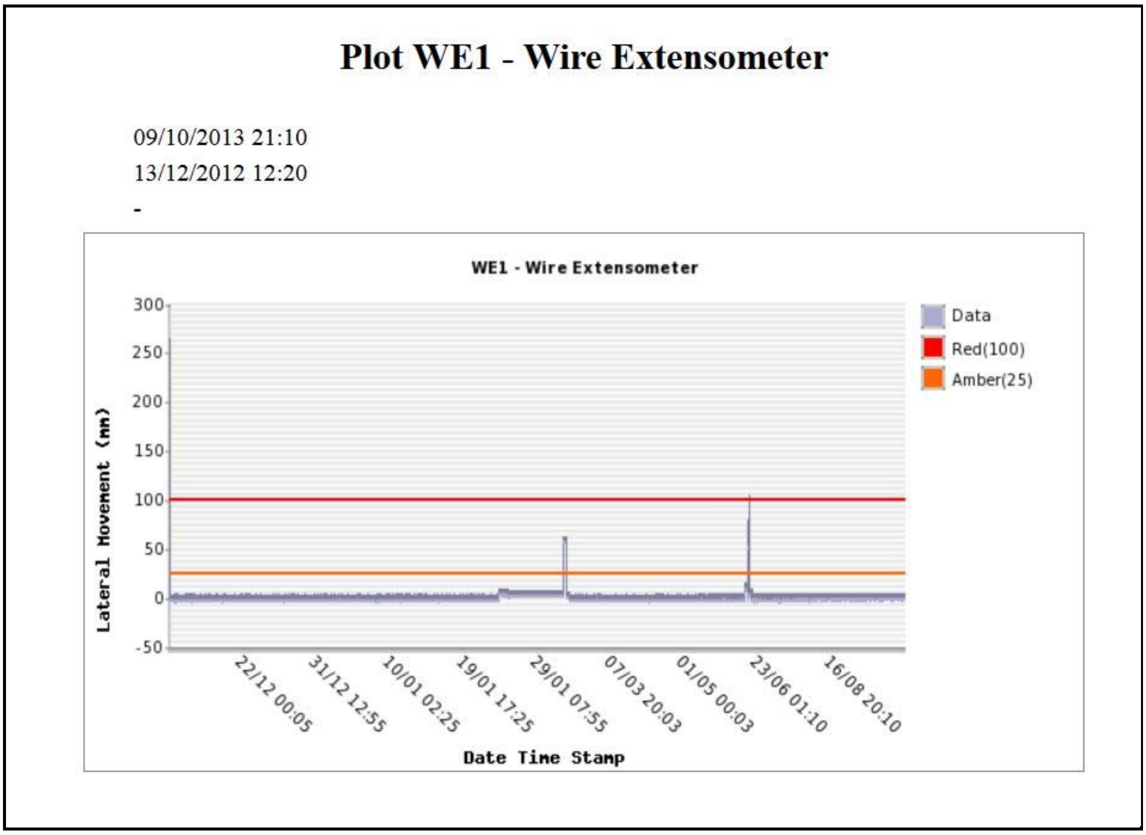


Figure 73 – Plot of WE1: recorded lateral movement over time

6.3. Analysis of Data

Since the instruments were commissioned, a number of events have caused anomalies in the recorded data. In this section, a detailed analysis of the captured data will be undertaken in order to explain the cause of these anomalies. In order to conduct this analysis, the data from the various instruments was imported into Microsoft Excel.

Increase in displacement can be seen when viewing plots for all three wire extensometers. Figure 74 shows the plot of WE1 with the two major events labelled.

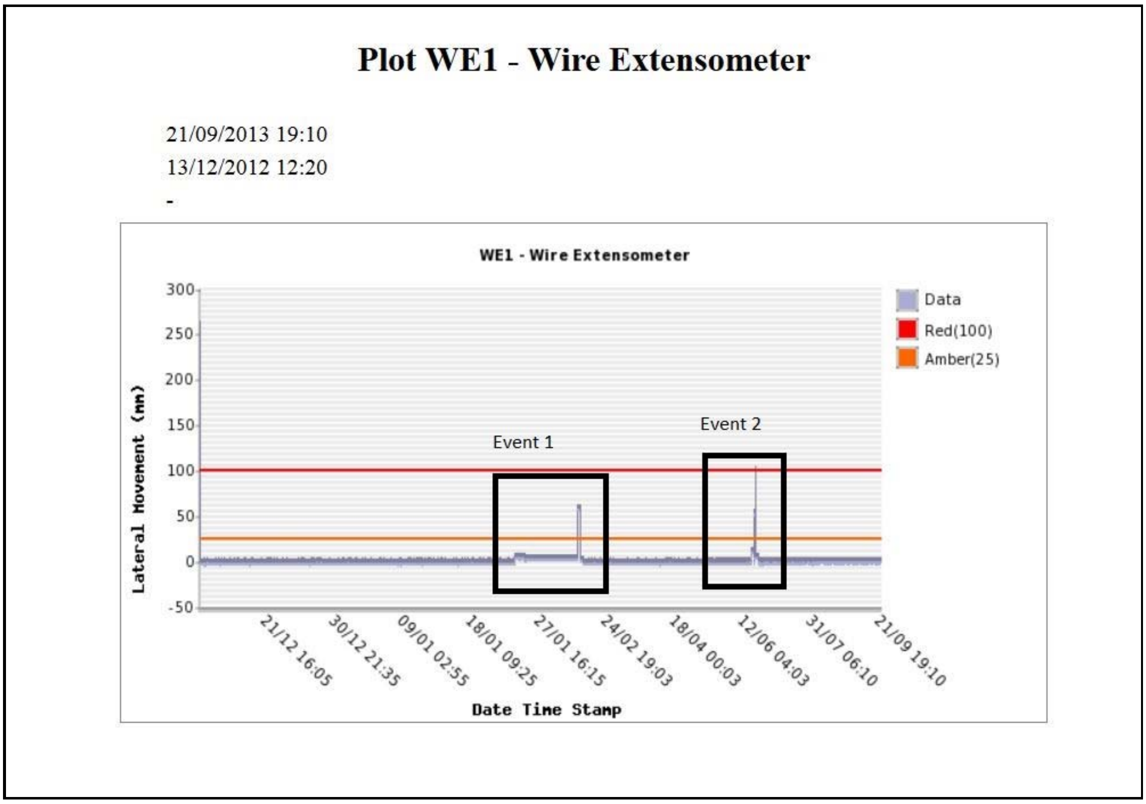


Figure 74 – Plot of WE1 showing major displacement events

6.3.1. Event 1: Severe Weather and Function Test

Towards the end of January 2013, Ex. Tropical Cyclone Oswald resulted in over 140 mm of rainfall being recorded over a 48 hour period. The rainfall data can be seen in Figure 75. In the days following this event, the system also failed to upload data to the server.

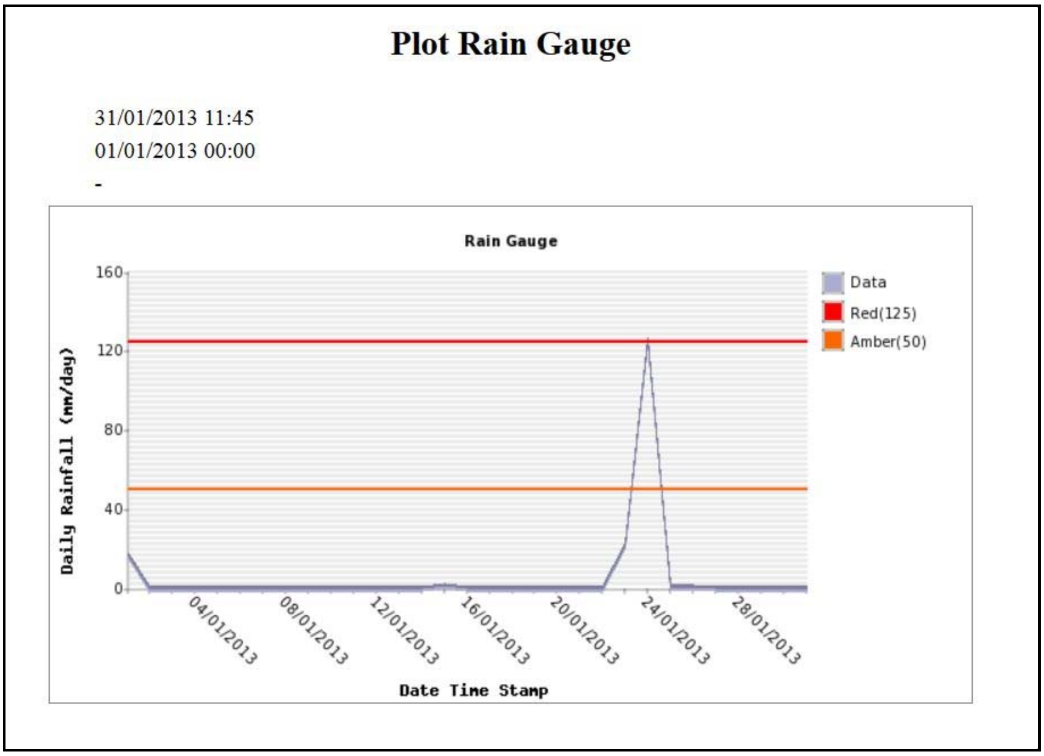


Figure 75 – Plot of daily rainfall for January 2013

A site visit was conducted, and upon arrival it was discovered that the batteries were severely discharged. The level of battery charge was insufficient to power the modem but enough to enable logging of the instruments to continue, so fortunately, no data was lost from any of the sensors. The cause of the power failure was eventually traced to a faulty charging relay which prevented the solar panel from charging the batteries. The effect of the faulty relay can be seen in the plot of the battery voltage during this time period, which is shown in Figure 76.

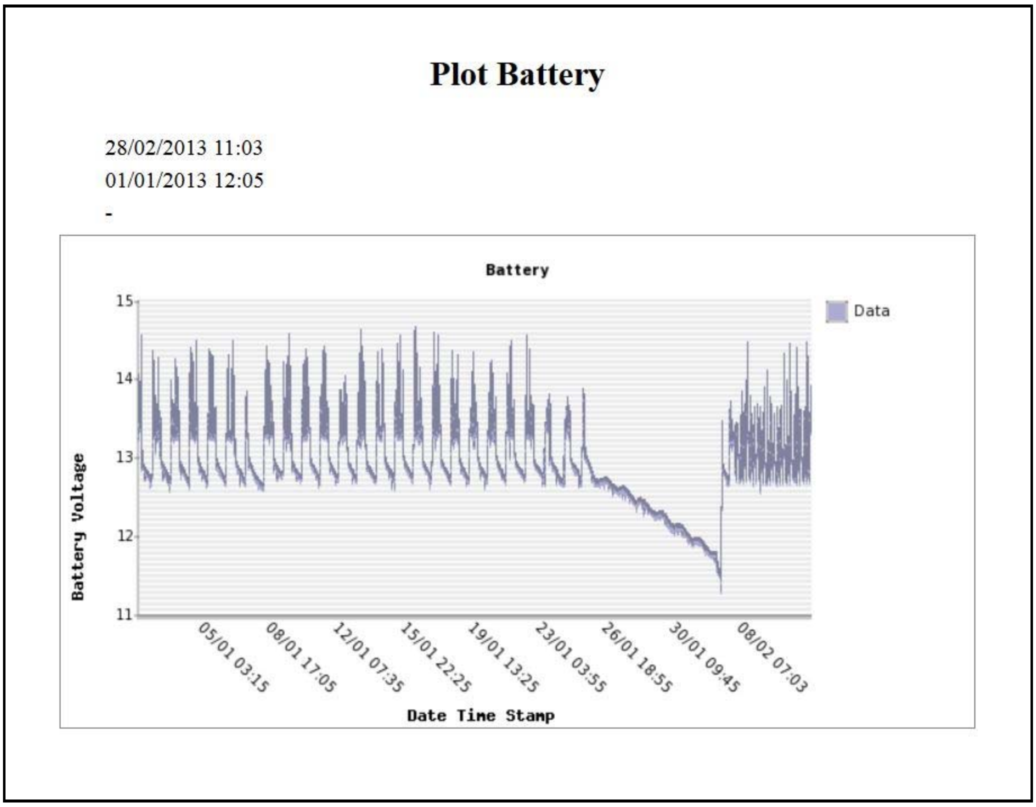


Figure 76 – Battery voltage plot for Jan-Feb 2013

The severe weather event resulted in a large amount of overland flow on both sides of the roadway, and this resulted in severe erosion around the pits. Upon opening the wire extensometer pits, it was evident that they had filled with water up to the level of the extensometers (this can be seen in Figure 77 and Figure 78). The instruments were opened and inspected, and a function test was undertaken to ensure that they were still operational.

Figure 77 – Erosion and cracking around WE3 installation

Figure 78 – Water at bottom of pit in WE2 anchor

When the data from the wire extensometers was downloaded, it was evident that an increase in lateral displacement had occurred. This increase was of a similar magnitude in all three devices. Microsoft Excel was used to plot the data recorded over the duration of the event. The plot for WE1 displacement and rainfall is shown in Figure 79.

After careful analysis, settlement of the installations, including pits and conduits were reported as being the cause of the displacements following the weather event. Quite simply, settlement of the conduits will induce tension on the wires, thus triggering movement in the devices. This is a common occurrence in new installations of this type.

From viewing Figure 79, Figure 80 and Figure 81, it is evident that the displacements recorded in WE3 are of a lesser magnitude than WE1 and WE2. This may be due to the different installation techniques used to install the extensometer conduits, as WE1 and WE2 were installed by directional boring and WE3 by direct burial in an excavated trench. Trenching and backfilling may provide a firmer base for the conduit, while the nature of directional boring means that the conduit will inevitably be of a smaller diameter than the bored hole. This leaves the conduit prone to some displacements and settlement over time.

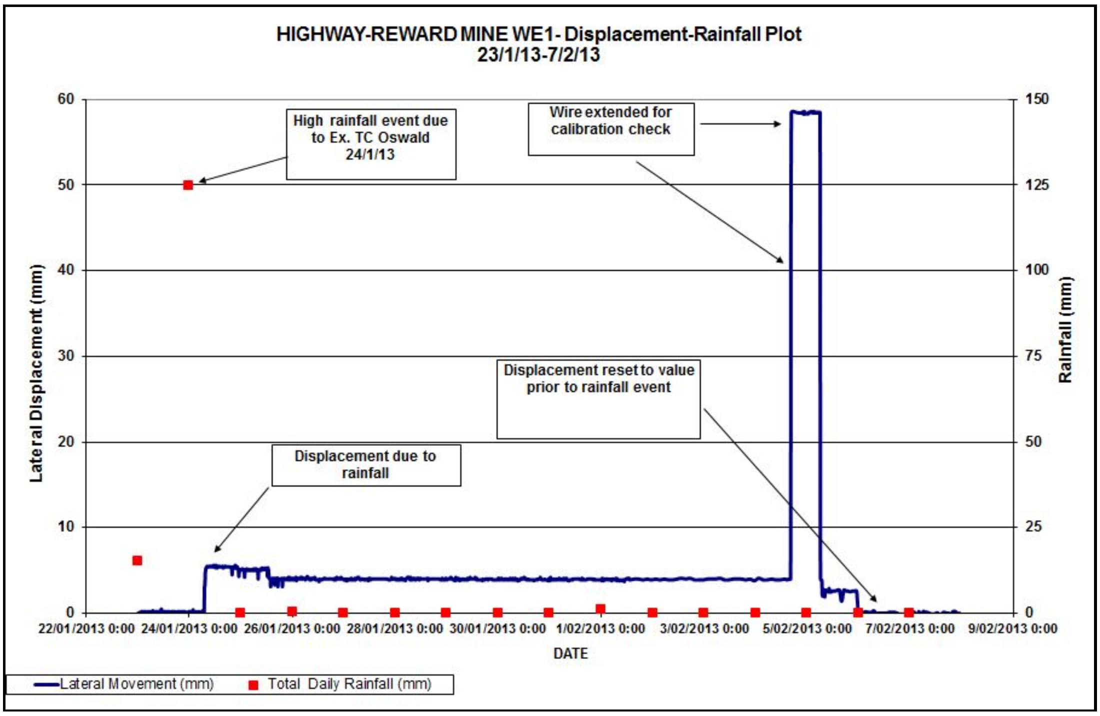


Figure 79 – WE1 lateral displacement and rainfall plot for severe weather event

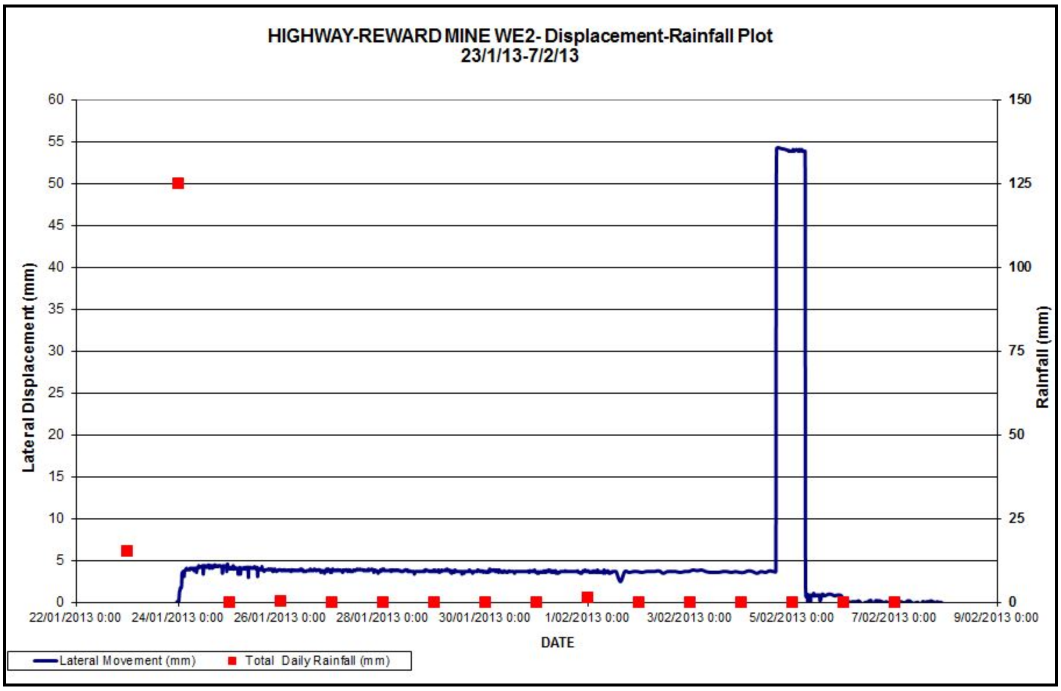


Figure 80 – WE2 lateral displacement and rainfall plot for severe weather event

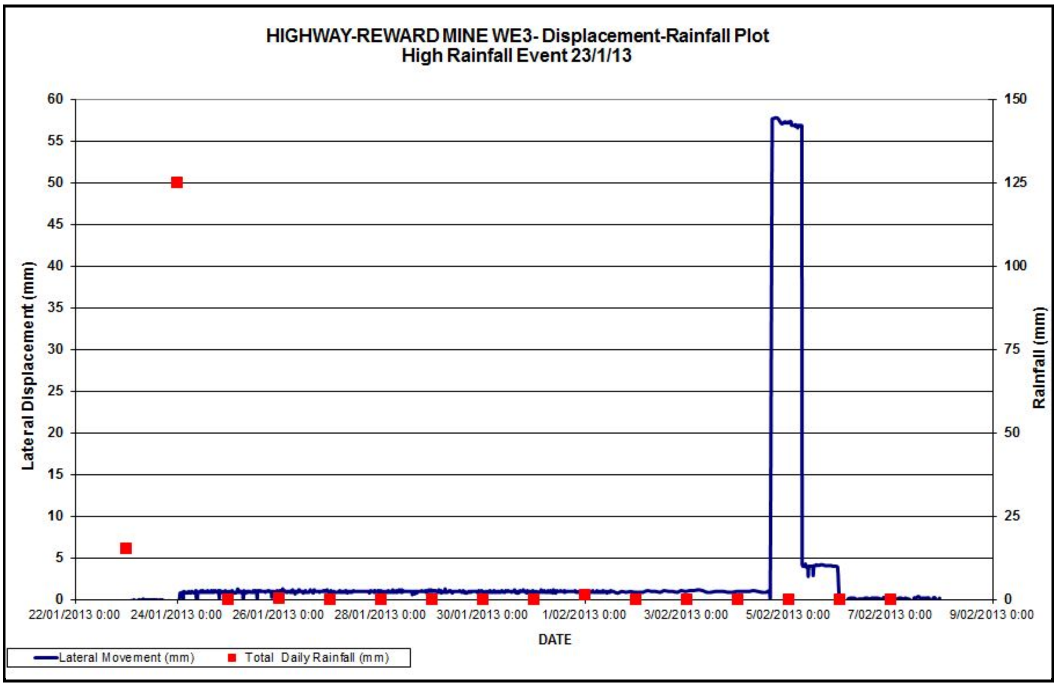


Figure 81 – WE3 lateral displacement and rainfall plot for severe weather event

6.3.2. Event 2: Instrument Function Tests

During the site visit in June 2013, the Wire Extensometers were checked for correct function. This was done by manually extending the wires on the three extensometers and clamping them in place while the device logged for a short period. On each device, the wire was first extended to just over 50 mm and then just over 100 mm. This also allowed the triggering of the Amber and Red levels of the early warning system to be checked. Because of this, all personnel on the contact list were notified that a test was being undertaken.

After completion, the displacements recorded were then compared to the actual distance of wire extension. A plot of the displacement during the function test of WE1 is shown in Figure 82.

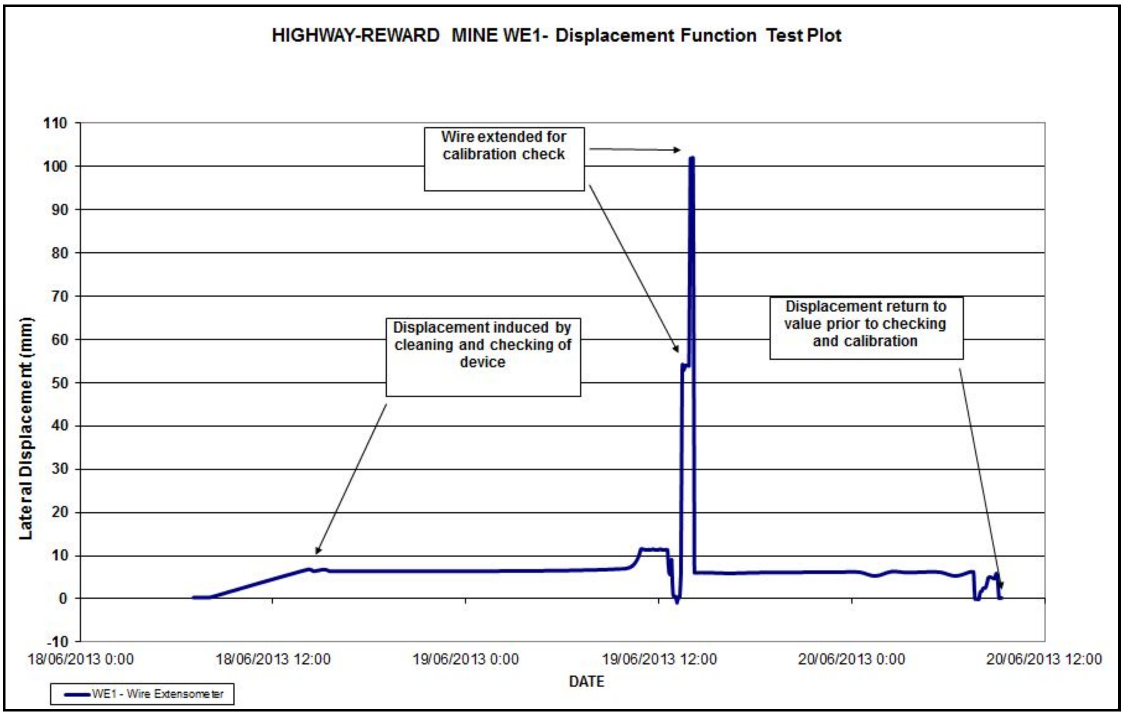


Figure 82 – Plot of WE1 displacement from function test

It is also important to note that after the function test was complete, the lateral displacement on each device had to be carefully reset to the initial displacement before the function test was conducted. This is because some displacement had been recorded by the devices, so it had to be treated as if it were legitimate movement.

This was a difficult process and was accomplished by trial and error. It was possible to reset each device within 1 mm of the initial displacement.

6.3.3. Further Analysis of Data: Increase in Displacement

As mentioned previously, following the severe weather event, the displacement on each instrument was reset to zero. However, after this time, the instruments began to record lateral displacement. The lateral displacement for each device was plotted against rainfall using Microsoft Excel. These plots are shown in Figure 83 to Figure 85.

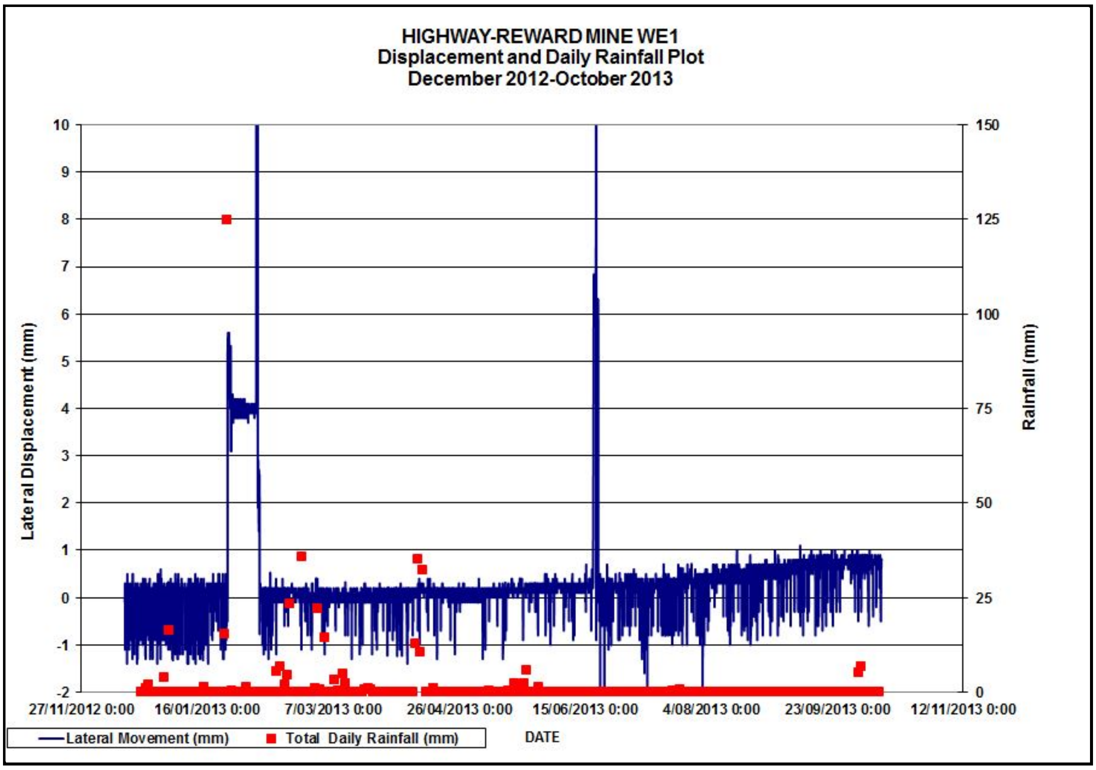


Figure 83 – WE1 lateral displacement and rainfall

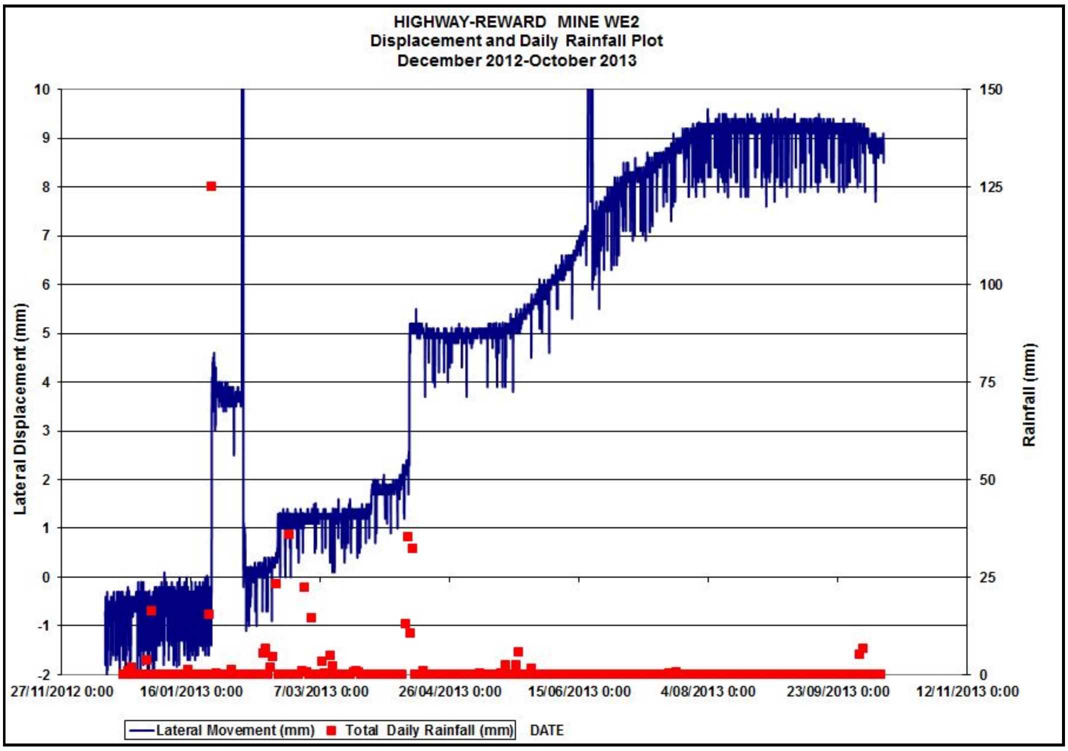


Figure 84 – WE2 lateral displacement and rainfall

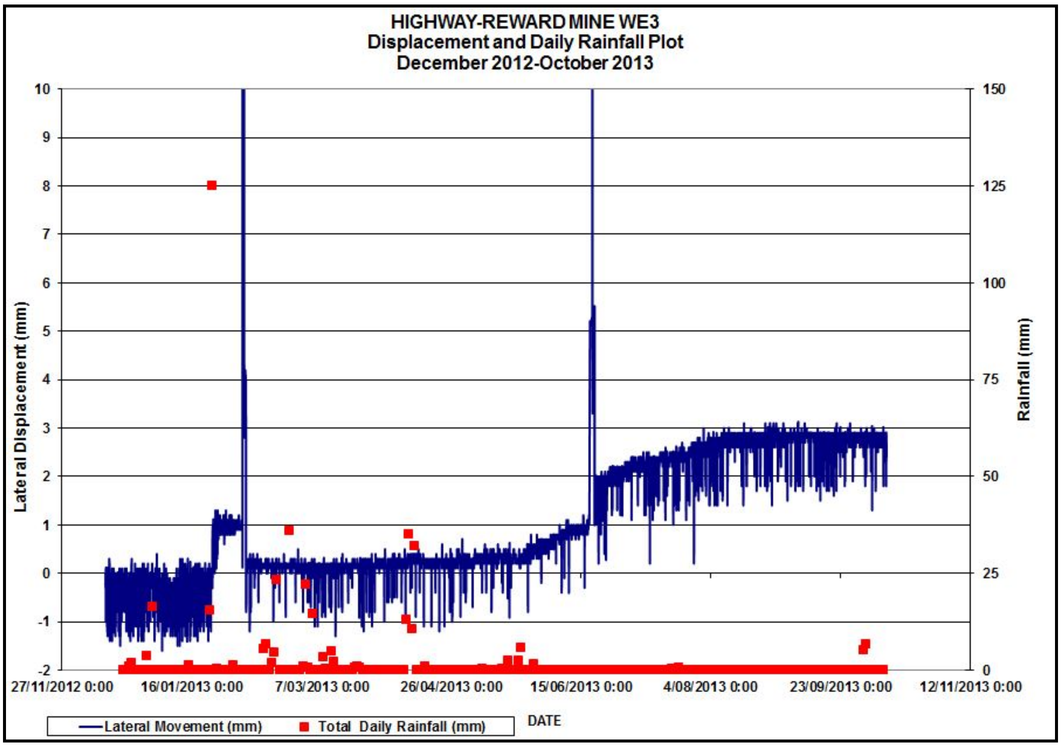


Figure 85 – WE3 lateral displacement and rainfall

From the plot of WE1 which is shown in Figure 83, it can be seen that the lateral displacement has increased a negligible amount, and is still within the error tolerance of the instrument. WE2 however (shown in Figure 84), has shown some increase in lateral displacement over the duration of operation, and from this plot increases in displacement do appear to coincide with rainfall events.

The slight increase in lateral displacement for WE3 has occurred before and after the calibration check in June 2013. Displacement was induced during the calibration check, as the device was not returned to its exact initial displacement, but a slight increase has also occurred after this time.

Increases in displacement coinciding with rainfall events (as can be seen with WE2) may be due to further rainfall induced settlement of pits and conduits, as was the case after the severe weather event. However, referring again to Figure 84, it can be seen that displacements in WE2 have increased from 5 mm after the last major rainfall event to in excess of 9 mm. This displacement is not associated with significant rainfall. The site observations presented in the following section may explain this unexplained increase in displacement.

<u>Observed cracking</u>

During the calibration check in June 2013, suspicious cracking was located around the WE2A pit (on the eastern side). The location and extent of this cracking can be seen in Figure 86 and Figure 87.

Figure 86 – Cracking in the vacinity of WE2A

Figure 87 – Close-up of cracking at WE2A location

The crack appears to extend a few metres south of the pit, and extends into the concrete pit surround, where it terminates. A closer inspection revealed that the crack may be a tension crack (5 – 10 mm wide), as it was quite different to the other ground cracking in the area which is consistent with shrinkage and evaporation. A tension crack in this area may explain the increasing lateral displacement in WE2, as the crack is within the span of the instrument. Adding to the suspicion is the fact that the appearance of this cracking looks much like the cracking observed near the West Wall Fault back in 2007. An image of this cracking was shown earlier, in Figure 39.

6.3.4. Further Analysis: Data Spikes

Besides the displacements due to the severe weather event and function tests, it was also evident that the data was not linear and contained variations of up to 2mm. This can be seen when viewing the plots in Section 6.3.3. To show this clearly, a plot of WE1 lateral displacement with a reduced scale is shown in Figure 88.

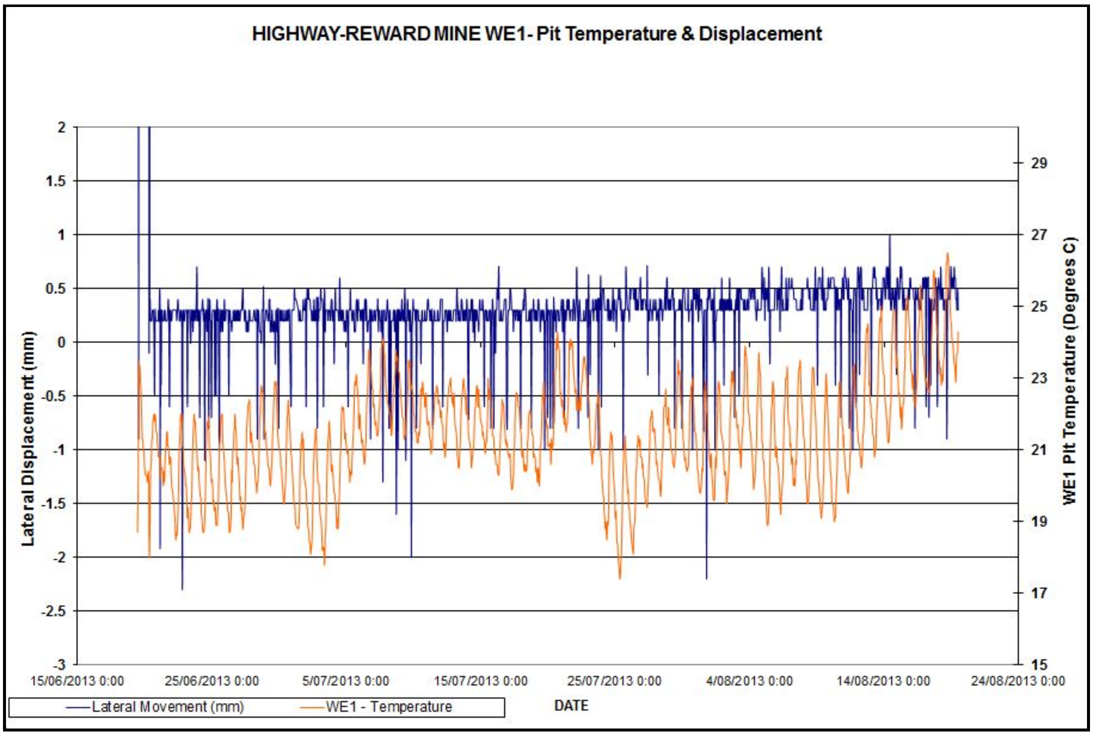


Figure 88 – WE1 pit temperature and displacement

An initial assumption was that the data spikes may be a result of the influence of fluctuating temperatures on the wires, as the temperature variations will result in a variation in strain on the wires, therefore altering the displacement.

To confirm if this assumption was correct, the period of data with the largest apparent temperature spikes were plotted. The results can be seen in Figure 89 to Figure 91, in which pit temperature, atmospheric temperature and displacements have been plotted for all instruments. Figure 92 shows a comparison between all instruments and the atmospheric temperature.

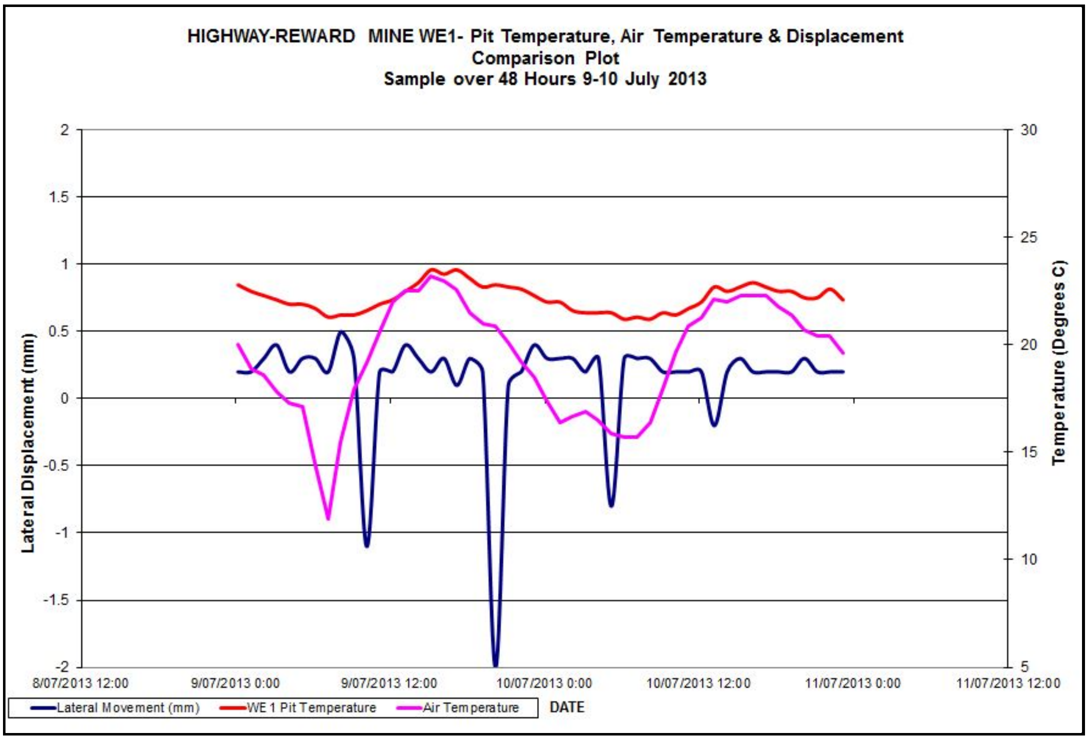


Figure 89 – Comparison of temperatures and displacement in WE1

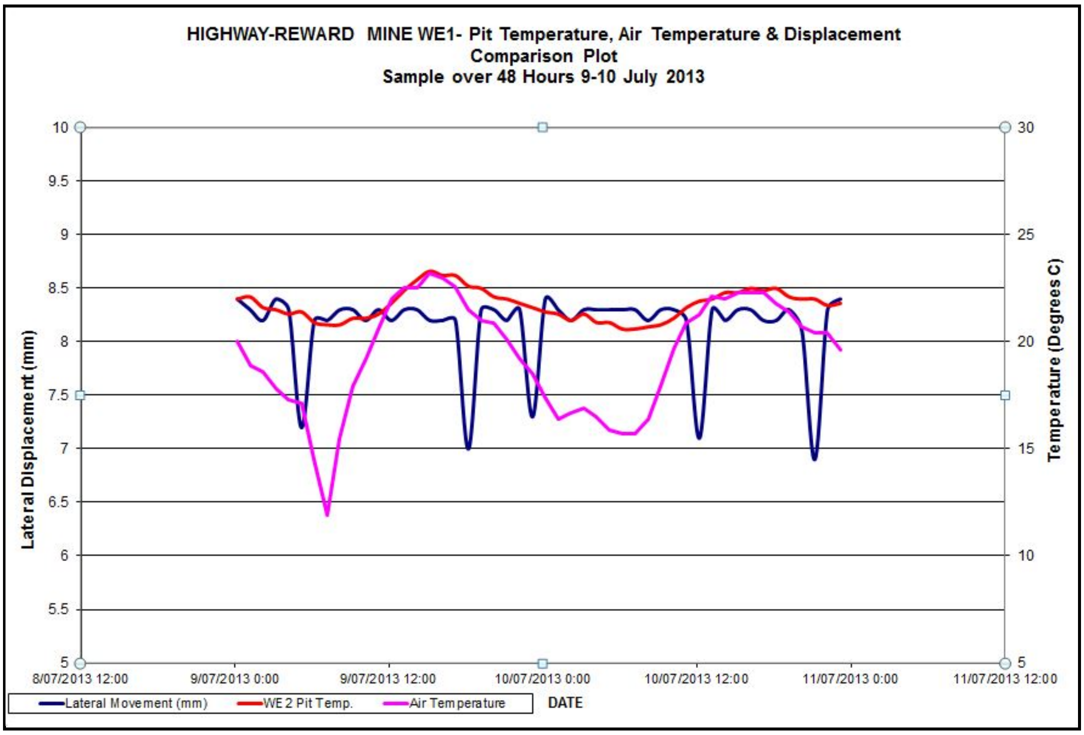


Figure 90 – Comparison of temperatures and displacement in WE2

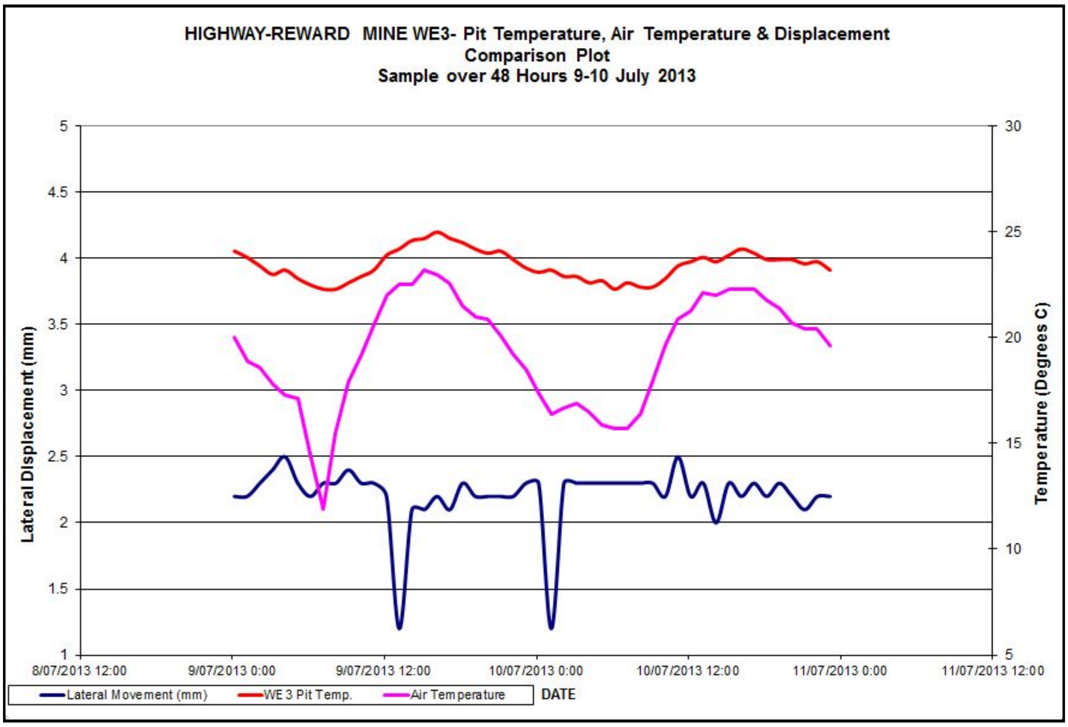


Figure 91 – Comparison of temperatures and displacement in WE3

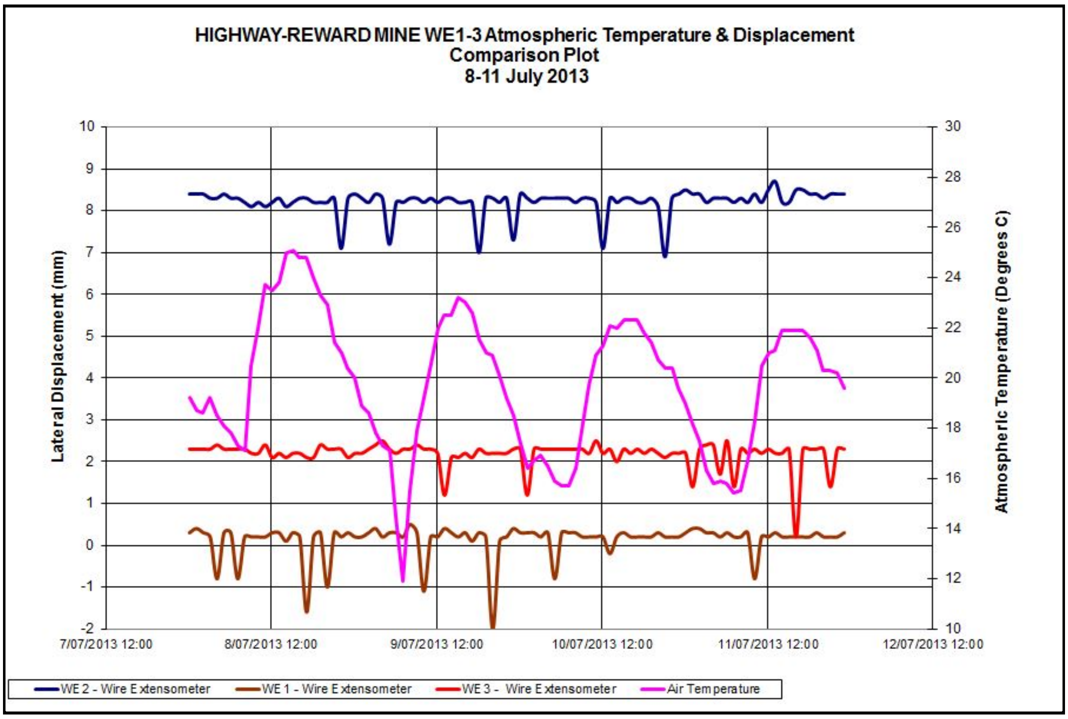


Figure 92 – Comparison of all extensometer displacements and atmospheric temperature

From the comparison between the displacements, pit and atmospheric temperatures, it is apparent that the fluctuations in displacements do not appear to follow the trend of the temperature fluctuations.

It is clear that the pit temperatures fluctuate less than the atmospheric temperature, due to the insulation effect of the below-ground pits. The small fluctuation of temperature within the pits mean that the actual temperature fluctuations throughout the length of the wire would be even less significant, due to most of the wire length having even greater insulation, as they are buried below ground. Therefore, it is unlikely that temperature fluctuations have a significant effect on the displacements recorded.

6.3.5. Piezometer Data Analysis

The final part of the data analysis was to compare the response of the VWP to the recorded rainfall, and to determine if these fluctuations have had an effect on displacements on any of the devices, particularly WE2, which has recorded the most displacement.

Figure 93 shows the groundwater level determined from the installed VWP. On this plot, the ground RL and the RL of the VWP are recorded.

Figure 94 also shows the groundwater level, but a reduced scale has been used for clarity. From this plot it is evident that the groundwater level does respond to rainfall, although the overall increase in groundwater level is minor.

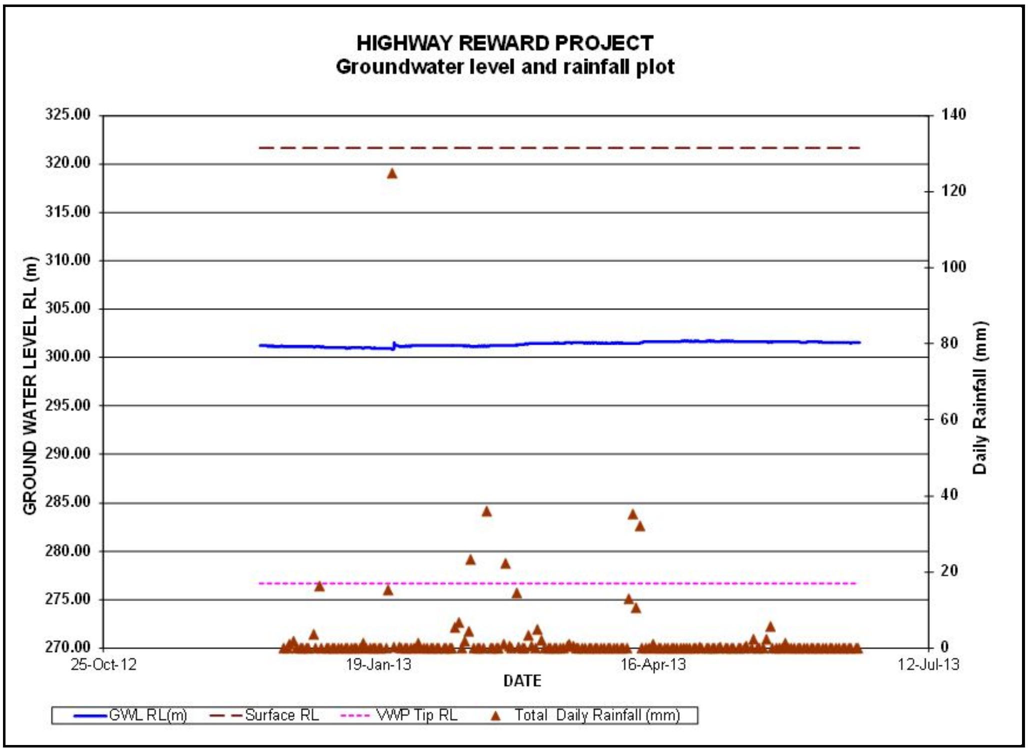


Figure 93 – Groundwater level and rainfall plot

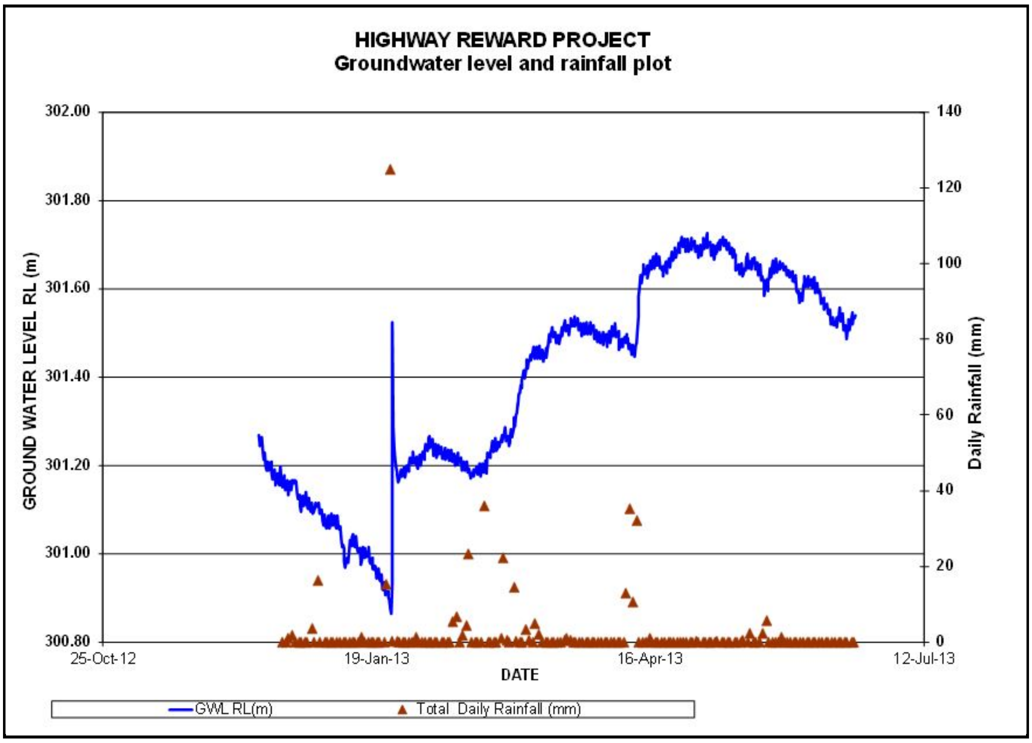


Figure 94 – Groundwater level and rainfall plot: reduced scale

Figure 95 to Figure 97 shows the groundwater levels plotted against displacement for the three extensometers. A common feature of all three plots is that they show that increase in displacement during the severe weather event also coincided with an increase in groundwater level. However, WE1 and WE2 do not carry this trend through to other increases in groundwater level later in time.

On the other hand, WE2 has displayed a significant increase in displacement which follows the rise in groundwater levels, but has shown a continued increase in displacement after groundwater levels begin dropping.

<u>Summary</u>

In Section 3.3, Coffey Geotechnics (2011a) state that one of the causes of the major failures in the mine pitwalls are elevated groundwater pressures. Therefore, any increase in groundwater level has the potential to enhance the possibility of further slope instability.

Furthermore, although the groundwater levels definitely show response to rainfall, it is difficult to determine if the groundwater levels do have an impact on displacements recorded in the devices, as the recorded groundwater fluctuations are quite small, and the installed VWP is located a significant distance from the wire extensometers (around 200 m north of WE3 location) Further data will be required in order to prove or disprove any possible correlations, and if possible, a monitoring well closer to the site would need to be established.

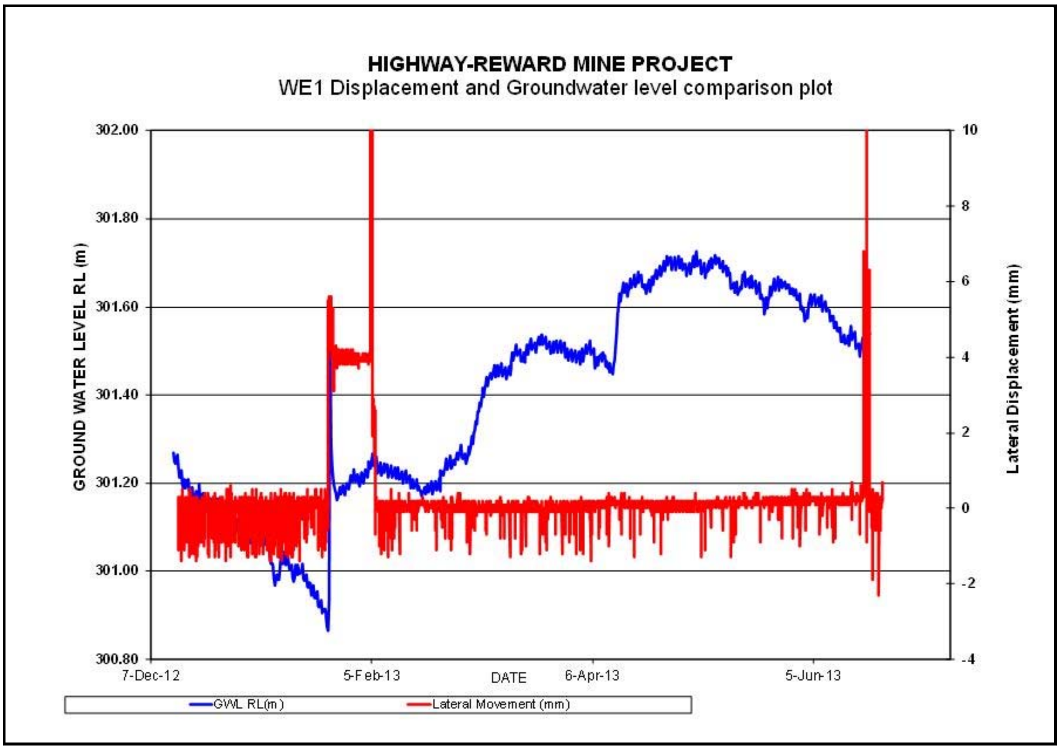


Figure 95 – Groundwater levels and displacement comparison for WE1

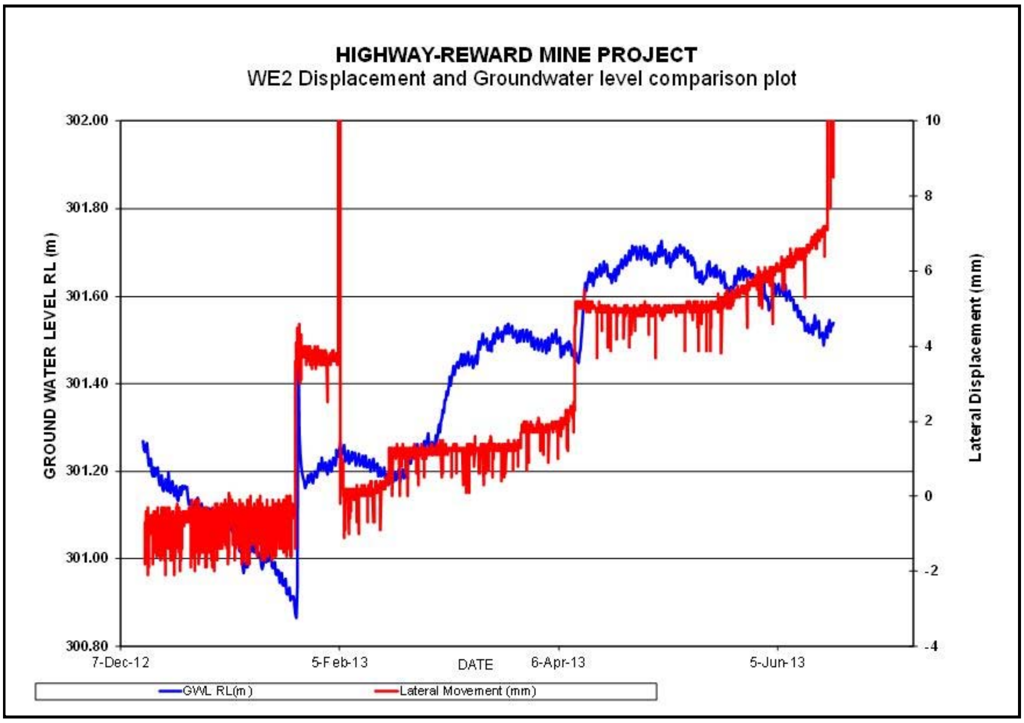


Figure 96 – Groundwater levels and displacement comparison for WE2

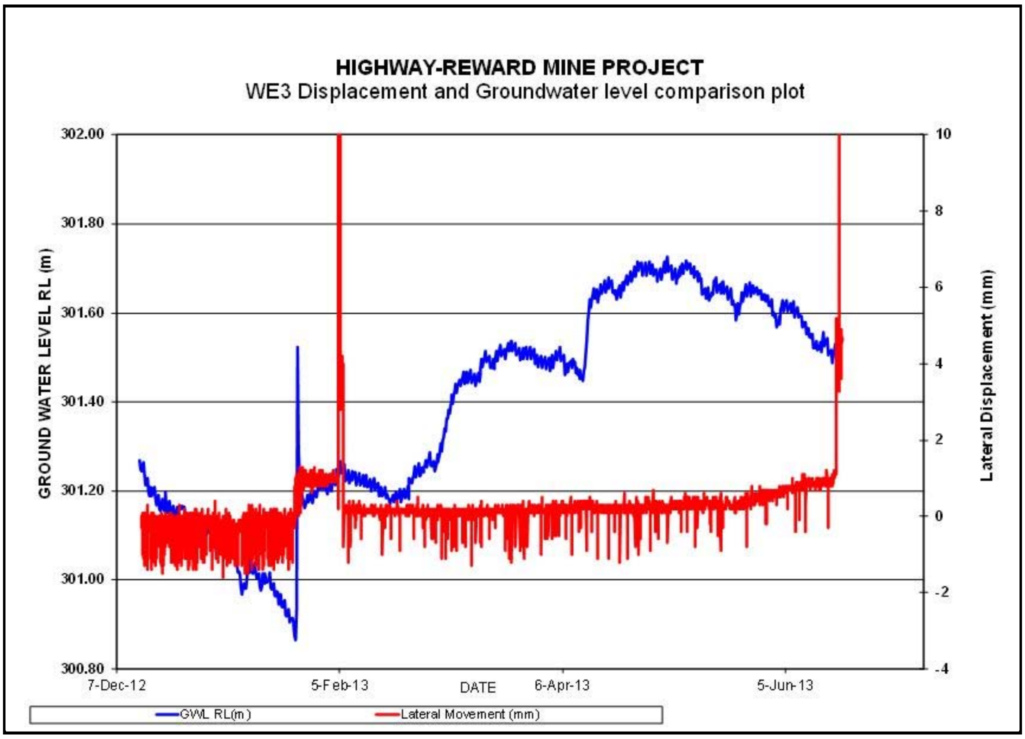


Figure 97 – Groundwater levels and displacement comparison for WE3

7. Conclusions and Recommendations

7.1. Conclusions

The wire extensometer early-warning instrumentation system has provided a unique solution to the risk management of the Gregory Developmental Road adjacent to the Highway-Reward Mine site. It should be considered as a viable alternative over conventional types of instrumentation for undertaking monitoring of road pavements or other structures which are prone to cracking and failure due to slope instability.

The fact that the system can be installed without any disruption to traffic should be considered as a key advantage of wire extensometers, as well as the ease of setup, access for maintenance and relatively low cost in comparison to the identified alternatives. The use of a mid-hinged pole as the base for the system communications is ideal for use in remote locations, as it provides protection from bushfire and vandalism while still allowing hassle-free access to the hardware for maintenance purposes. It is also significantly easier and cheaper to install than a fenced enclosure.

The relatively complex geological history of the Highway-Reward Mine has caused some difficulty in interpreting the type and extent of failure of the western wall of the mine, which is adjacent to the roadway. Therefore, some uncertainty lies when it comes to determining whether the observed cracking on the site is associated with slope instability on the mine wall. This has caused problems in determining if the detected movement in the devices, particularly WE2, is related to the cracking observed on site, and if so, is the cracking a symptom of slope instability.

It is clear that the wire extensometers do respond to rainfall. This is evident from the displacements following the large rainfall event recoded during Ex. TC Oswald in January 2013. However, as these recorded displacements have been assumed to be purely the result of the initial settlements of the installations due to the rainfall, another significant event will be required in order to provide more evidence to support this assumption.

It is also important to note the importance of continuing to gather data relating to the groundwater levels present on site, as historical failures of parts of the mine wall adjacent to the roadway have been associated with elevated groundwater pressures.

It is envisaged that over the coming years, the large amounts of weather, groundwater level and displacement data gathered from the site will shed some light on the uncertainties described above, so a more thorough overall understanding of the site will be achieved. This will enable decisions to be made with respect to a possible long-term solution for the site, which may include a road realignment or the installation of additional instrumentation.

Investigation into the data spikes within the extensometer readings has revealed that it is unlikely that thermal effects on the instrument wires are the cause of the spikes in data. Although some of the data anomalies are outside the advertised error on the wire extensometers, it does not impede on the overall function of the system as an early-warning monitoring system, as the discrepancy is insignificant when compared to the defined trigger levels of 25 mm and 100 mm.

Any further investigation into these anomalies will be purely from a research perspective, so will have no significant contribution to the improvement of the functionality of the system as a whole. Additional investigation, if warranted, could continue with a Fast Fourier transform (FFT) on the displacement raw data in an attempt to discover the source of the data spikes.

7.2. Recommendations

Data from instrumentation which records displacement is normally used in conjunction with survey data. The survey prisms installed on the site have been deemed to be inadequate for producing reliable data. Therefore, it is recommended that the current star-picket mounted survey prisms be replaced with more reliable and robust survey prisms. These prisms will need to be installed on steel posts which are concreted into the ground.

In addition, to date, the concrete pit surrounds have not been re-surveyed since cracking was observed in the vicinity of WE2. This would be quite an easy method of verifying the movements recorded by the device, and also determining any settlements experienced since installation.

It is also recommended that a monitoring camera be installed so a visual assessment of the condition of the pavement can be undertaken remotely. This would be an invaluable addition to the early-warning system as a visual assessment will immediately indicate if the road is in a trafficable condition in the event a trigger level for rainfall or movement is reached. It will also enhance the security of the site by making the installations less attractive to vandals, thereby reducing the probability of false alarms.

Ideally, this camera would be installed on the communications pole, but additional hinged poles may be installed on site for this purpose. The current Campbell Scientific logger also has the capacity to support several cameras, but the power system will need to be upgraded.

In addition, further work into protecting the wire extensometer pits from inundation in times of heavy rainfall needs to be undertaken. Some work recently undertaken in this area was the construction of earth bunds around the live end pits. However, the effectiveness has not been tested as the site has not experienced rainfall for quite some time. Installation of water level sensors at the base of the extensometer transducers may be useful, as these will indicate if and when personnel will need to attend site in the event of the devices being totally submerged.

Finally, in order to gain a more thorough understanding of the groundwater conditions on the site, additional piezometers could be installed in the immediate vicinity of the wire extensometers.

7.3. Future Work

The usefulness of wire extensometers for monitoring other structures such as dam walls and earth embankments could be investigated.

In addition, comparison of wire extensometers to the other types of instrumentation as discussed in the literature review (see Chapter 2) could be undertaken. For this to occur, a test site with ongoing slope movement that has contributed towards cracking and displacements in a road pavement would be required. A suitable site which meets these criteria is the South West Transport Corridor (SWTC) site, which was also discussed in the literature review (see Section 2.2.2).

The SWTC site has an array of inclinometers and piezometers installed, and the failure mechanism is well-known, so the installation of wire extensometers would give invaluable information regarding the pavement performance in relation the actual slope movement and groundwater data collected from the inclinometers and piezometers.

If additional of instrumentation were installed in the pavement (such as soil strainmeters and FBG sensors) it would allow correlations to be made between these instruments. Additional benefits from this type of study could also include revealing any previously unknown limitations or errors arising from the installations of these instruments, so their ultimate reliability could be determined.

8. References

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Appendix A: Project Specification and Letter of Confidentiality

University of Southern Queensland

FACULTY OF ENGINEERING & SURVEYING

ENG4111/4112 Research Project

PROJECT SPECIFICATION

FOR:	Jeremy Nicholas KIRJAN
TOPIC:	USE OF WIRE EXTENSOMETERS FOR MONITORING PAVEMENT PERFORMANCE IN AREAS OF SLOPE INSTABILITY
SUPERVISOR:	Dr. Jim Shiau Mr. David Marks, Principal Technologist, DTMR
PROJECT AIM:	This project seeks to investigate the suitability, design and implementation of a wire extensometer instrumentation system for monitoring pavement performance and managing risk on the Gregory Developmental Road: Highway Reward Mine site.
PROGRAMME:	**Issue B, 12 March 2013**

1. Research the typical mechanisms of slope instability and the affect on pavements.
2. Research the background information relating current instrumentation options for monitoring pavements, including data logging systems.
3. Critically evaluate instrumentation options and introduce the Geregory Developmental Road: Highway Reward Mine site, also provide history and background information for this site.
4. Design and implement an instrumentation system to monitor pavement performance and manage risk by implementing a near real-time warning system.
5. Analyse the data and identify any shortfalls with the system and investigate possible improvements to be made.

As time permits:

6. Identify other possible suitable applications for the system.
7. Select additional site(s) where the application of the system would be suitable. The proposed site is the Centenary Motorway- South West Transport Corridor landslide area.
8. Design the system to monitor the pavement performance of this site(s) to supplement existing ground monitoring instrumentation.

AGREED: ________________ (student) ________________ (supervisor)

Date: / / 2013 Date: / / 2013

Examiner ________________________________

UNIVERSITY OF SOUTHERN QUEENSLAND
AUSTRALIA

CS:CS:13:Confidentiality

FACULTY OF HEALTH, ENGINEERING & SCIENCES
Mr Chris Snook
Examiner ENG4111/2 Research Project
PHONE +61 746312534| FAX +61 746312526
EMAIL chris.snook@usq.edu.au

14 October 2013

0050018464
Mr Jeremy Kirjan
51 Paramount Terrace
SEVEN HILLS QLD 4170

Dear Jeremy

Re: ENG4111/2 Research Project – Letter of Confidentiality

Thank you for your correspondence of 14 October requesting confidentiality for the *ENG4111/2 Research Project* course project entitled *Use of Wire Extensometers for Monitoring Pavement Performance in Areas of Slope Instability.*

To meet your request for confidentiality I hereby undertake not to forward the notional "Library Copy" CD of your project dissertation to the University Library. However, please note that this copy must remain with the University: it will remain in the safekeeping of your supervisor, Dr Jim Shiau and be shown to no-one outside the Faculty of Health Engineering and Sciences except with your specific permission to do so.

As stated in the ENG4111/2 Project Reference Book, this undertaking lapses after a period of five (5) years from the date of this letter. However, you may wish to contact the University again nearer the expiry date and request that we renew the undertaking.

Yours sincerely

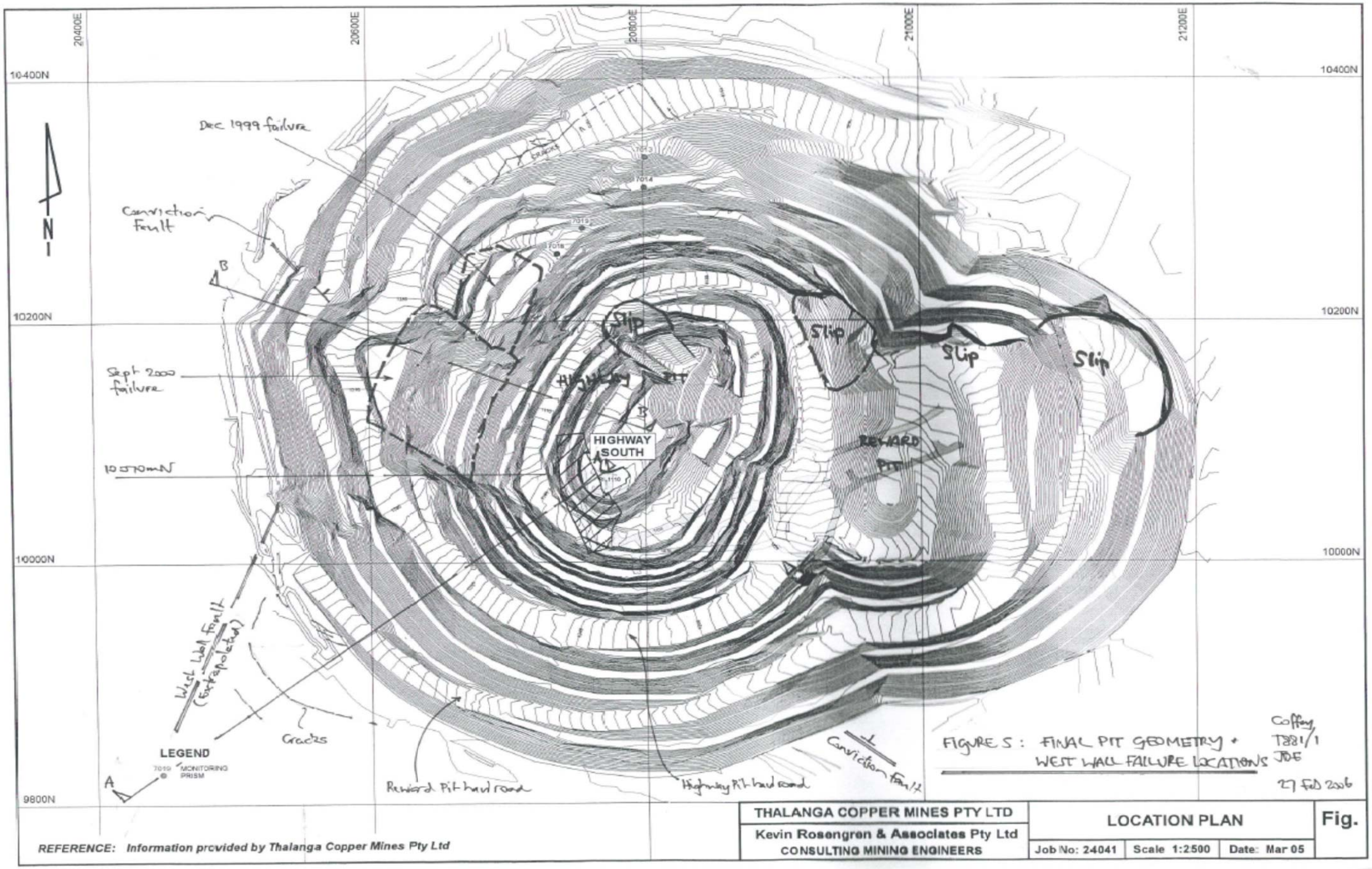
Chris Snook
Examiner ENG4111/2 Research Project

Copy: Jim Shiau, Project Supervisor Faculty of Health Engineering and Sciences
Carolyn Saffron, Project Administrator, Faculty of Health Engineering and Sciences
Student Records TRIM

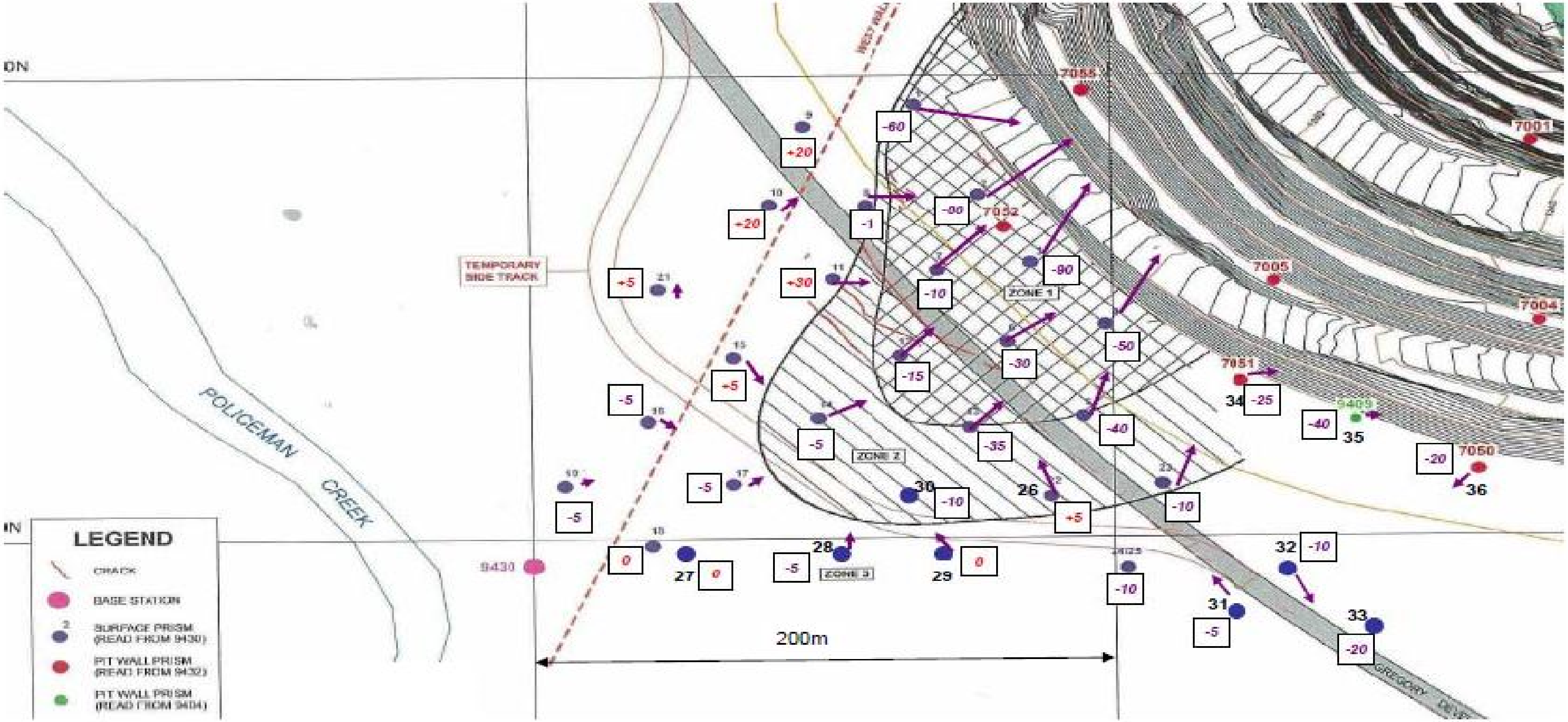
University of Southern Queensland
Toowoomba I Springfield I Fraser Coast

usq.edu.au
CRICOS QLD 00244B NSW 02225M
TEQSA PRV12081

Appendix B: Mine Location Plan


20400E
20600E
20800E
21000E
21200E
10400N
10200N
10000N
9800N
N
Dec 1999 failure
Conviction Fault
Sept 2000 failure
10070mN
Slip
Slip
Slip
Slip
HIGHWAY PIT
HIGHWAY SOUTH
REWARD PIT
West Wall Fault (Extrapolated)
Cracks
LEGEND
7019 MONITORING PRISM
Reward Pit haul road
Highway Pit haul road
Conviction Fault
FIGURE 5: FINAL PIT GEOMETRY + WEST WALL FAILURE LOCATIONS
Coffey T381/1 JOE
27 Feb 2006
REFERENCE: Information provided by Thalanga Copper Mines Pty Ltd
THALANGA COPPER MINES PTY LTD
Kevin Rosengren & Associates Pty Ltd
CONSULTING MINING ENGINEERS
LOCATION PLAN
Fig.
Job No: 24041
Scale 1:2500
Date: Mar 05

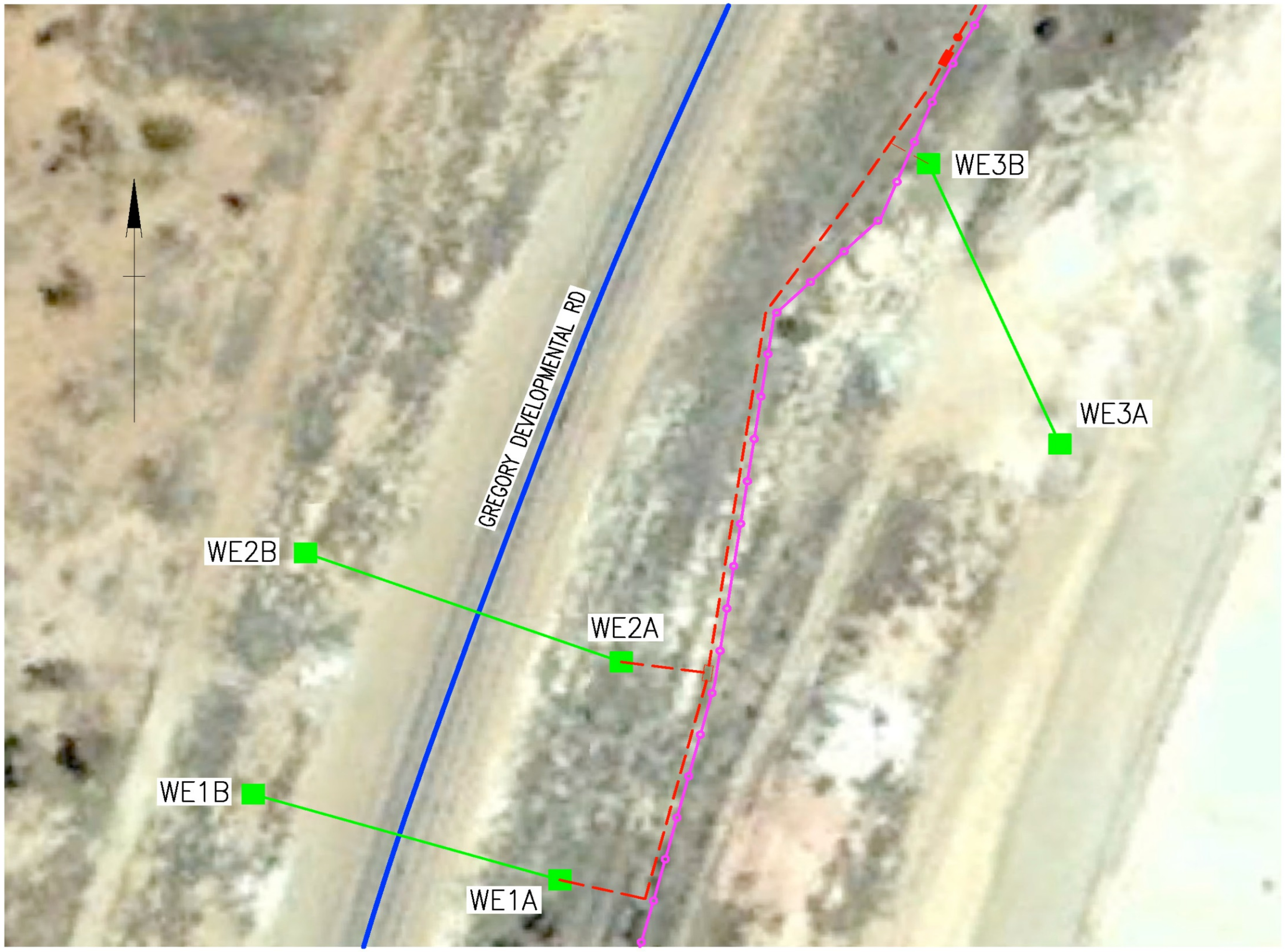
Appendix C: Survey Prism Locations



Original drawing from GHD Report
28 February 2011, Job No 32/13809

drawn	JDE	coffey geotechnics SPECIALISTS MANAGING THE EARTH	client: QUEENSLAND DEPT OF TRANSPORT AND MAIN ROADS
approved	JDE		project: HIGHWAY REWARD MINE SLOPE MOVEMENT – REVISED RISK ASSESSMENT
date	13/04/2011		
scale	NTS		title: PRISM LOCATIONS & MOVEMENT SUMMARY TO FEB 2011
original size	A4		project no: GEOTGARB00881AA-AG / figure no: FIGURE 6

Appendix D: Wire Extensometer Location Plans



LEGEND

WE1A — Detail A wire extensometer end number and location

WE1B — Detail B anchor end number and location

Junction pit

Communications pole termination pit

Communications pole

400W x 600D cable trench (2 pair instrumentation cable in 40mm electrical conduit)

Fence

Extensometer (65mm communications conduit containing 3mm stainless steel extensometer cable)

PRELIMINARY
17 January 2013

Client: –

Project Name: HIGHWAY REWARD MINE PROJECT

Investigation Type: –

SURVEY DATA — GDA

Horiz. Grid: MGA94 Zone 55

Height Origin: AHD

Survey Books: –

Scales: 0 2 4 6 8 10m

Dimensions shown in metres except where shown otherwise

CTL CHGE –

Reference Points –

Preceding RP	Dist. to start of job (km)	From start to end of job	From end to Following RP	Following RP
–	–	–	–	–

Through Chainage from –

PLAN 3
INVESTIGATION LOCATIONS
WIRE EXTENSOMETER AND ANCHOR END

AREA	NAME	–	–
PROJECT ENGINEER			
PROJECT GEOLOGIST			
DRAFTER			

Queensland Government
Transport and Main Roads

Job No. –
Project No. –
Plan No. 3 A
Series Number 3 of 3
MRG_Detail (01/10)

	Revisions/Descriptions	Ref	Certification	Date	Microfiled
E					
D					
C					
B					
A	Original Issue A3				

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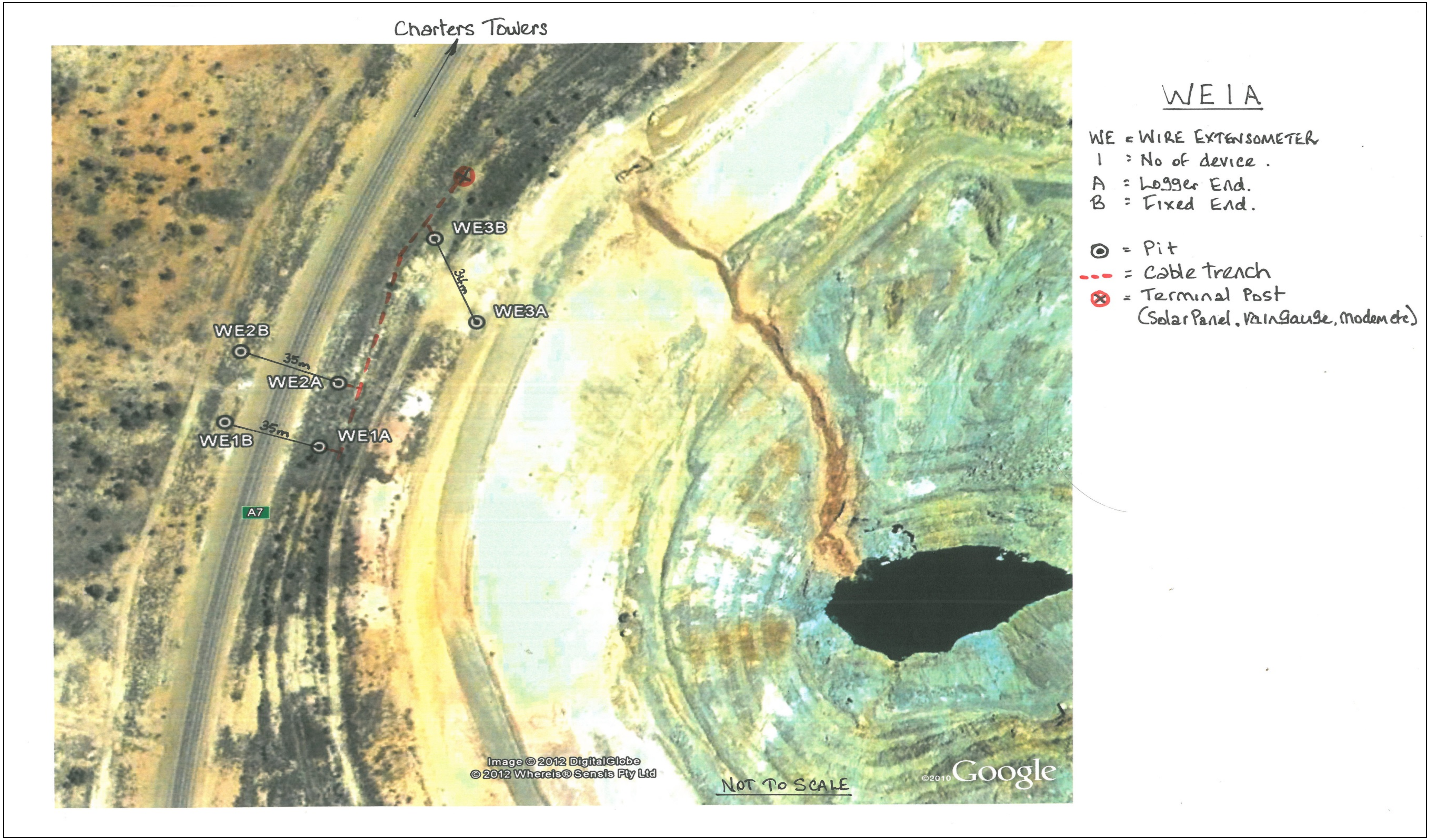
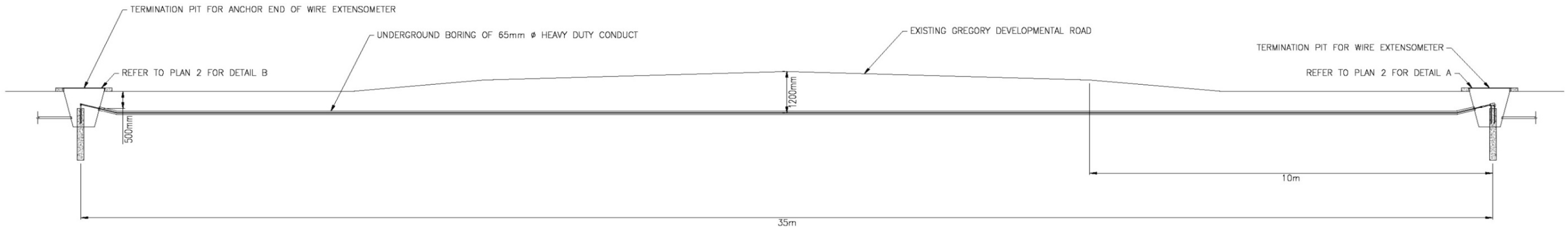
Last Modified :- Jan 17, 2013 - 4:16pm XREF'S :-


Charters Towers
WE3B
34m
WE3A
WE2B
35m
WE2A
WE1B
35m
WE1A
A7
Image © 2012 DigitalGlobe
© 2012 Whereis® Sensis Pty Ltd
NOT TO SCALE
©2010 Google
WE1A
WE = WIRE EXTENSOMETER
1 = No of device.
A = Logger End.
B = Fixed End.
= Pit
= Cable trench
= Terminal Post
(Solar Panel, raingauge, modem etc)

Appendix E: Wire Extensometer Detail Drawings



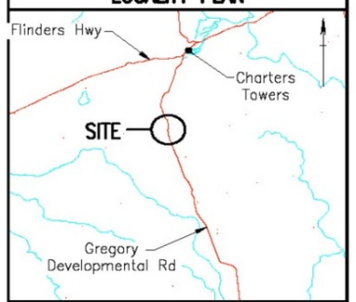
	EASTING	NORTHING
WE1A	416421	7747927
WE1B	416386	7747938
WE2A	416428	7747955
WE2B	416392	7747969
WE3A	416478	7747983
WE3B	416463	7748019

CROSS SECTION – TYPICAL INSTALLATION OF WIRE EXTENSOMETER

NOTES:

1. Locations determined from hand held GPS coordinates.
2. A denotes Detail A wire extensometer end.
3. B denotes Detail B anchor end.

LOCALITY PLAN



Scale

PRELIMINARY
17 January 2013

XREFS :-
Last Modified :- Jan 17, 2013 - 3:35pm

Rev	Revisions/Descriptions	Ref	Certification	Date	Microfiled
E					
D					
C					
B					
A	Original Issue A3	[redacted]			

CAD FILES G:\GeotechBranchDrafting\Drafting\HIGHWAY REWARD MINE for Jeremry\Plan.dwg

Client: –

Project Name: HIGHWAY REWARD MINE PROJECT

Investigation Type: –

SURVEY DATA — GDA

Horiz. Grid	MGA94 Zone 55
Height Origin	AHD
Survey Books	–

Scales: 0 1000 2000mm

Dimensions shown in metres except where shown otherwise

–

–

CTL CHGE –

Reference Points –

Preceding RP	Dist. to start of job (km)	From start to end of job	From end to Following RP	Following RP
–	–	–	–	–

Through Chainage from –

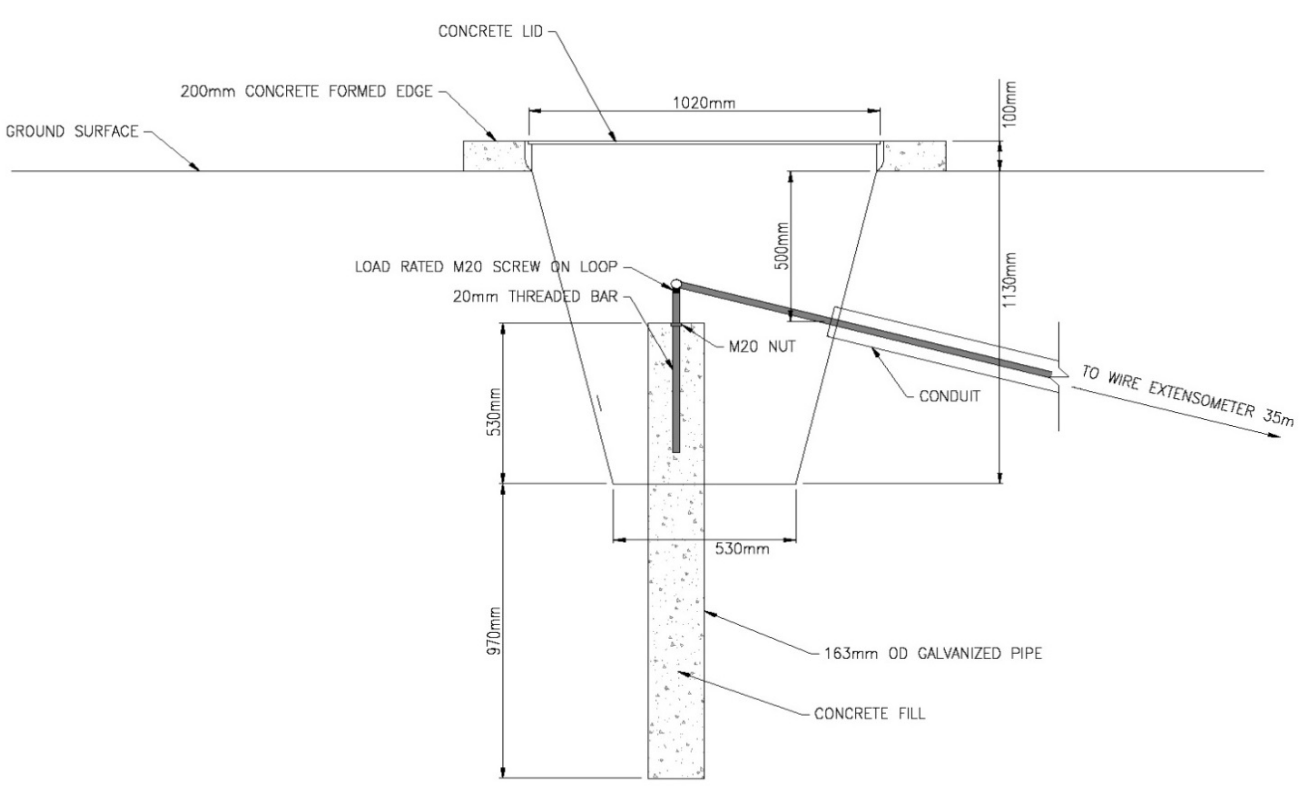
PLAN 1
CROSS SECTION – TYPICAL INSTALLATION

AREA	NAME	–	–
PROJECT ENGINEER			
PROJECT GEOLOGIST			
DRAFTER			

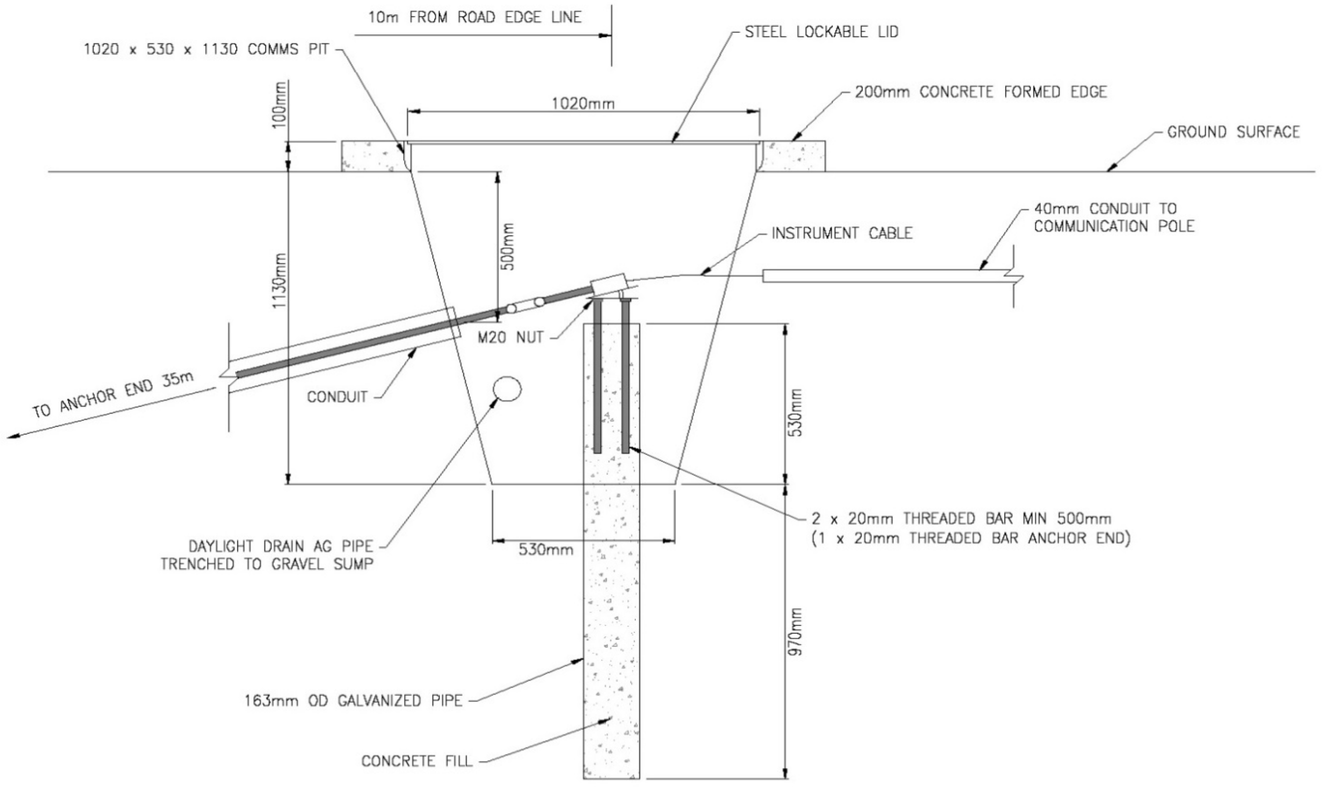
Queensland Government
Transport and Main Roads

Job No.	–
Project No.	–
Plan No.	1 A
Series Number	1 of 3

MRG Detail (01/10)



DETAIL B – ANCHOR END



DETAIL A – WIRE EXTENSOMETER END

PRELIMINARY
17 January 2013

XREF'S :-
Last Modified :- Jan 17, 2013 - 3:36pm

E				
D				
C				
B				
A	Original Issue A3	[redacted]		
	Revisions/Descriptions	Ref	Certification	Date	Microfiled

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Client: –

Project Name: HIGHWAY REWARD MINE PROJECT

Investigation Type: –

SURVEY DATA — GDA

Horiz. Grid	MGA94 Zone 55
Height Origin	AHD
Survey Books	–

Scales: 0 100 200 300 400mm

Dimensions shown in metres except where shown otherwise

CTL CHGE –

Reference Points

Preceding RP	Dist. to start of job (km)	From start to end of job	From end to Following RP	Following RP
–	–	–	–	–

Through Chainage from –

PLAN 2
DETAIL A – WIRE EXTENSOMETER AND
DETAIL B – ANCHOR END

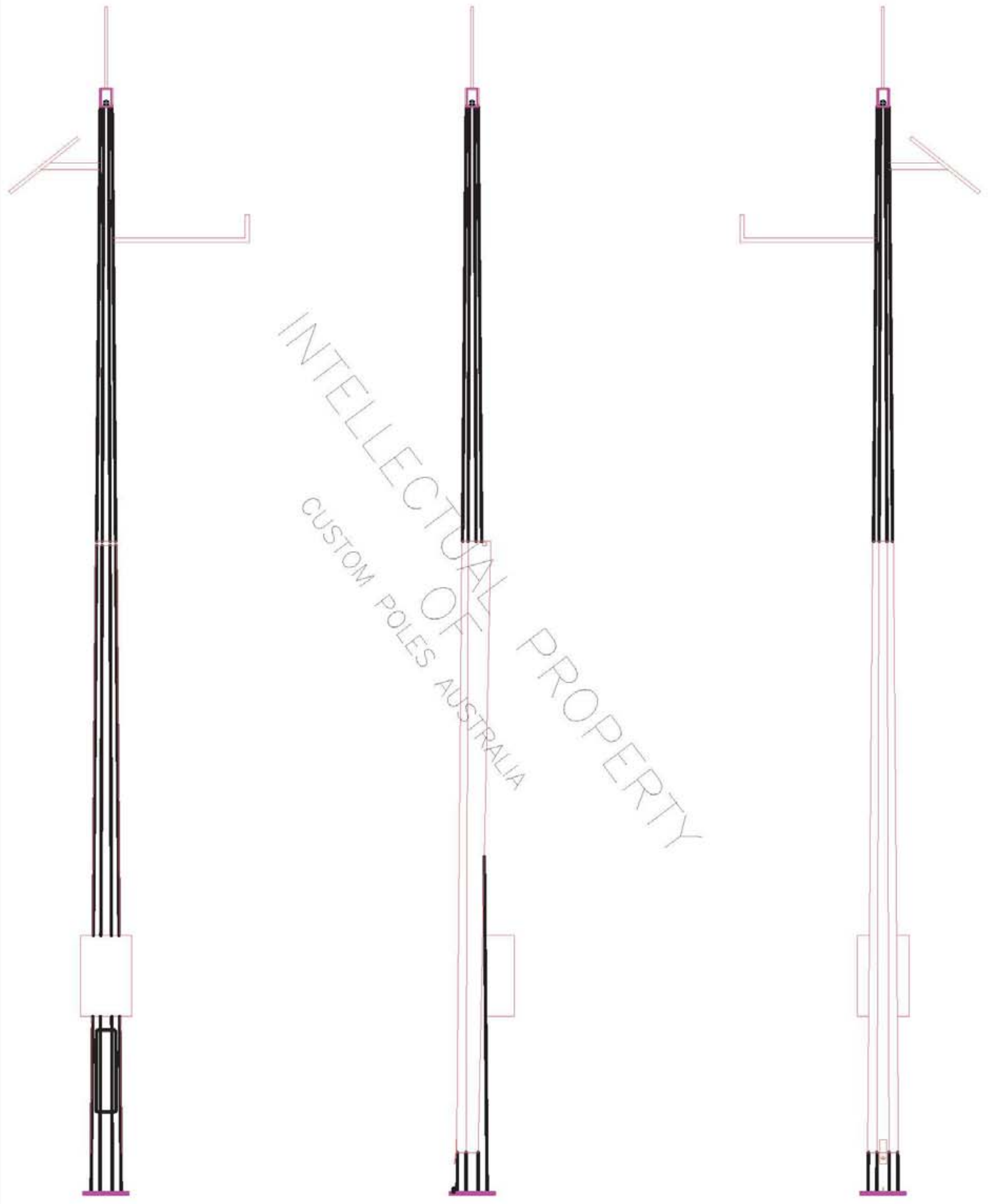
AREA	NAME	–	–
PROJECT ENGINEER			
PROJECT GEOLOGIST			
DRAFTER			

Queensland Government
Transport and Main Roads

Job No.	–
Project No.	–
Plan No.	2 A
Series Number	2 of 3

MRG_Detail (01/10)

Appendix F: Hinged Pole Detail Drawing

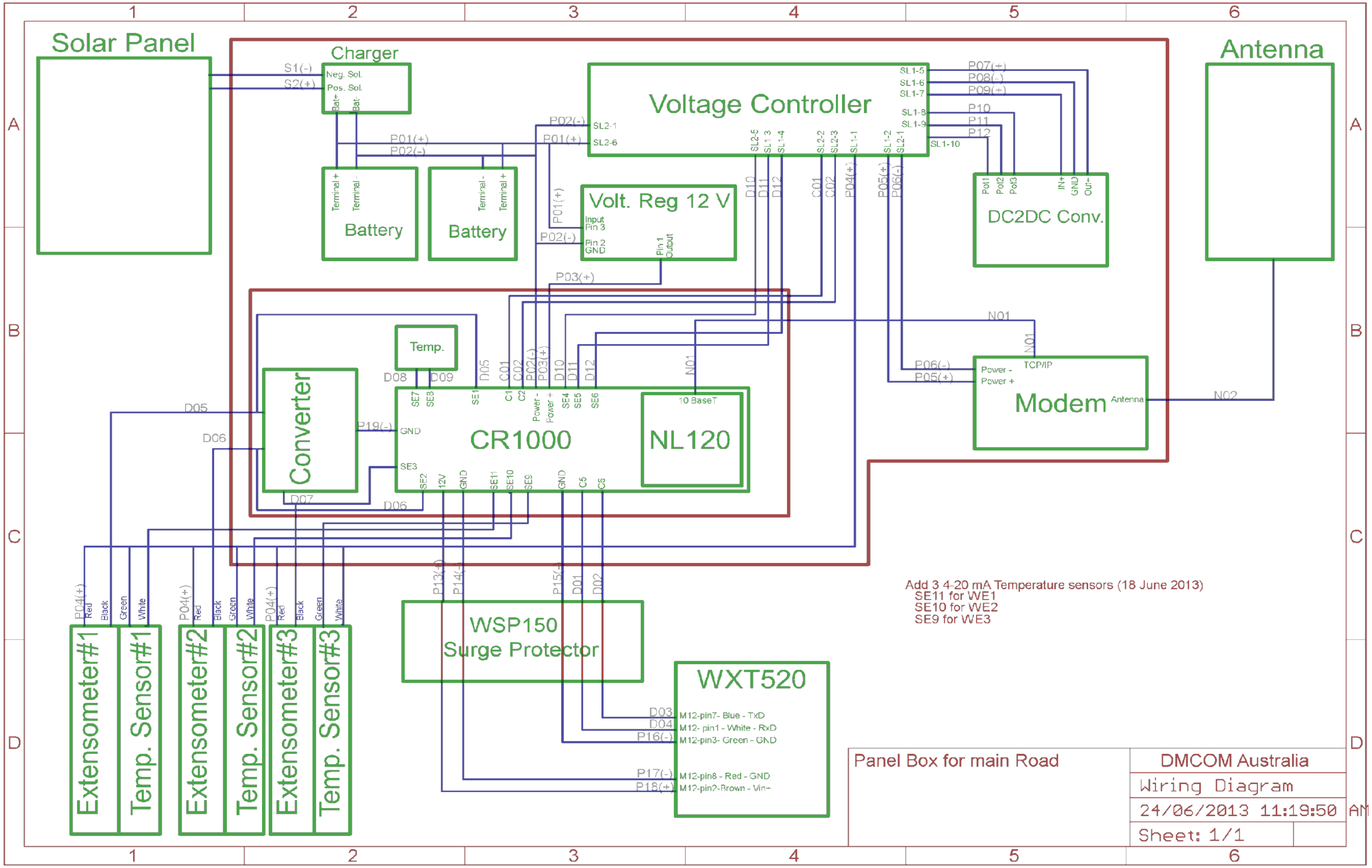


Customer QA – Please Initial Boxes		Sign
Customer	TMR	
Region	A2	
Type	Mid hinge M Utility Pole	
Length	8m	
Bolt & PCD	4M24 350PCD	
Spigot	ø90x120mm	
Finish	HD GAL	

Designed By
Custom Poles Australia

		Specifications	
PART NO 106S		Design	AS 4677/4802
Drawing No: AS ABOVE		Welding	AS 1554
Drawn By/Date	WM 25/01	Finish	AS 4680
Approved By/Date	WM 25/01	Finish	N/A
Sheet/Version	01 / 01	Weight	154kg

Appendix G: Wiring Diagram



Solar Panel
Charger
Neg. Sol.
Pos. Sol.
S1(-)
S2(+)
Battery
Battery
Voltage Controller
P01(+)
P02(-)
Volt. Reg 12 V
P03(+)
DC2DC Conv.
Antenna
Temp.
Converter
CR1000
NL120
Modem
N01
N02
P05(+)
P06(-)
D05
D06
D07
D08
D09
P19(-)
WSP150
Surge Protector
WXT520
M12-pin7- Blue - TxD
M12- pin1 - White - RxD
M12-pin3- Green - GND
M12-pin8 - Red - GND
M12-pin2-Brown - Vin-
Extensometer#1
Temp. Sensor#1
Extensometer#2
Temp. Sensor#2
Extensometer#3
Temp. Sensor#3
Add 3 4-20 mA Temperature sensors (18 June 2013)
SE11 for WE1
SE10 for WE2
SE9 for WE3
Panel Box for main Road
DMCOM Australia
Wiring Diagram
24/06/2013 11:19:50 AM
Sheet: 1/1

Appendix H: Site Survey Details

Our ref 110318
Your ref 042/98B/57
Enquiries

Queensland Government

Department of
Transport and Main Roads

8 November 2012

Mr. D.A. Dance
Technical Services Coordinator
Department of Transport & Main Roads
P O Box 1089
Townsville Qld 4810

Subject: Wire Extensometer and Communication Site Survey
Road Name: 98B Gregory Developmental Road – Highway Reward Mine Site
Job No: 042/98B/57
File No: 217037

Extent of Works:
The survey was for location of the monitoring sites on the highway adjacent to the Highway Reward Mine that has ceased operating.

Datum:
Survey has been completed with an Azimuth datum of GDA 94 Zone 55.
Level Datum was AHD D obtained from PM71074 on the Policeman Creek bridge; this marked was used on previous monitoring surveys.
Coordinate datum is GDA 94 Zone 55.

Survey Details:

GNSS RTK survey method was used to locate the steel pillar used for slippage monitoring, together with two stations (Stns 1 & 2, both steel pickets) placed approximately 100 m North East and South East from the Pillar. These points are the datum for this survey.

Survey marks being ramset or dyna nails were placed in the concrete surrounds of the Wire Extensometer (WE) and Anchor pits as well as the communication pit. The communication pit lies beside a tower with solar panel, and aerials attached.

Department of Transport and Main Roads
Northern Region
Townsville Office
Jurekey Street, Cluden

P.O. Box 1089 Townsville, QLD, 4810

Our ref 110318
Your ref 42/98B/57
Enquiries John Grandison
Telephone +61 7 0747268537
Facsimile +61 7 0747268592
Website www.tmr.qld.gov.au
Email John.Grandison@tmr.qld.gov.au

The survey marks were then located using a Leica Total Station that provides better accuracy than GNSS.

A radiation from the pillar to the communications pit (COMS1) using Stn 1 as a backsight was undertaken using 'Sets of Angles' method to locate this mark.

A radiation to all other marks in the various pits using the same method was then carried out.

The distance between the related pits I.e. WE1A to WE1B was then measured.

A comparison was now possible using the calculated distance from the COMS1 radiations and direct measurements. Good agreement between these was obtained with the difference being 0.003 m or less. Note all these measurements were independent set ups.

The centre of the communication pole, WE pits, communication pit and MW borehole were also surveyed.

Heights were obtained using PSM71074 as the datum, and using two way digital levelling to obtain AHD Derived heights.

Two spreadsheets are enclosed, being the coordinate and height data for the points and a comparison table of the check measurements across the WE and anchor pits, together with a 12da file of the survey. Note that the points in the cdist SURVEY TRAVERSE model are the check measurements.

Yours sincerely

John Grandison
Senior Surveyor
Transport & Main Roads Surveys Townsville

Department of Transport and Main Roads
Northern Region
Townsville Office
Jurekey Street, Cluden

P.O. Box 1089 Townsville, QLD, 4810

Our ref 110318
Your ref 42/98B/57
Enquiries John Grandison
Telephone **+61 7 0747268537**
Facsimile +61 7 0747268592
Website www.tmr.qld.gov.au
Email John.Grandison@tmr.qld.gov.au

HIGHWAY REWARD MINE WE SITE SURVEY				
SURVEY MARK DATA				
Name	**Easting**	**Northing**	**Height**	**Code**
PILLAR	416243.068	7747998.229	318.865	PFSC
STN1	416303.848	7747907.104	317.974	PFSC
STN2	416310.215	7748059.085	317.137	PISP
COMS1	416466.371	7748031.435	321.242	PISP
WE2B	416392.382	7747969.107	319.124	PISP
WE1B	416383.872	7747940.442	318.888	PISP
WE1A	416416.804	7747930.603	319.556	PISP
WE2A	416425.840	7747958.478	319.798	PISP
WE3A	416474.447	7747985.758	321.570	PISP
WE3B	416462.145	7748017.140	321.097	PISP
STRUCTURE LOCATIONS - CENTRE OF PITS AND POLE				
Name	**Easting**	**Northing**	**Height**	**Code**
COMMS1	416466.958	7748031.594	321.215	PELB
WE2A	416426.490	7747958.619	319.770	PELB
WE2B	416393.078	7747969.220	319.099	PELB
WE1B	416384.557	7747940.589	318.850	PELB
WE1A	416417.479	7747930.748	319.536	PELB
WE3A	416475.013	7747985.306	321.534	PELB
WE3B	416462.734	7748016.683	321.070	PELB
MW4	416626.637	7748238.569	321.636	PMBH
COMS POLE	416468.319	7748034.275	322.460	PNSP

HIGHWAY REWARD MINE MONITORING			
LINE	HORIZ DISTANCE	COMPUTED RADIATIONS	DIFFERENCE
WE1B - WE1A	34.374	34.371	0.003
WE2B - WE2A	35.106	35.105	0.001
WE3B - WE3A	33.709	33.708	0.001

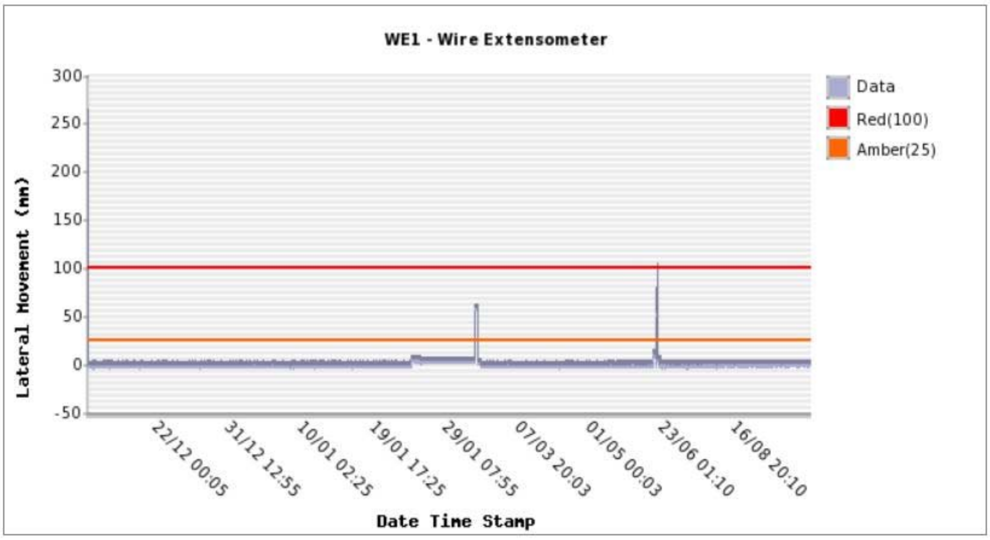
Appendix I: Site Emergency Response Plan

				PRIMARY NOTIFICATIONS				
				DAVID MARKS TMR GEOTECHNICAL UNIT BRISBANE Ph. 0417 742 763 dave.f.marks@tmr.qld.gov.au	**RUDY MONIAGA** GEOTESTA PTY LTD MELBOURNE Ph. 0427 562 080 rudy.moniaga@dmcom.com.au	**CHERYL RIDD** TMR NORTHERN REGION TOWNSVILLE Ph. 0418 989 053 cheryl.a.ridd@tmr.qld.gov.au	**DON GRINSTEAD** HIGHWAY REWARD MINE CHARTERS TOWERS Ph. 0427 014 384 don@maxgate.com.au	**GEOFFREY JACKSON** CHARTERS TOWERS REGIONAL COUNCIL CHARTERS TOWERS Ph. 0429 915 300 gjackson@charterstowers.qld.gov.au
	TRIGGER LEVELS			**BACKUP NOTIFICATIONS**				
ALARM CONDITION	TOTAL DAILY RAINFALL (mm) Total rainfall in a 24 hour period	WIRE EXTENSOMETER MOVEMENTS (+/-mm)	RESPONSE	**Jeremy Kirjan** TMR GEOTECHNICAL UNIT BRISBANE Ph. 0423 843 101 jeremy.n.kirjan@tmr.qld.gov.au	**Aathee Aatheesan** GEOTESTA PTY LTD MELBOURNE Ph. 0432 571 139 at@geotesta.com.au	**Gina Turner** TMR NORTHERN REGION TOWNSVILLE Ph. 0434 604 661 gina.f.turner@tmr.qld.gov.au	**tba** HIGHWAY REWARD MINE CHARTERS TOWERS	**Ken Risdale** CHARTERS TOWERS REGIONAL COUNCIL CHARTERS TOWERS Ph. 0409 647 870
GREEN	**<50mm**	**<25mm**	No specific action or response necessary - continue monitoring at established frequency	Routine monitoring and reporting	Routine System checking	Routine Report receipt	Routine travel past sight observations	Routine travel past sight observations
AMBER	**>50mm**		Site visit with visual observations of road surface for deformations or cracking - Open pit lids and pump out water if neccessary	Notify all alarm recipients	Check system for errors	Inform TMR management of Amber alert status	Site visit with visual observations of mine for signs of landslide - Open pit lid on WE and contact Geoff to pump out water if neccessary	Site visit with visual observations of road surface for signs of deformation or cracking - Open pit lids on western side of road and pump out water if neccessary
		>25mm	Site visit with visual observations of road surface for deformations or cracking - Open pit lids and check devices for correct configuration	Notify all alarm recipients	Check system for errors	Site visit with visual observations of road surface for signs of deformation or cracking - Arrange for pits to be opened and check wire	Site visit with visual observations of mine for signs of landslide - Open pit lids and check wire on WE3	Site visit with visual observations of road surface for signs of deformation or cracking - Open pit lids and check wires on WE1 and WE2
RED	**>125mm**	**>100mm**	Steps for more severe actions include increased monitoring vigilance and frequency. A structured inspection by suitably trained and qualified TMR staff is recommended. Speed restrictions are likely to be required pending the finding of visual observations and Road closure with the diversion road utilised. Traffic management control and signage required. Road cracking should be mapped and measured on a daily basis.	Notify all alarm recipients	Check system for errors	Site visit with visual observations of road surface for signs of deformation or cracking - Arrange for pits to be opened and check wire. -Speed restrictions are likely to be required pending the finding of visual observations and Road closure with the diversion road utilised. Traffic management control and signage required. Road cracking should be mapped and measured on a daily basis.	Site visit with visual observations of mine for signs of landslide - Open pit lid on WE3, check wire and contact Geoff to pump out water if neccessary	Site visit with visual observations of road surface for signs of deformation or cracking - Open pit lids on western side off road We1 and WE2 , check wire and pump out water if neccessary

Appendix J: Instrumentation Plots

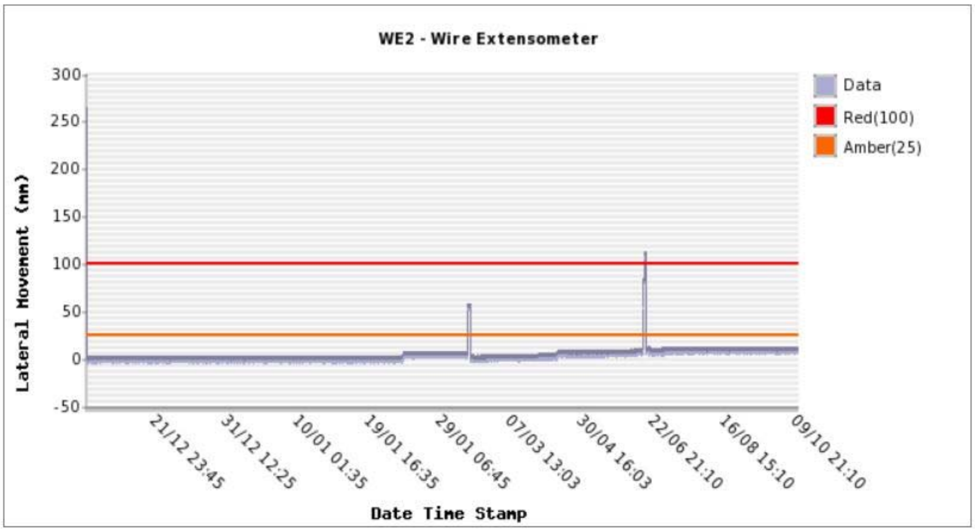
Plot WE1 - Wire Extensometer

09/10/2013 21:10
13/12/2012 12:20
-



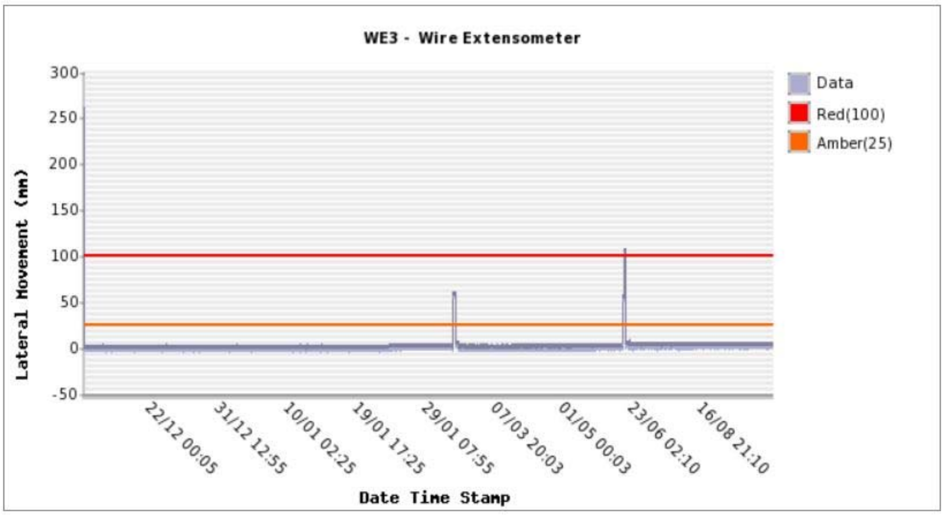
Plot WE2 - Wire Extensometer

09/10/2013 21:10
13/12/2012 12:20
-



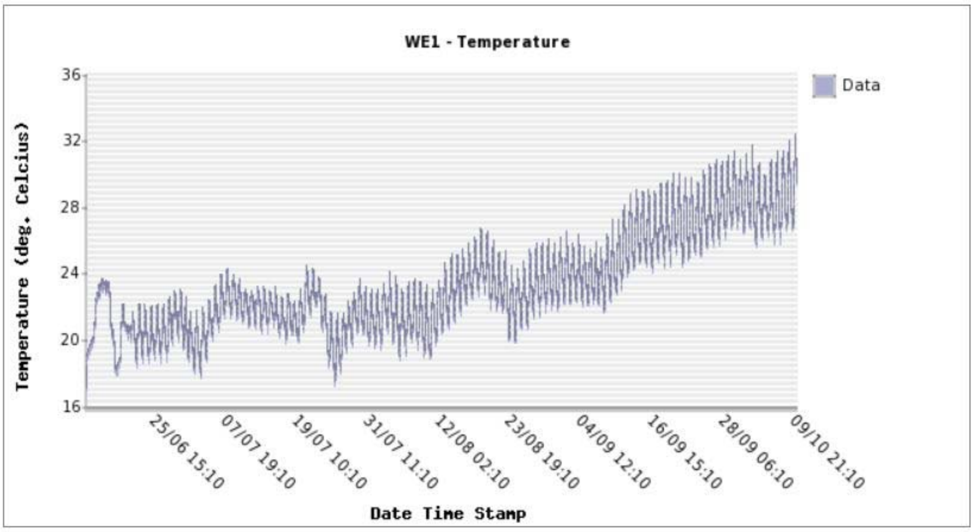
Plot WE3 - Wire Extensometer

09/10/2013 21:10
13/12/2012 12:20
-



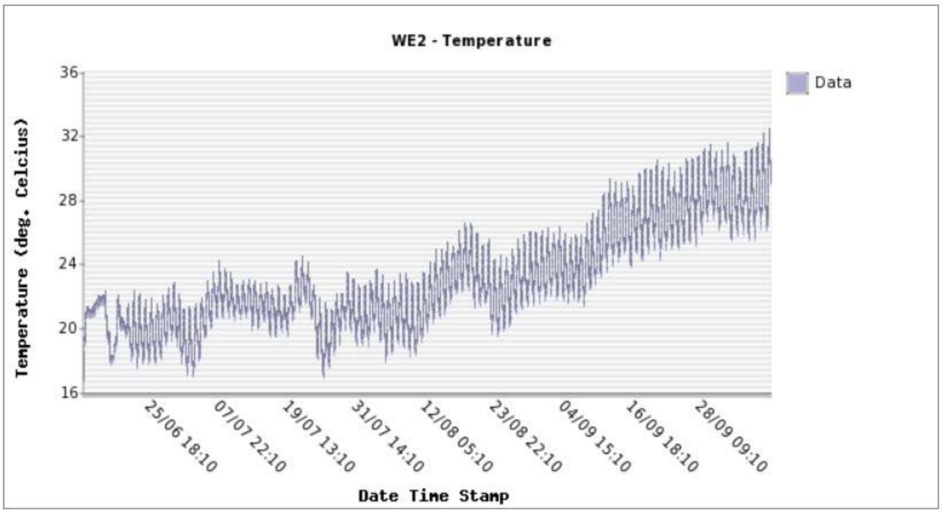
Plot WE1 - Temperature

09/10/2013 21:10
19/06/2013 09:56
-



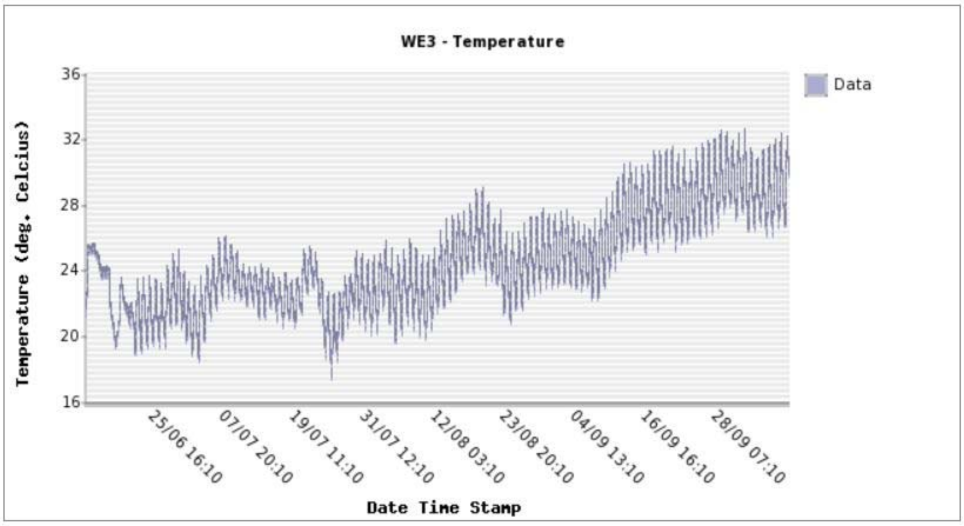
Plot WE2 - Temperature

09/10/2013 21:10
19/06/2013 09:56
-



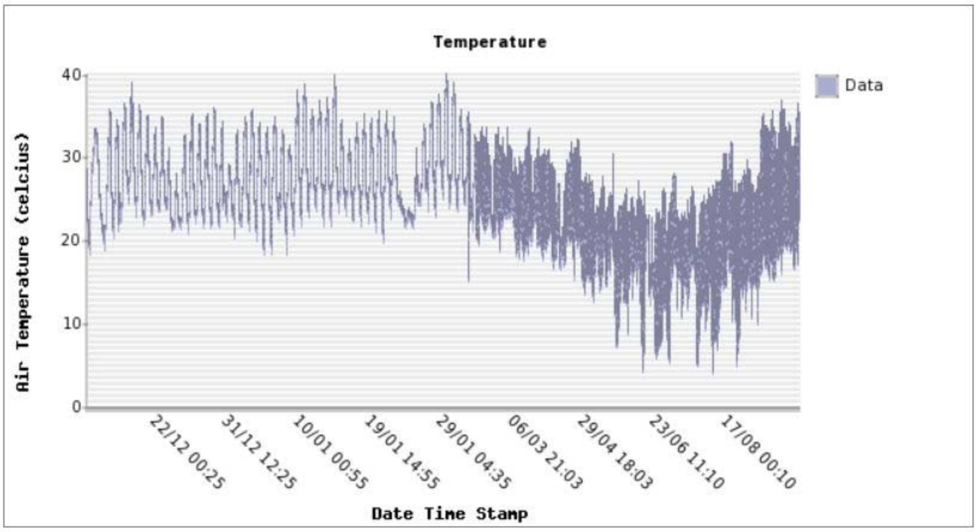
Plot WE3 - Temperature

09/10/2013 21:10
19/06/2013 09:56
-



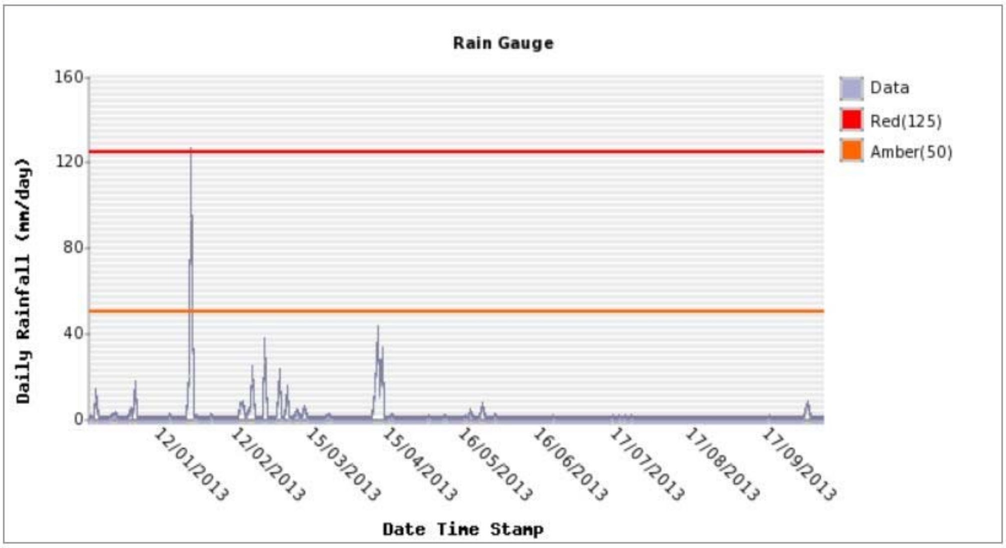
Plot Temperature

09/10/2013 21:10
13/12/2012 19:22
-



Plot Rain Gauge

09/10/2013 21:10
13/12/2012 00:00
-

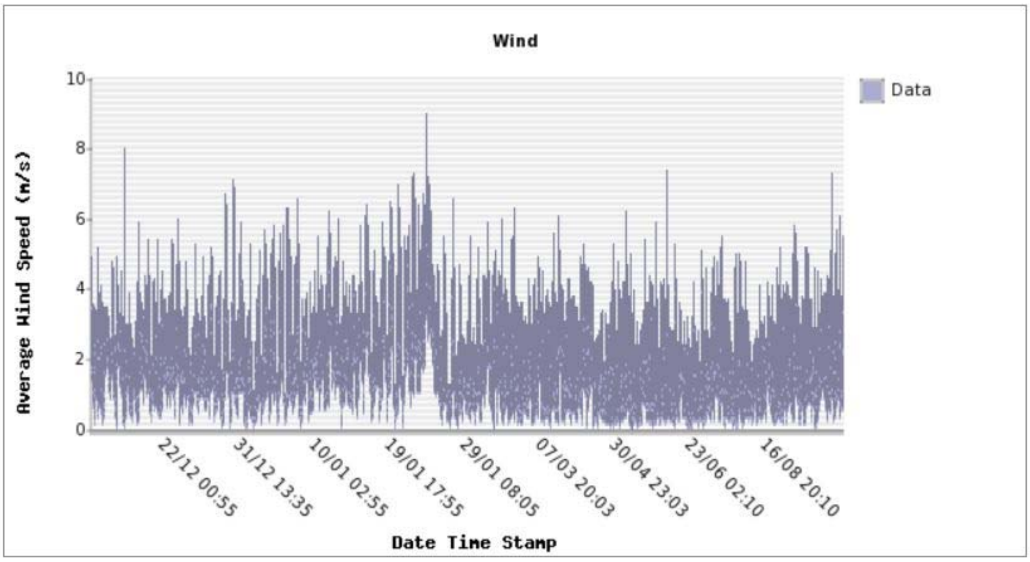


Plot Wind

09/10/2013 21:10

13/12/2012 19:22

-

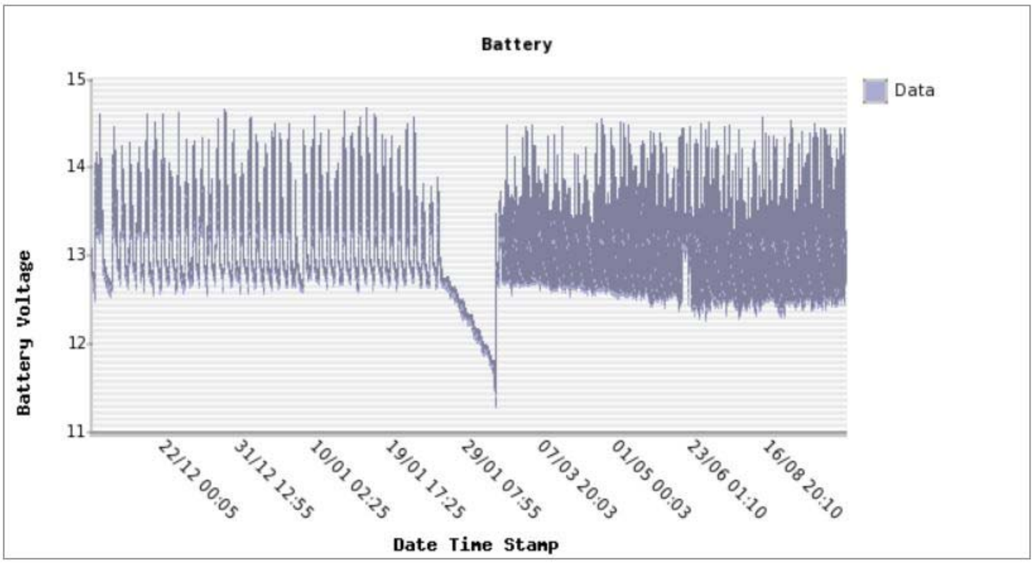


Plot Battery

09/10/2013 21:10

13/12/2012 12:20

-



Appendix K: Wire Extensometer Calibration Sheets

SISGEO Specifications and Compliance Certificate

WE HEREBY CERTIFIED that the manufactured instruments listed below,
in the amount specified in the TABLE A, and furnished to

Customer	GEOTESTA		
Address	Melbourne: U6/31-37 Howleys Road Notting Hill VIC 3168 VICTORIA		
Reference Sisgeo Job No.:	OV12-00781	*Date:*	26/10/12
Shipped to: GEOTESTA		*Date:* November, 2012	*Via:* Forwarder

Complies with International System of Units (SI) and with all aspects of the requirements and specifications of your

Purchase Order / Contract	No: e-mail of 26/10/2012	Ref.: Mr. Stephen Darmawan

WE FURTHER CERTIFY that the items listed in the TABLE A have been manufactured, tested and calibrated in compliance with the relevant specifications and drawings, according to the CERTIFIED Quality System of Sisgeo, in conformance to the standards UNI EN ISO 9001:2008, with reference to the following documents:

ISTD6027-96	ASTM test for calibr. Lin. displacement transd.	IST09/02	Standard practice for cable sealing
IST10/06	Technical instruction for calibration	IST10/19	Standard test for water leakage
IST10/20	Standard test method for acceptance	IST15/07	Standard practice for packaging

" TABLE A "

Instrument Description		WIRE CRACKMETER, RANGE 240 MM		
Model		0D241A20000	*Quantity*	3
Serial Number		D121632÷D121634	*Batch Number*	
Country of Origin		ITALY-EC	*Traceable to*	IST 8/01
OUTFIT	*Model*	*Serial Number*	*Equipment Description*	
	☐ D111PV5500		PVC corrugate sheath	
	☐ D232AN5000		Embankment anchoring plate diam. 500mm	
	☐ D232AN5500		Embankment anchoring plate 500x500mm	
	☐ D2320BM100		Embankment Extensom.rod 1m zinc-plated extens. rod	
	☐ D2320BM200		Embankment Extensom.rod 1m zinc-plated extens. rod	
	☐ D2320BM300		Embankment Extensom.rod 1m zinc-plated extens. rod	

TECHNICAL SPECIFICATIONS

WE FURTHER CERTIFY that the technical specifications of the instruments are in accordance to the last revision of the relative technical data sheet consultable on our web site WWW.SISGEO.COM

SISGEO S.r.L.	*Production Chief*	*Sales Engineer*	*Data:06/11/12*

SISGEO S.r.l.-Via F. Serpero (S.P. 179), 4/F1 - 20060 MASATE (MI)
Tel.++39-02-95764130 – Fax ++39-02-95762011 E-mail:info@sisgeo.com – http://www.sisgeo.com

SISGEO

CALIBRATION REPORT

Model: Crackmeter D241A200 Serial/Number: D121632

Sensor: potentiometer

Customer: GEOTESTA Job number: 12-00781

Cable Length: 1 m Date: 31/10/2012

TEST CONDITIONS :

Power supply [Vdc] : 24

Temperature [°C] : 20

Humidity [%] : 56

Atmospheric pressure [mbar] : 998

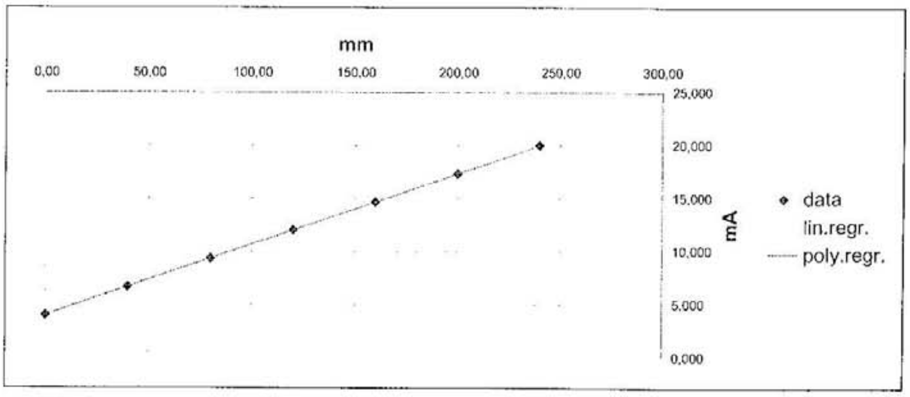
Calibration has been made according to the Quality Assurance System UNI EN ISO 9001:2008 - IST. 10/06 Metrological chain

Main: Metrica Gage blocks s/n 11002 - Metrica Tape mod.39192 s/n SC1269 - Yokogawa Calibrator mod. 7651 s/n 51WK0176 - Hameg Function generator mod. HM8030-5 s/n 54710037

Secondary: Heidenhain Linear Encoder mod. LS403 s/n 4 145 104 k - Sisgeo read-out s/n 085

measures uncertainty: ± 45 x 10e-5 mm / I = 0.004 mA

length	readings [mA]				statistics		
mm	I up	I down			avg.[mA]	lin.[mm]	polyn.[mm]
0,00	4,016	4,016			4,016	0,18	0,07
40,00	6,664	6,671			6,668	39,96	39,96
80,00	9,325	9,310			9,317	79,72	79,78
120,00	12,011	12,012			12,012	120,15	120,23
160,00	14,650	14,664			14,657	159,84	159,90
200,00	17,341	17,344			17,343	200,13	200,13
240,00	20,001	20,001			20,001	240,02	239,92



RESULTS

Linear sensitivity factor	S	max.err.
	[mA/mm]	%F.S.
	0,06665	0,16249

Polynomial sensitivity factors	A	B	C	max.err.
[mm] = A·[mA]² + B·[mA] + C	[mm/mA²]	[mm/mA]	[mm]	%F.S.
	-2,897E-03	1,507E+01	-6,042E+01	0,14146

NOTES : Resulting error depends on the effects of linearity and hysteresis.
With "Multilogger" software the linear factor S has to be inserted reverted (1/S)

Wiring : red=+Loop; black=-Loop; white=thermistor; green=thermistor

Quality Assurance Manager : Roberta Puppo Production chief : [signature]

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Cap. Soc. 99.000 Euro i.v. - VAT n. IT10732420152 - Tribunale Milano:333230 - REA Milano:1413159

SISGEO

CALIBRATION REPORT

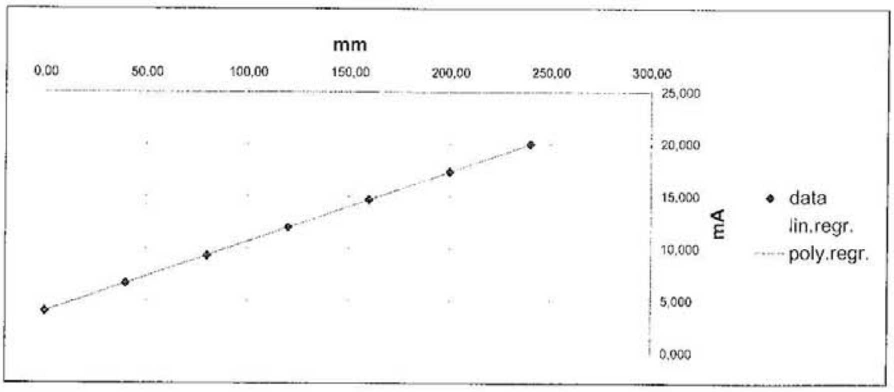
Model: Crackmeter D241A200 Serial/Number: D121633
Sensor: potentiometer
Customer: GEOTESTA Job number: 12-00781
Cable Length: 1 m Date: 31/10/2012

TEST CONDITIONS :

Power supply [Vdc] : 24
Temperature [°C] : 20
Humidity [%] : 56
Atmospheric pressure [mbar] : 998

Calibration has been made according to the Quality Assurance System UNI EN ISO 9001:2008 - IST. 10/06 Metrological chain
Main: Metrica Gage blocks s/n 11002 - Metrica Tape mod.39192 s/n SC1269 - Yokogawa Calibrator mod. 7651 s/n 51WK0176 -
Hameg Function generator mod. HM8030-5 s/n 54710037
Secondary: Heidenhain Linear Encoder mod. LS403 s/n 4 145 104 k - Sisgeo read-out s/n 085
measures uncertainty: ± 45 x 10e-5 mm / I = 0,004 mA

length	readings [mA]				statistics		
mm	I up	I down			avg [mA]	lin.[mm]	polyn.[mm]
0,00	3,989	3,989			3,989	0,12	0,04
40,00	6,659	6,662			6,661	40,13	40,13
80,00	9,291	9,296			9,294	79,56	79,60
120,00	12,001	12,002			12,002	120,11	120,18
160,00	14,659	14,661			14,660	159,92	159,97
200,00	17,350	17,354			17,352	200,24	200,24
240,00	20,001	20,002			20,002	239,92	239,84



RESULTS

Linear sensitivity factor

	S	max.err.
	[mA/mm]	%F.S.
	0,06677	0,19996

Polynomial sensitivity factors

$[mm] = A \cdot [mA]^2 + B \cdot [mA] + C$

A	B	C	max.err.
[mm/mA^2]	[mm/mA]	[mm]	%F.S.
-2,152E-03	1,503E+01	-5,987E+01	0,18093

NOTES : Resulting error depends on the effects of linearity and hysteresis.
With "Multilogger" software the linear factor S has to be inserted reverted (1/S)

Wiring : red=+Loop; black=-Loop; white=thermistor; green=thermistor

Quality Assurance Manager : Roberta Puppo Production chief : [signature]

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Cap. Soc. 99.000 Euro i.v. - VAT n. IT10732420152 - Tribunale Milano:333230 - REA Milano:1413159

SISGEO

CALIBRATION REPORT

Model: Crackmeter D241A200 Serial/Number: D121634

Sensor: potentiometer

Customer: GEOTESTA Job number: 12-00781

Cable Length: 1 m Date: 31/10/2012

TEST CONDITIONS :

Power supply [Vdc] : 24

Temperature [°C] : 20

Humidity [%] : 56

Atmospheric pressure [mbar] : 998

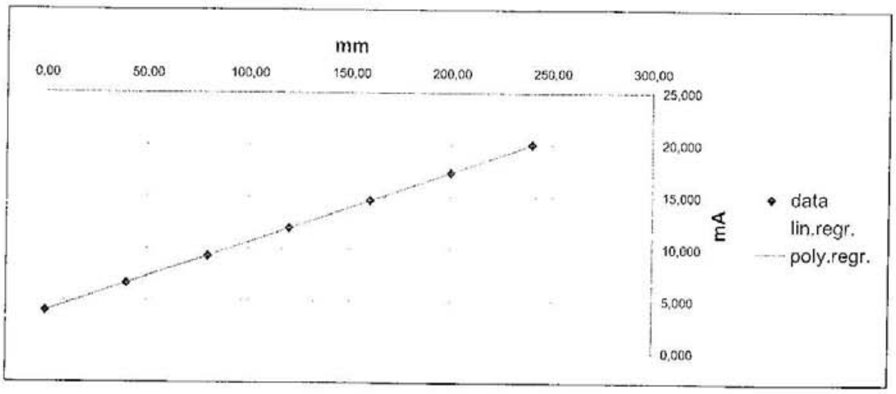
Calibration has been made according to the Quality Assurance System UNI EN ISO 9001:2008 - IST. 10/06 Metrological chain

Main: Metrica Gage blocks s/n 11002 - Metrica Tape mod.39192 s/n SC1269 - Yokogawa Calibrator mod. 7651 s/n 51WK0176 - Hameg Function generator mod. HM8030-5 s/n 54710037

Secondary: Heidenhain Linear Encoder mod. LS403 s/n 4 145 104 k - Sisgeo read-out s/n 085

measures uncertainty: ± 45 x 10e-5 mm / I = 0.004 mA

length	readings [mA]				statistics		
mm	I up	I down			avg.[mA]	lin.[mm]	polyn.[mm]
0,00	4,001	3,994			3,998	0,26	0,06
40,00	6,654	6,658			6,656	40,04	40,04
80,00	9,295	9,301			9,298	79,58	79,70
120,00	11,998	12,002			12,000	120,02	120,17
160,00	14,660	14,665			14,663	159,86	159,98
200,00	17,354	17,358			17,356	200,17	200,17
240,00	20,021	20,024			20,023	240,08	239,88



RESULTS

Linear sensitivity factor

	S	max.err.
	[mA/mm]	%F.S.
	0,06682	0,19691

Polynomial sensitivity factors

[mm] = A·[mA]² + B·[mA] + C

A	B	C	max.err.
[mm/mA²]	[mm/mA]	[mm]	%F.S.
-5,467E-03	1,510E+01	-6,020E+01	0,14858

NOTES : Resulting error depends on the effects of linearity and hysteresis.
With "Multilogger" software the linear factor S has to be inserted reverted (1/S)

Wiring : red=+Loop; black=-Loop; white=thermistor; green=thermistor

Quality Assurance Manager : Roberta Puppo Production chief : [signature]

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