Instrumentation and Real Time Monitoring of a Landslide on Highway No. 302 Near Prince Albert, Saskatchewan

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Abstract

Saskatchewan Department of Highways and Transportation (SDHT) implemented a Risk Management System for the provincial highway network in 2003. The Risk Management System was developed to prioritize sites for investigation and allocate resources for construction and maintenance. The Risk Management System identified a section of Provincial Highway No. 302, approximately 4.5 km west of Prince Albert, Saskatchewan, as an urgent site requiring immediate investigation and monitoring. As of April 2006, a 420 m of the highway was dropping as a result of large retrogressive landslides along the North Saskatchewan River.

Investigation and slope stability analysis indicated the remediation options were limited to the re-alignment of the highway. However, re-alignment of the highway would be costly and require time to design and construct. Daily inspection and monitoring of the site instrumentation were recommended until remedial measures could be implemented but the remote location of the site and high speed of landslide movement were not amenable to traditional means of inspection and monitoring. As a result, an automated real time monitoring and warning system was installed in the summer of 2005. Data was collected by data loggers and transmitted by cell phone modem to a server where the data was uploaded to the ARGUS Monitoring Software System on the internet. Data provided by the instrumentation included the movement at the shear zone (at the river

bank and at the highway), piezometric pressures (above, below and at the shear zone at both monitoring locations), the depth of water in the river together with atmospheric pressure and temperature at each sensor location. Alarm levels for the data were set so that risk on the impacted section of highway could be managed until remedial measures were enacted. This paper documents the site conditions and how the real time monitoring system has assisted in characterizing the landslide movement and managing risk at the site.

Introduction

Saskatchewan Department of Highways and Transportation (SDHT) required a landslide risk management system to prioritize sites for monitoring and remediation and provide recommended response levels based upon risk level. In 2003, SDHT took the first step in landslide management by implementing a landslide risk management system based upon the Alberta Transportation model (Kelly et al. 2004).

Risk in the landslide model was evaluated by defining the likelihood of landslide occurrence or probability factor (PF) and consequences of a landslide or consequent factor (CF). The resultant of the two factors provided a numerical assessment of risk which could be ranked and categorized for response levels and management approach.

Multiple retrogressive landslides, located adjacent to the North Saskatchewan River about 4.5 km west of Prince Albert, Saskatchewan, are impacting a 420 m section of Provincial Highway No. 302-02. Figure 1 shows the location of the landslide site where Provincial Highway No. 302-02 approaches within 250 m of the river. The slide mass extends 260 m from the river to the headscarp and is seated on a shear zone located at a depth of 50 m., Figure 2. A risk assessment assigned the landslide to the urgent risk category as there were threats to public safety and a significant impact on infrastructure, Figure 3.

Between October 2002 and May 2004 four boreholes were drilled and electric-logged to determine site stratigraphy, locate the failure plane, monitor the rate of slope movement and define the site pore water pressures. Two of the bore holes, SI001 and SI002, were completed with slope inclinometers adjacent the road and the river bank and a third bore hole near the river bank was completed with a piezometers nest. Both slope inclinometers indicated a well defined shear plane with high rates of movement.

A stability analysis of the landslide indicated that relocation of the highway was the best remedial option for this highway section (Kelly et al. 2005). Because relocation of the highway is expensive and will take several years to implement, the risk to the public from a catastrophic failure will be managed in the interim through an automated monitoring and warning system. The instrumentation was installed to provide daily assessments of the site stability and provide timely warnings to SDHT of increased instability.

Two locations were recommended for automated instrumentation, one for the lower landslide block and the second for the upper landslide block where Provincial Highway No. 302-02 is located. The lower block moves the greatest and fastest in response to the triggering mechanism of river erosion. The movement at the upper block is time lagged and reduced, as the movement in the lower block translates back into the upper blocks. Determining the time lag and predicting the amount of movement in the upper block with two automated locations will provide a means to manage risk at the site. Early warning systems built into the automated instrumentation will identify high pore water pressures or anomalous movement in the lower block which may lead to deformation of the highway in the upper block. Advanced notice of accelerated movement of the upper block will allow SDHT to allocate appropriate maintenance resources and place signage in a timely manner.

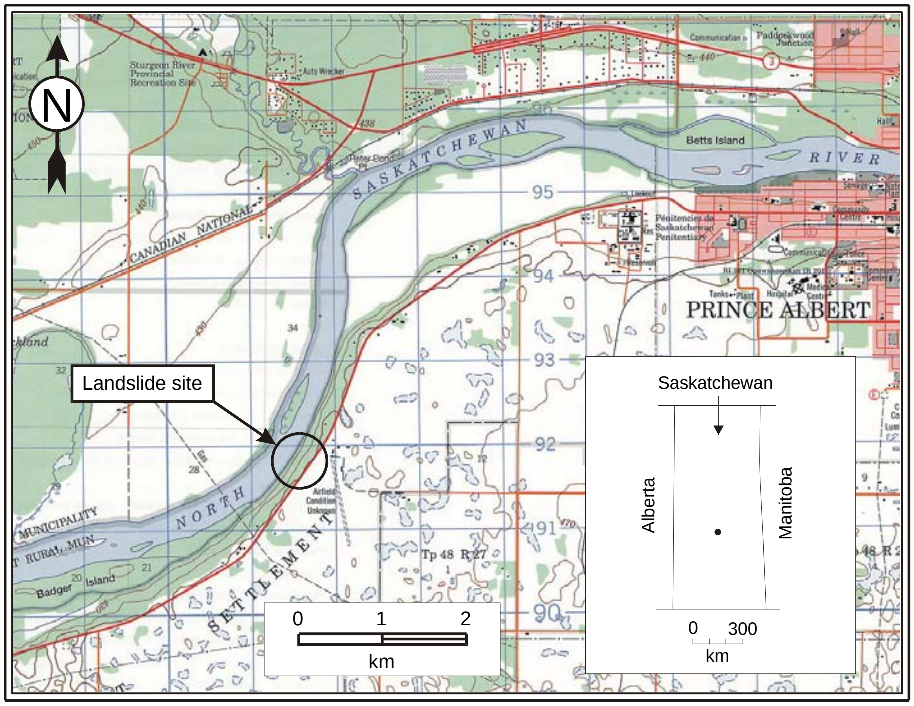

Figure 1. Location map showing the landslide site

Figure 2. Photograph showing multiple landslide blocks.


Figure 3: Landslide head scarp in upslope highway ditch (Photo taken on 16 April 2006).

Overview of monitoring system

An automated real time monitoring and warning system was installed in the summer of 2005. The system consists of in-place inclinometers, vibrating wire piezometers, barometer and temperature sensors. The instrumentation was installed in two locations, one located on the river bank and the other adjacent to the highway (Figure 4). Table 1 presents a summary of the instruments installed in both locations. All real time monitoring equipment was purchased from Durham Geo Slope Indicator.

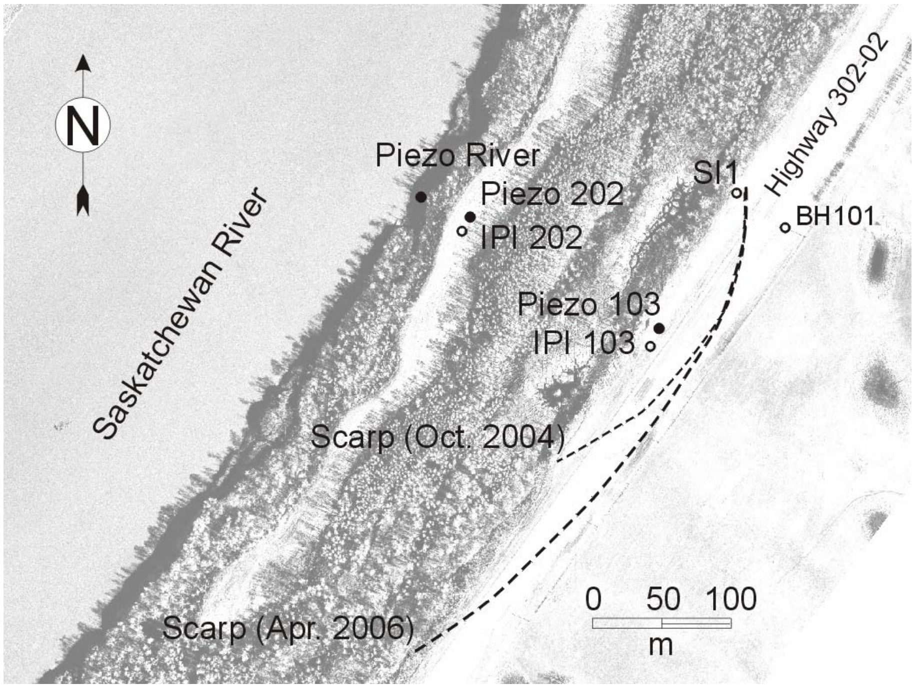

Figure 4. Plan view showing instrumentation locations and landslide features

Table 1. Summary of instrumentation installation

Location	Instrument	Name	Elevation (m)	Measurement
Highways (BH 103)	Data logger	CR10X103	Ground	
	Voltmeter	CR10X103	Ground	Battery voltage
	In-place-inclinometer (IPI 103)	IPI12783	406.40	Movement above shear zone
		IPI12784	404.40	Movement at shear zone
		IPI12785	402.40	Movement below shear zone
	VW piezometer (Piezo 103)	PZO83404	409.32	Head above shear zone
		PZO83405	404.27	Head at shear zone
		PZO83406	399.37	Head below shear zone
River bank (BH 202)	Data logger	CR10X202	Ground	
	Voltmeter	CR10X202	Ground	Battery voltage
	Barometer	Baro	Ground	Barometric pressure
	In-place-inclinometer (IPI 202)	IPI12786	395.7	Movement above shear zone
		IPI12787	393.7	Movement at shear zone
		IPI12788	391.7	Movement below shear zone
	VW piezometer (Piezo 202)	PZO83401	399.07	Head above shear zone
		PZO83402	394.07	Head at shear zone
		PZO83403	389.07	Head below shear zone
		PZO83513	River	Depth of river water

In-Place-Inclinometer (IPI)

The in-place inclinometer system consists of inclinometer casing and a string of electrolytic inclinometer sensors. The inclinometer casing is installed in a vertical borehole that passes through a suspected zone of movement. The string of sensors is positioned inside the casing to span the zone of movement. The sensors measure the inclination of the casing. Changes in the inclination readings indicate that the casing has been displaced by ground movement. The amount of displacement is calculated by finding the difference between the current inclination reading and the initial reading and then converting the result to a lateral distance. The sensors are connected to a data acquisition system that continuously monitors movements and can trigger an alarm when it detects a change, or rate of change, that exceeds a preset value.

Vibrating-Wire Piezometer (VW Piezometer)

A VW piezometer was required for real-time monitoring because it offered rapid response to changes in pore water pressure and has the ability to be connected to the automatic data acquisition system. The VW piezometer converts water pressure to a frequency signal via a diaphragm, a tensioned steel wire, and an electromagnetic coil. The piezometer is designed so that a change in pressure on the diaphragm causes a change in tension of the wire. When excited by the electromagnetic coil, the wire vibrates at its natural frequency. The vibration of the wire in the proximity of the coil generates a frequency signal that is transmitted to the readout device. The readout device processes the signal, applies calibration factors, and displays a reading in the required engineering unit.

Other instruments

Because temperature can affect the response of the VW piezometer and IPI; all VW piezometers and IPIs are equipped with temperature sensors. For the piezometers and IPIs installed at the site, temperature corrections were not useful because the temperature of the sensors remains relatively constant at about 5^{o}C.

One barometer was installed at the site to monitor barometric pressure. Because one of the VW piezometers was used to measure the river water level, which is open to atmosphere; a barometric correction may be required to eliminate measurement uncertainty introduced by barometric pressure.

Data logger

The CR10X data logger from Campbell Scientific Inc. was used. A CR10X has a multi-tasking operating system that allows it to simultaneously interrogate sensors, perform control functions, and transmit data. The CR10X collected transmitted data by cell phone modem to a server where the data was uploaded to the ARGUS Monitoring Software System on the internet. Figure 5 shows a photograph of the data logger together with the solar panel of the instrumentation nest near the river bank. Monitoring data at the site are recorded hourly; the frequency of data scan can be varied according to the actual conditions at the site.

Figure 5. Photograph showing instrumentation nest near the highways

ARGUS monitoring software

The ARGUS monitoring software is a web-based data management, calculation and presentation tool. The development of ARGUS started in the summer of 2003 in Germany. It was initially created to monitor stability instrumentation at a Soccer Stadium in Portugal.

ARGUS handles all data processing requirements, starting with storage of data into a MySQL database, performing the required calculation on the data, presenting the results in graphical and numerical format, generating alarm messages and creating automated PDF reports. Because Argus works on the internet, distribution of the processed data is immediate. Users anywhere can log on to view data and graphs with only their web browsers (Boart Longyear Interfels 2005).

ARGUS processes the readings collected from sensors at the project site and makes the resulting data available on the internet. Users access the data and graphs via their web browsers. Data files from the project site are forwarded to ARGUS. ARGUS scans the files for alarm conditions and then stores the data in a project database. The data are available wherever there is an internet connection, and anyone who needs the data has immediate access (Figure 6).

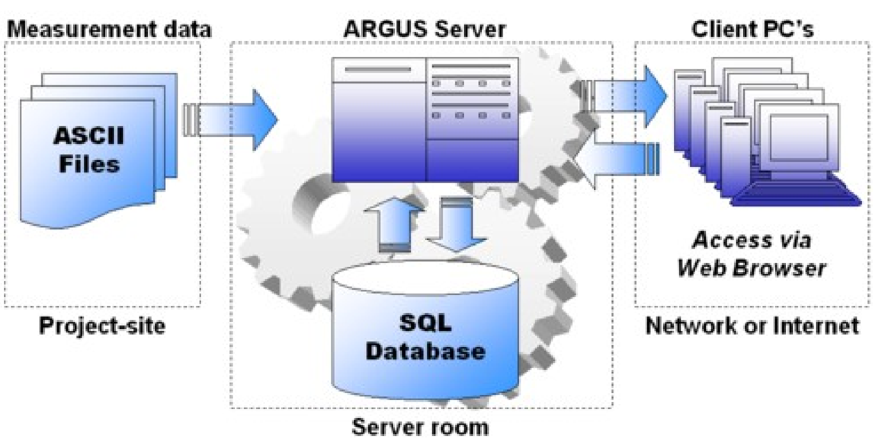

Figure 6. Schematic of ARGUS monitoring software

Users view data and graphs with their web browsers. ARGUS presents data in the following ways:

Plan Views show the location of sensors at the site, their current readings, and their alarm status. Plan views are updated in near real time and can show alarms, as required. Figure 7 presents a plan view showing location of sensors and their current readings. Figure 8 presents a photograph showing instrumentation nest adjacent to the highway and their current readings.

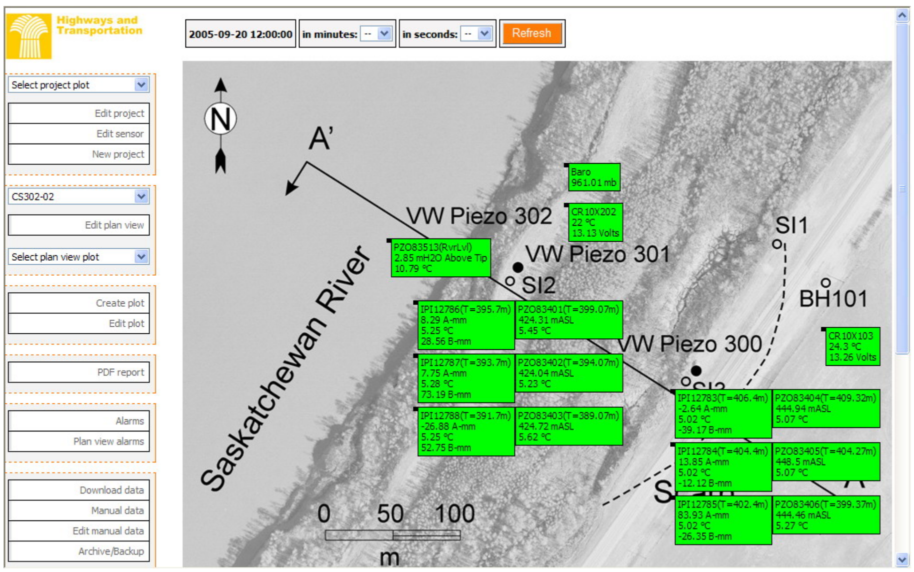

Figure 7. Plan view showing location of sensors and their current readings

Figure 8. Photograph showing instrumentation nest adjacent to the highway and their current readings

Trend Plots including time plots, profile plots, and correlation plots, can be printed or included in reports. An example of the trend plots is shown in Figure 9.

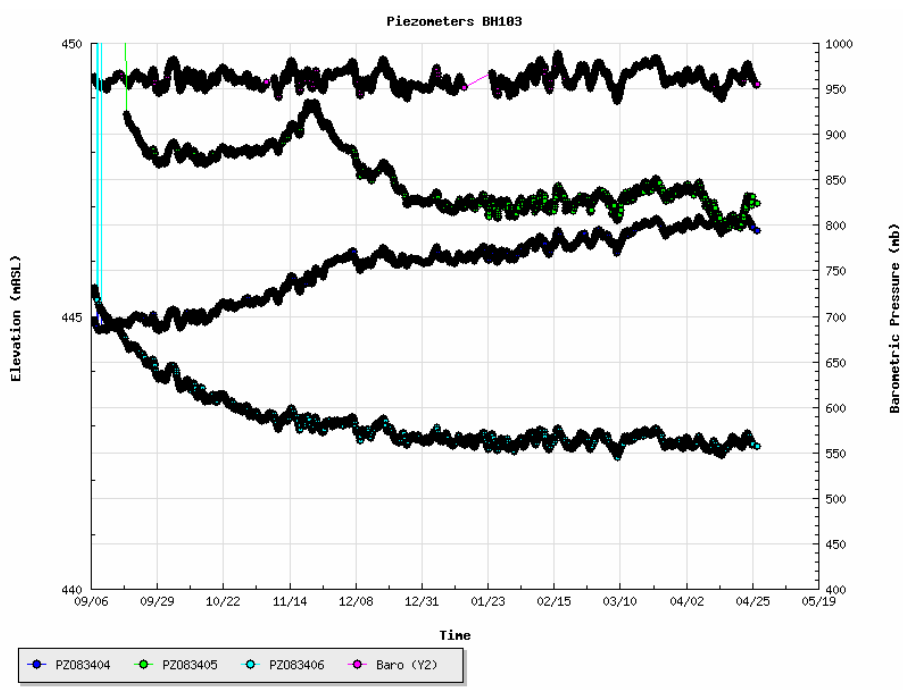

Figure 9. Time plots of piezometric levels and barometric pressure at the highway location

Reports are generated automatically and e-mailed to users on a user defined daily, weekly, or monthly schedule.

Data Downloads provide access to raw or processed data required for further analysis in spreadsheets. Figure 10 shows a plot of cumulative resultant movements recorded by In-Place-Inclinometers; raw data were downloaded from the website.

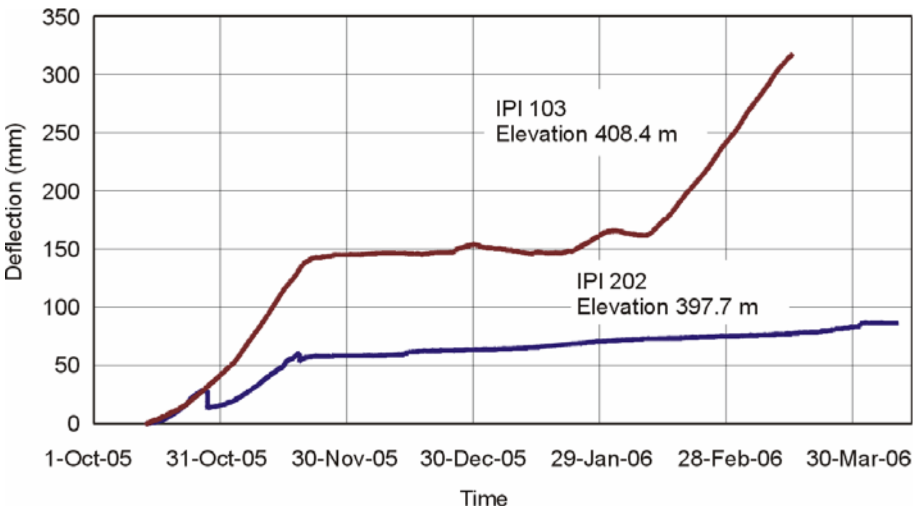

Figure 10. Cumulative resultant movement recorded by In-Place-Inclinometers

Alarms appear on screen and alarm notifications are sent out by e-mail and can be forwarded by fax, Short Message Service (SMS) text messaging or pager.

Concluding remarks

Instrumentation data has been continuously monitored for the Prince Albert landslide site since September 2005. ARGUS Monitoring System Alarms have provided timely information for risk management at the site and the conditions of the monitoring system itself (e.g., battery life).

Saskatchewan Department of Highways and Transportation is currently in the process of implementing their own ARGUS Monitoring Server. Following the Prince Albert site; plans are being prepared to monitor all sites of “urgent” category within SDHT Risk

Management System. Future monitoring of SDHT Thermister Network is also being planned.

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