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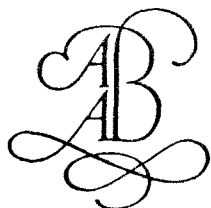
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Remote instrumentation for slopes during rainstorms in Rio de Janeiro

Auscultation à distance des pentes de Rio de Janeiro pendant de fortes pluies

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Abstract This paper describes a remote data acquisition and instrumentation system named *Sigra* (*System for remote geotechnical instrumentation via radio*) which has been experimentally used for monitoring slopes in Rio de Janeiro. *Sigra* allows remote, real time and continuous monitoring and data transmission to a central station. Development, instrument selection, installation and system performance are described.

Introduction

Rio de Janeiro lies between the sea and very steep mountains. Almost every year in the Summer it suffers from severe rainstorms that lead to slope failures. The most hazardous rainstorms occurred in 1966 and 1967 (Barata, 1968) and more recently in 1988, when failures were responsible for several casualties (Barros et al, 1992). Thirty years ago the Geo-Rio Foundation (formerly the Geotechnical Institute) was formed in Rio became the state authority in charge of slope stabilization works and prevention of slope failures.

Conventional techniques for slope monitoring have been used by Geo-Rio, employing piezometers, inclinometers and surface displacements gauges. They are not totally adequate because no information has ever been obtained *during* a rainstorm. Therefore, mechanisms during severe rainfall cannot be well studied. An advanced monitoring system was required.

Sigra was designed for continuous remote monitoring of slopes. A series of transducers is utilized for measurement of rainfall, pore pressures and water levels, soil suction, internal and surface displacements. Data are collected at the slope by a *Remote Station* (RS) and transmitted by radio to a central data acquisition station located at the head-office of the Geo-Rio. *Sigra* can trigger alarms to

warn authorities if pre-set threshold levels are reached by specific instruments.

Reliability in data acquisition, transmission and storage was sought during *Sigra* design. Data are transmitted as soon as collected. Storage only takes place safely at the central station.

Sigra has been experimentally installed in two slopes: at the Borel and the Formiga Hills in North Rio. Access these sites is difficult, and frequent visits have to be avoided. The work carried out to date was aimed at testing the system and checking its reliability. Therefore, the remote station was programmed to send continuous information on its performance, power level, temperature and other information for hardware and software checking.

Description

Sigra encompasses *Remote Stations* (RS) and one *Central Station* (CS) (Figure 1). The RS's are located at the slopes. They have data acquisition boards that scan transducer signals, take readings, convert analogue to digital signals and send data to the transmitter-receiver units which forward data to the CS.

Each RS can accommodate up to 32 different transducers, although this number can be easily increased with minor modifications in the hardware.

SIGRA

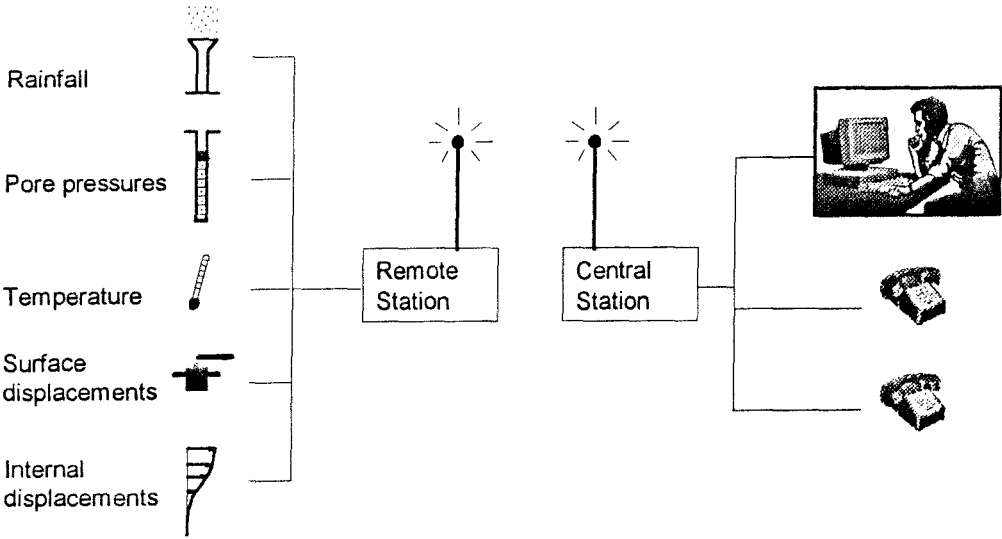


Figure 1 *Sigra*

The most common instruments are: rainfall meter, temperature gauge, piezometers and water level indicators, soil suction or tensiometers, flowmeters and soil displacements gauges.

The CS comprises an IBM-PC type microcomputer linked via RS-232 to a transmitter-receiver station. This microcomputer stores all data automatically and the data acquisition software allows reporting, alarms and communication with other systems.

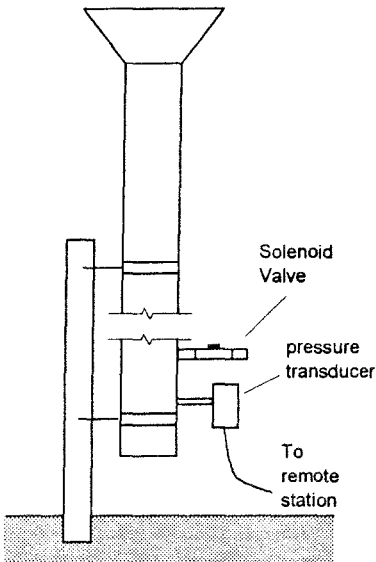


Figure 2 *The rainfall meter*

Rainfall meter

The rainfall meter (Figure 2) comprises a 250 mm diameter funnel on the top of a 50 mm diameter 1.8 m high steel pipe. At the base of the pipe there is a water pressure sensor and a solenoid valve. The pressure sensor operates in the 0 to 10 kPa range and measures the water column in the steel pipe. As rain water fills 80% of the pipe height, the RS automatically opens the solenoid valve and drains the water.

Piezometers and water level indicators

Piezometers and water level indicators are conventional standpipe instruments (Figure 1) with an electrical pressure transducer dipped in the access pipe. The transducers have a 0 to 300 kPa range and an output of 4 to 20 mA. It can be retrieved at any time for calibration and checking.

A mechanical cone packer, shown in Figure 1, is employed to plug the access pipe just above the piezometer sand bulb. This ensures a low flexibility of the system and short response time for pore water pressure measurements in fine grained soils.

Soil suction measurements have not yet been attempted by *Sigra*. However, electrical soils suction

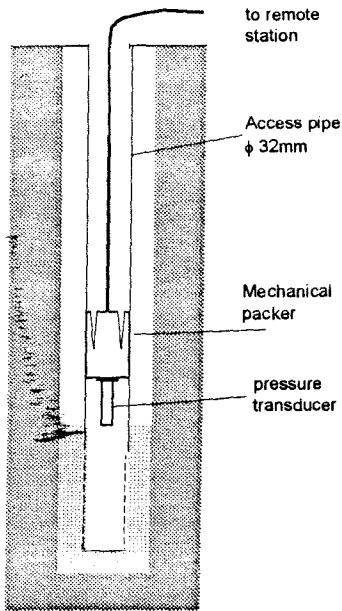


Figure 3 Piezometer

meters as the one developed by Fleming et al (1992) can be easily connected to *Sigra*.

Surface displacements

Two different surface displacement systems were developed. One is a simple mechanical system and the other is the advanced *Sima*. The mechanical system is a temporary device (Figure 4) installed at

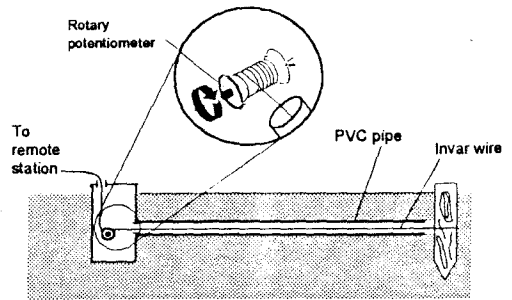


Figure 4 Mechanical surface displacement gauge

the slopes, until *Sima* can be deployed.

Surface displacements system are measured in the mechanical by an invar wire stretched between two points. One end is fixed to the ground, the other to a precision rotary potentiometer. The accuracy is close to 1 mm. Temperature effects may decrease the accuracy to 5 mm. The maximum distance between the fixed points is 20 m.

An advanced instrumentation for measurement surface displacements has been designed and tested in laboratory conditions but not yet in the field. It is due to be deployed in the Winter 1994. It is called *Sima* (*System of Marks*) and is shown in Figure 5. It has no moving parts, no temperature effects, no cables and no physical link between marks. Measurements are obtained automatically by radio. The operating principle is similar to the radar. Electronic surface marks are laid on the slope in a desired pattern. Three antennas connected to a read-out system are located outside the zone affected by slope movements. Each surface mark in turn sounds

SIMA

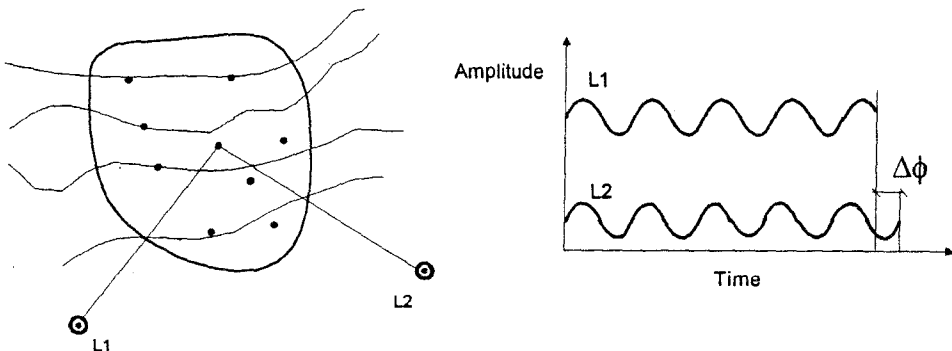


Figure 5 The *Sima* system for measuring surface movements on a slope

a short ping (an electromagnetic wave) which is received by the antennas. The phase difference of the ping is compared with an initial reading. Therefore, the precise location of a surface mark is obtained and the difference between previous readings allows the calculation of horizontal displacements.

The electronics on board each surface mark is powered by NiCd batteries rechargeable by a small solar cell. The system was designed for an accuracy of 1 mm, although it can be increased. The accuracy does not depend on the distance between the marks and the antennas. The maximum design operating distance between marks and antennas is 1 km.

Internal displacements

Continuous monitoring of internal displacements in soil mass can be obtained with *Cliper* (*Permanent Inclinator*) (Figure 6). It consists of a train of tiltmeters installed in a conventional inclinometer access tube. The tiltmeters are liquid level gauges used for more than 3 decades in the aeronautics industry, but only recently have found applications in geotechnical instrumentation (eg, Campanella et al, 1994). The tilt gauges are tiny glass phials containing an electrolytic liquid and four opposite electrodes. As they tilt, the electrodes dip in or out in the liquid and give a signal proportional to the tilt. With appropriate electronics, the accuracy that can be achieved is comparable to a standard inclinometer device.

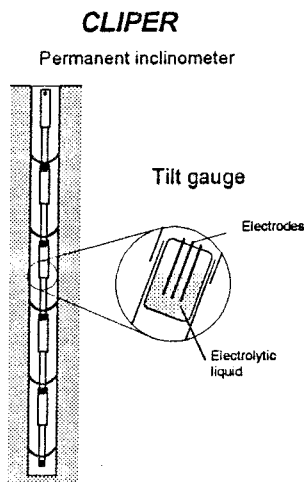


Figure 6 *Cliper*: The Permanent Inclinator

Water flow

Surface and internal drainage systems in slopes can be evaluated by *Sigra* by measurement of flow during rainstorms. Turbine type flowmeters can be installed at the output of sub-horizontal drains to measure water flowing out.

Water flowing on surface of a slope can be measured by a *V* type notch weir, as it is used in dams. Measurements can easily be automated by a water level transducer in the pond behind the weir.

These measurements however have not yet been made by *Sigra*.

Characteristics of the Remote Station RS

The RS employs a central processing unit CPU with a 80C31 microcontroller and a clock of 12 MHz. The analogue-digital converter has a 10 bit resolution and 16 kbytes EPROM. The data acquisition board has a total of 32 channels, being 28 for analogue 4-20 mA signals and 4 input/output digital ports.

Power is supplied by a no-break circuit from a set of rechargeable batteries. They are recharged automatically from solar panel energy. The CPU checks the integrity of the solar panel and the power level in the batteries. If any problem is detected a warning is given at the CS.

Before taking a reading, the CPU turns on the voltage to a single transducer, allows warm-up time, take a reading and turn it off again. Then, it turns on the power to the transmission module and sends the data from one single channel. It repeats the procedure for all transducers in turn.

The CPU controls the water level inside the pipe of the rainfall meter. When it reaches a pre-set maximum level, it opens the solenoid valve to drain the water out.

Self-checking *watch-dog* routines are run periodically in the CPU. This is a procedure to detect and correct running time errors. If a fault is found, it stores all data in non-volatile memory, shuts down the system and re-initializes it again.

Communication

Radio and satellite communication were considered, but the first was selected for distances up to 30 km, because of its lower cost. Beyond that distance, radio wave propagation in *Sigra's* operating

frequency starts to deteriorate. In this case, a satellite communication system is preferred and *Sigra* was designed to have that option too.

Digital signals processed by the CPU are sent to the communication unit that sends and receives data. This unit modulates digital signals and transmits them via a radio circuitry. It also receives, demodulates and decodes signals sent by the CS.

The CS and RS's communicate by radio waves in full-duplex mode at a frequency of 250 MHz and a rated power of 1 W. This is a private telephone radio channel. Therefore, at any time the CS can communicate with the RS's or vice-versa. This also allows voice communication which is very useful during system installation and testing.

Full-duplex mode enables *hand-shaking* of information, ie, CS and RS's exchange data in either ways. The data acquisition process has two modes: the *automatic* or the *commanded*. In the automatic mode, the CS orders data acquisition in selected intervals of 15 minutes, according to current system configuration. Alternatively, the operator can command at any time a measurement package from a RS.

The CPU of a RS can be programmed to give warnings, if a pre-set value risk level is reached. This is informed automatically to the CS which, in turn, warns the operator, send faxes to selected machines, communicates with another computer system, and can even warn a rescue brigade. This could be useful for traffic control during severe rainstorms, as it occurred in the mountains outside Rio, that roads have to be closed during heavy rains.

Software

Sigra software that runs in the PC computer in the CS was written in Borland's C++ language for DOS. It has the following modules: communication, presentation, control and analysis.

The *communication* software is a TSR (Terminate and Stay Resident) program. It runs in the high memory, independently of the operator. Therefore, the microcomputer can be used for any other DOS or Windows application while it receives data from the RS's, stores in a memory buffer and eventually stores data in hard-disk.

The *presentation* software manages screens, graphics, reports and menus that help the operator to use the system.

The *control* software encompasses the basic microprocessor software that runs independently at the RS's and is responsible for the data acquisition tasks, already described.

The *analysis* program, filters and organizes a data bank and has graphics packages for presentation on the screen. It also exports data in ASCII format for further analysis high resolution plotting in spreadsheet programs.

Protections

The Remote Station is physically protected by a heavy sealed steel box. Protection against lightning is provided by efficient grounding.

Vandalism can be a problem for unattended remote instrumentation. The slopes where the RS's are located are inhabited by poor people living in shanty towns. We found out, however, that the best protection against vandalism is to convince people that *Sigra* can result in their benefit. The neighbourhood association of each site was contacted and the research programme was explained in an understandable language. A flyer was produced and distributed. Therefore, the RS's never suffered from vandalism to date.

In one occasion, however, a family of goats ate instrument cables at the Formiga Hills. Their preference for delicious cable wires was not appreciated. Since then, all cables were buried at least 80 cm deep backfilled trenches.

Sigra performance

Sigra started to operate in April 1992 and its performance is continuously monitored in respect to communication, operating temperature inside the RS box, grounding and electric isolation, power consumption, mechanical protection and software.

Temperature inside the box reached a level well beyond the maximum expected. It affected hardware and several electronic components were redesigned or replaced. Today the *Sigra* is safe against temperature up to 70°C.

A few months after the first unit became operational seven faults were detected. Two due to power failures, other two due to insufficient grounding during a thunderstorm, one due to a cable failure, others from unknown reasons.

Power failures were corrected by the installation of a no-break system. The grounding was substantially improved.

Measurements at the Borel Hill

The instrumented section at the Borel Hill is shown in Figure 7. Two piezometers of the type shown in Figure 1 were located close to the contact with the gneissic bedrock, since this is the most likely water seepage path. Surface displacements devices are not shown.

Examples of measurements taken during rain are shown in Figure 8. The measured accumulated rainfall is around 80 mm during a couple of days. The resulting porepressure rise in piezometers P1 and P2 is shown in the figure.

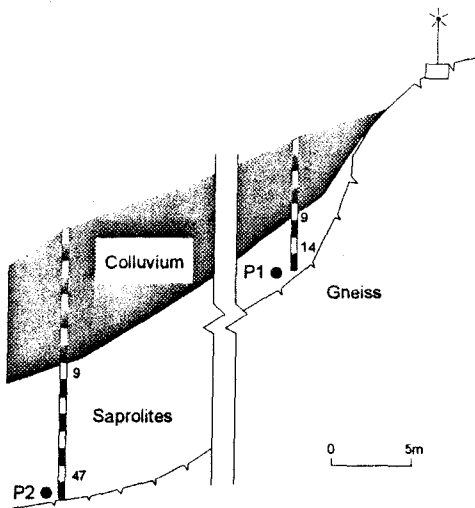


Figure 7 Instrumented section at the Borel Hill

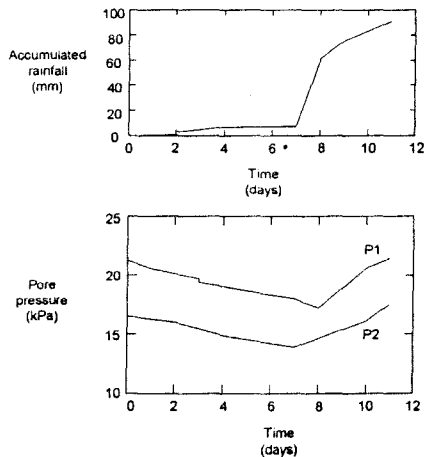


Figure 8 Porepressure rise during rain

A local (within a slope) wireless communication system was developed for *Sima* and it can also be used to eliminate cables from instruments to the RS.

Long range satellite communication has also been developed and tested, although the price is slightly higher than radio communication.

Final remarks

Sigra has proved to be a reliable system and has been operating without any fault for more than a year. Maintenance is reduced to an yearly inspection.

Short range radio communication is a low cost option limited to 30 km distance between the CS and RS's. For longer distances, it can be easily replaced by satellite communication. Local communication (within one slope) can be wireless, via FM frequency.

In-house hardware and software development allows production of a low cost system. *Sigra* software can be easily modified and be tailored it to specific needs.

Acknowledgments

The development of *Sigra* was sponsored by the Geo-Rio Foundation. Support from Aldo Rosa, Wilmar Barros, Efraim Akherman, Renato Cunha and Luis Otávio Vieira is appreciated. Collaboration from Sylvio Silva and Adalsino Gonçalves from Insitutek Ltd is acknowledged. Lucia Alves and Javier Far helped in the preparation of the paper.

Current stage of development

Sigra was experimentally installed at the Borel Hill by the end of 1992 and at the Formiga Hills in 1993. The units had only a very limited amount of soil instrumentation, since the primary purpose at the current stage of our research is to evaluate performance and to correct problems.

Sima is in the final stages of development and is due to be deployed in the field by the Winter of 1994.

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