

# Application of Innovative Monitoring Techniques at Four Selected Natural Hillsides in Hong Kong

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## ABSTRACT

With the continuous improvement of instrumentation techniques and better understanding of slope behaviour, it is anticipated that instrumentation for long-term performance monitoring of landslide development at individual sites will become more frequently used in Hong Kong. To prepare for this trend, a project is being undertaken to carry out real-time monitoring of four selected hillsides in Hong Kong and to assess the conditions of the hillsides with respect to ground movements and hydrogeological conditions. All field instrumentation works at the four hillsides have now been completed and real-time monitoring has been ongoing since late 2007. A wide range of conventional and state-of-the-art geotechnical instruments, real-time automatic data communication and geotechnical data processing system have been installed. This paper presents the background, relevant technical details of the instrumentation scheme (including highlights of the basic principles of the some of the innovative instruments adopted), data collected and interim findings.

## 1 INTRODUCTION

Geotechnical instrumentation has been adopted in many countries for assessment of the likelihood of landslide occurrence and the need for further mitigation measures (NCR, 2004). This practice has not been widely adopted in Hong Kong because of its urban setting and the potentially severe consequences of most local landslides (Wong et al, 2006). With the close proximity of densely used facilities to slopes in Hong Kong, it is more technically and economically viable to stabilise slopes showing signs of distress. Moreover, the sudden occurrences of small-scale, brittle landslides, most common in Hong Kong, often exhibit few signs of distress.

The geotechnical profession in Hong Kong is familiar with the use of geotechnical instrumentation as a ground investigation tool for stability assessment of slopes and design of slope stabilisation measures. Geotechnical instrumentation has also helped collection of field data for research and development projects that further our understanding of slope behaviour in Hong Kong. In structural and bridge engineering, performance monitoring is gaining importance as an asset management tool to assess, verify and monitor the performance of a given structure. As instrumentation techniques continue to improve and the profession continue to gain a better understanding of slope behaviour, it is anticipated that instrumentation for long-term performance monitoring of landslide development at individual sites will become more frequently used in Hong Kong (Wong et al, 2006).

To prepare for this trend, the Geotechnical Engineering Office (GEO) is undertaking relevant technical development work to test the performance of new monitoring and instrumentation techniques and arranging pilot instrumentation schemes to set up a prototype real-time instrumentation network in Hong Kong. The first of these pilot schemes was initiated in June 2005 when the GEO engaged the services of Ove Arup & Partners Hong Kong Limited (Arup) to undertake detailed engineering geological and hydrogeological studies of four landslide prone areas across Hong Kong, and plan site specific instrumentation and monitoring schemes applicable to the predicted types of ground movements and groundwater conditions present at each site.

A wide range of conventional and state-of-the-art geotechnical instruments were installed since late 2007 (Table 1) and a Instrumentation Database Monitoring System (IDMS) has been recently set up in the Civil Engineering and Development Department (CEDD) for real-time collection, transmission, processing and

dissemination of the monitoring data. The following sections present the ground movements and hydrogeological conditions of the four selected hillsides, and the applications of the innovative instruments installed with highlights of the basic principles and preliminary findings.

Table 1: Geotechnical Instruments Installed at the Four Selected Hillsides

Conventional Geotechnical Instruments		State-of-the-art Geotechnical Instruments
<ul style="list-style-type: none"> <li>• Surface Markers</li> <li>• Crack Meters</li> <li>• Manual Inclinometers</li> <li>• In-place Inclinometers</li> <li>• Earth Pressures Cells</li> </ul>	<ul style="list-style-type: none"> <li>• Rain Gauges</li> <li>• Automatic Piezometers</li> <li>• Evaporimeter</li> <li>• Jet Fill Tensiometers</li> <li>• Flowmeter</li> </ul>	<ul style="list-style-type: none"> <li>• Differential Global Positioning Systems</li> <li>• Translation, Rotation &amp; Settlement Sensors</li> <li>• Displacement Time Domain Reflectometry</li> <li>• Water Content Time Domain Reflectometry</li> <li>• Thermal Conductivity Suction Sensors</li> </ul>

## 2 THE FOUR SELECTED NATURAL HILLSIDES

The four natural hillsides were selected on the basis of various geological/hydrogeological conditions and landslide mechanisms anticipated, none of which presented an immediate hazard to the general public. The differing nature of the four sites meant that a variety of instrument types and monitoring scenarios could be tested with little risk to public safety and with a view to applying the findings to other slopes where potentially more hazardous conditions may exist.

### 2.1 Tsing Shan Foothills, North West New Territories

The Tsing Shan Foothills site comprises an active, elongate, very slow-moving translational earth slide with a basal shear surface typically at 4 – 6 m depth (Figure 1). The landslide is occurring along shallow dipping foliations within Completely Decomposed Andesite and it has been estimated that the volume of material experiencing long-term deformation is in the order of 45,000 m<sup>3</sup>. Further details of the geological setting and landslide processes operating at the site have been reported by Parry & Campbell (2003). Initial monitoring of landslide movement by means of an inclinometer was carried out between 2002 and mid-2006, when excessive deformation in the order of 200 mm cause damage to the inclinometer tubing and precluded further readings from being obtained. Given the active nature of the landslide at this site and its known history of slope deformation, especially during Hong Kong’s rainy season, this site was selected for instrumentation using a variety of different geotechnical instruments.

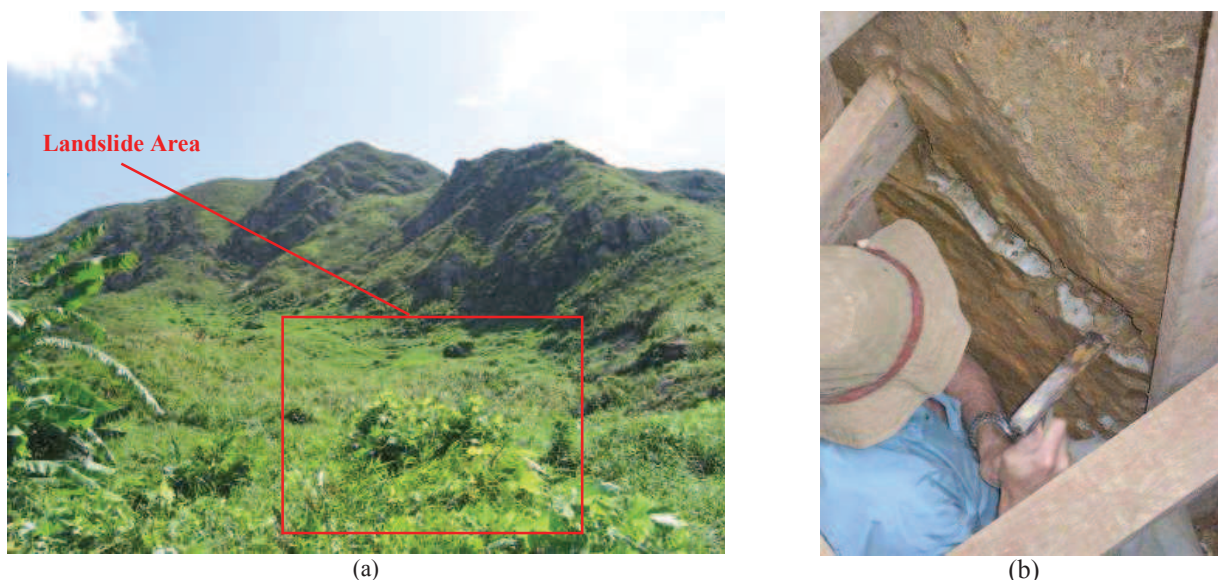


Figure 1: Landslide Study Area at (a) Tsing Shan and (b) the Landslide Basal Shear Surface

### 2.2 Tung Chung Foothills, Lantau Island

This site comprises a shallow slump failure that appears to have reactivated during the wet season, with small seasonal down slope movements observed. The landslide mass, estimated at about 1,500 m<sup>3</sup> in volume and 45 m across, moves along poorly defined rupture surfaces at 2 – 4 m depth. A notable back scarp has formed at the head of the landslide with lateral tension cracks (Figure 2) and small thrust features evident along the landslide flanks and at its toe. Detailed ground investigation works within the landslide area, including drillholes, trial trenches and electrical resistivity profile surveys, indicated that the movement was occurring just beneath the colluvium/saprolite boundary and was likely resulted from short term loss of soil suction due to transient development of high pore water pressures during rainstorms.



Figure 2: Landslide Study Area at (a) Tung Chung and (b) the Landslide Back Scarp

### 2.3 Pa Mei, Lantau Island

This site was selected due to the high frequency of relatively small-scale shallow open hillside failures. These failures, the locations of which are presented on Figure 3, typically comprised shallow open hillslope landslides with volumes less than 100 m<sup>3</sup> and varying degrees of mobility. Nearly all of the open hillslope landslides appear to have failed in a brittle manner, with little or no obvious signs of distress.

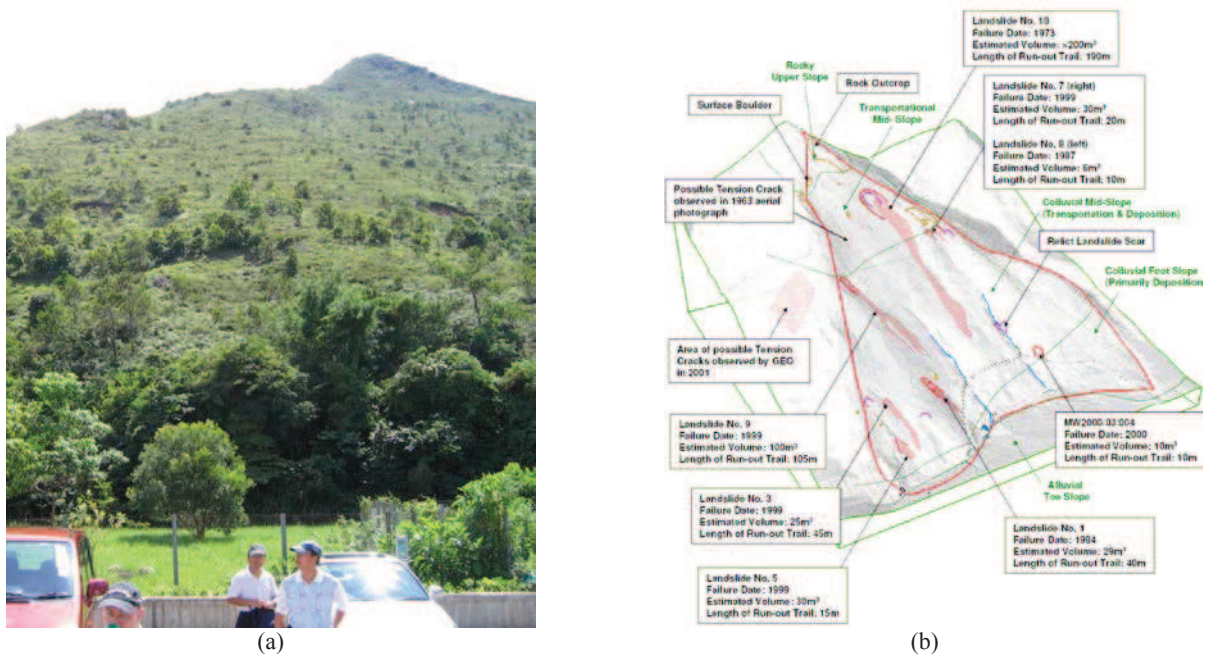


Figure 3: Landslide Study Area at (a) Pa Mei and (b) Block Model of Geomorphological Setting and Past Landslides

In addition to the high frequency of open hillslope landslides, field mapping of the site also identified an area of distressed ground close to the slope toe. This area comprised tension cracks, with up to 0.5 m vertical displacements, which extend across the slope from the head of a small retrogressive landslide located close to the toe of the hillside (Landslide No. 5 as indicated in Figure 3). Small discontinuous thrust features were also identified approximately 20 m below the tension cracks.

#### 2.4 Ching Cheung Road, Kowloon

This site comprised a series of cut slopes and a thin strip of natural terrain overlooking Ching Cheung Road. A number of large landslides had occurred on those cut slopes in 1972, 1982 and 1997, with notable delay between major rain storms and failures. The most notable of these, which occurred in 3 stages between 7 July 1997 to 3 August 1997, resulted in closure of the road, Figure 4. Details of the landslides together with a review of the past landslide history of the area and an account of the extensive slope stabilisation works, including a large rock fill buttress at the slope toe and over 1,000 soil nails within the surrounding cuttings, are discussed in Halcrow (1998).

The consistent delay between storm events and landslide initiations at this site is suggestive of a complex hydrogeological regime. Indeed, the landslide study postulated that subsurface groundwater flow within the hillside was controlled by a series of natural ‘tanks and pipes’ with soil erosion pipes acting as preferential flow paths and less permeable dyke materials damming/ tanking of the groundwater flow, (Okunshi and Okimura, 1987). In view of the above observations, the instrumentation proposal thus focussed primarily on monitoring of groundwater conditions at various levels within the slope profile.



Figure 4: Images of the July/August 1997 landslide within the Ching Cheung Road Study Area (Halcrow, 1998)

### 3 DIFFERENTIAL GLOBAL POSITIONING SYSTEM

Global Positioning System (GPS) is the only fully functional Global Navigation Satellite System (GNSS). It utilises a network of 24 United States satellites orbiting the earth and transmitting microwave signals back to the ground surface. Other systems include the Russian GLONASS and the Chinese BEIDOU, each with 8 and 4 operational satellites respectively. The time taken for these signals to reach a single GPS receiver can be used to calculate the satellite–receiver distance. By comparison of the time lags received from four or more satellites, a GPS unit is able to determine its longitude, latitude and altitude with accuracy in terms of meters.

The accuracy of the GPS readings can be improved by reducing the satellite navigation signal errors. This is achieved by comparing the differences between GPS signals received from its receiver and those signals broadcasted from a local reference base station of known fixed coordinates, thus commonly referred to as Differential Global Positioning System (DGPS). The positioning accuracy of a DGPS can be further improved by using receivers with dual frequency tracking capability to apply a precision correction to measure the difference delays between the L1 and L2 bands. Current high-grade DGPS receivers can achieve real-time positioning with 10 mm horizontal accuracy and 20 mm vertical accuracy.

Two types of DGPS were planned for the Tsing Shan site, Figure 5. The first system was installed in early March 2008, Figure 5(a) and (b). It comprises a GPS receiver and a single antenna to track the signals from

both the US GPS and the Russian GLONASS satellites, with the differential GPS signals broadcasted from a local reference base station operated by the Lands Department. Post-processing of the preliminary real-time DGPS data indicate that the horizontal and vertical accuracies can be improved to 5 mm and 10 mm respectively. The second system is a multi-antenna system with a GPS receiver custom-made by the Hong Kong Polytechnic University (HKPU) to receive sequential signals from several antennae (Ding et al, 2002), Figure 5(c). This system is currently under construction in research collaboration with the HKPU to receive GPS signals from a network of 5 antennae placed within the landslide body and differential GPS signals from a reference antenna placed just outside the landslide body.

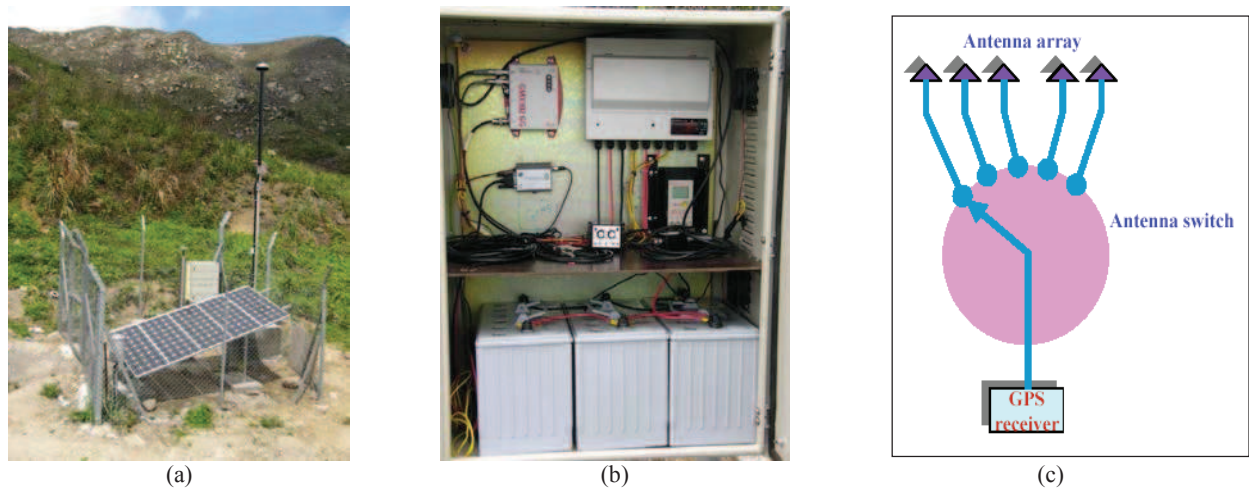


Figure 5: Single Antenna DGPS (a) Lightning Protection System & Solar Power System, (b) GPS Receiver, GPRS Modem and Back-up Power System, and (c) Schematic Design of Multi-antenna DGPS (Ding et al, 2002)

Both DGPSs were placed within chain link fence enclosures with lightning protection system to avoid theft or damage due to lightning strikes. Through collection and transmission of monitoring data at regular intervals, the movement path of the DGPS receivers can be plotted on plan and both the rate and direction of slope movement can be detected. The current set up allows the long-term performance of the two DGPS to be assessed and compared with each other and other conventional movement sensors like in-placed inclinometers installed at this site.

#### 4 TRANSLATION, ROTATION AND SETTLEMENT SENSOR

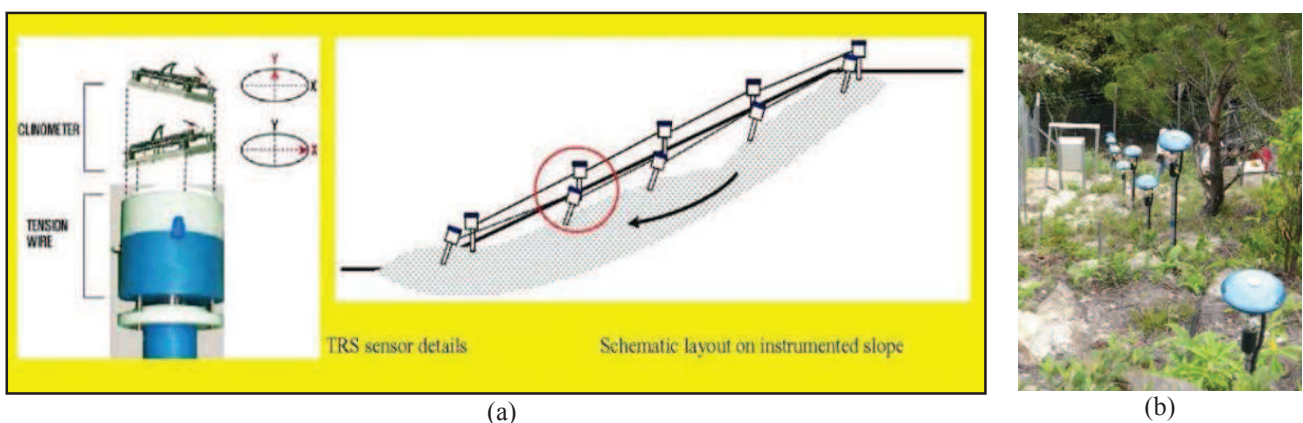


Figure 6: Multi-point TRS System (a) Schematic Layout & (b) TRS Sensors installed at Pa Mei Site

Developed in South Korea and discussed in detail by Chang et al (2006), this system comprises a series of translation, rotation and settlement (TRS) sensors, which are interconnected with tension steel wires and installed at designated points along the profile of a slope, Figure 6(a). Each TRS sensor consists of a precision potentiometer for measurement of linear displacement up to a range of 200 mm and a pair of orthogonally

arranged inclinometers to measure vertical tilt in directions parallel and perpendicular to the slope profile, with ranges of 20° and 10° respectively. Movements of a slope installed with TRS sensors will thus be recorded in terms of the displacements, rotations and settlements measured by the TRS sensors.

A single array of 8 TRS sensors has been installed within the distressed area at the slope toe of the Pa Mei site, making it the first application of this technique outside South Korea. A variety of other instruments have also been provided in this area to allow direct comparison of the recorded data and assessment of the effectiveness of this method.

**5 DISPLACEMENT TIME DOMAIN REFLECTOMETRY**

The Time Domain Reflectometry (TDR) technique has been employed by the power and communications industries to locate cable faults and breaks in an electrical co-axial cable. In recent years, this technique has been adopted in geotechnical applications to enable the depth to shear planes or zones of deformation within the ground to be detected.

The TDR technique passes a timed electronic pulse along a coaxial cable and can detect whether or not the cable has become damaged based on the reflected signal received. In order to monitor any movement within a slope, a coaxial cable is grouted in place within a borehole and its integrity continually checked using a reflectometer, which generates the electrical signal passed through the cable. As the electrical pulse passed through the cable is timed, both the location and magnitude of any faults within the cable can be determined, Figure 7. The characteristics of the test results are stored and, when plotted over time, will reveal any changes should the slope be moving.

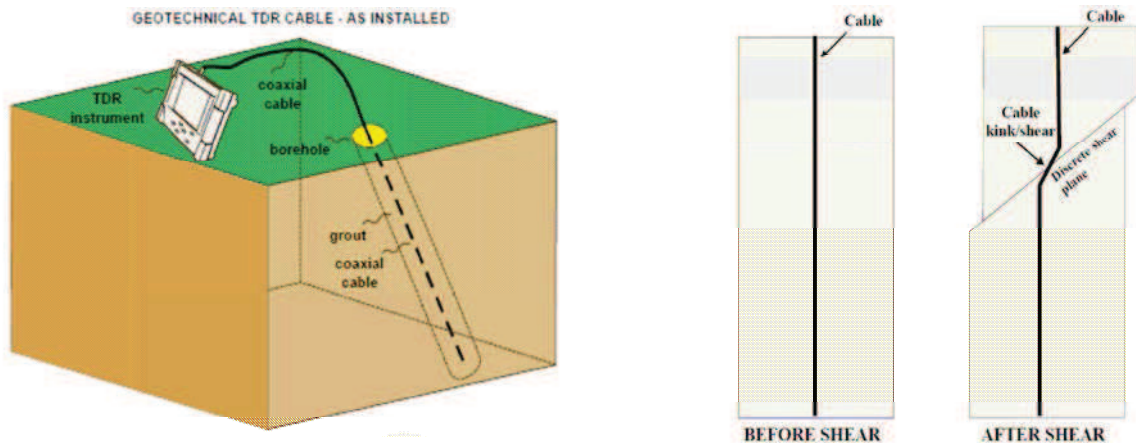


Figure 7: Schematic of Vertical TDR Monitoring System (Kane, 2000)

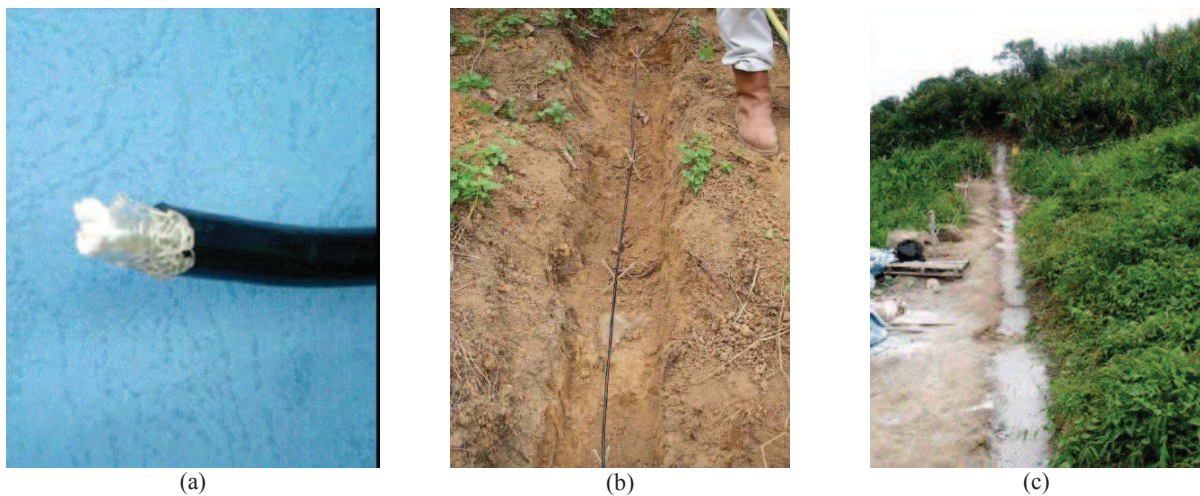


Figure 8: Trial Installation of a TDR Monitoring System at the Tsing Shan Site: (a) RG 58 Co-axial Cable; (b) Pre-grouting and (c) Post-grouting of Horizontal TDR Installation

Whilst this technique of slope monitoring has been implemented overseas for several years, mostly within the United States (Kane, 2000), it has not previously been adopted in Hong Kong. A trial installation was thus adopted at the Tsing Shan study site, with electrical co-axial cables grouted in drillholes adjacent to in-place inclinometers such that any indicated depths of movement could be verified. Instrument specific reflectometers were installed at the site and used for the cable testing. A cable was also grouted in-place within a 150 mm wide by 150 mm deep horizontal trench running across the site in order to test the effectiveness of delineating the extent of deformation using this technique (Figure 8). The strength of the grout was kept sufficiently low that the backfilled trench has no anticipated reinforcing effect on the surrounding soil and will freely crack and deform, thus inducing kinks in the installed cable.

## 6 THERMAL CONDUCTIVITY SUCTION SENSOR

The degree of soil suction in the shallow ground profile has significant impact on the stability of soil slopes and a number of past studies have been conducted on this effect (Shen, 1998; Sun et al, 1998; Sun & Ho, 2003; Ng & Chen, 2008). Initial consideration of a number of potential devices for monitoring soil suction, included Soil Psychrometers, Time Domain Transmission, Gypsum Blocks etc. Ultimately, Jet-Fill Tensiometers (JFT) was adopted mainly as a result of their ready availability and knowledge acquired through their past applications in Hong Kong. As a further development to the use of JFTs, which have been successfully used in Hong Kong for a number of years but require a high degree of manual maintenance, an array of 3 Thermal Conductivity Suction (TCS) sensors was also installed at the Tung Chung site, with depths at 0.2 – 0.6 m.

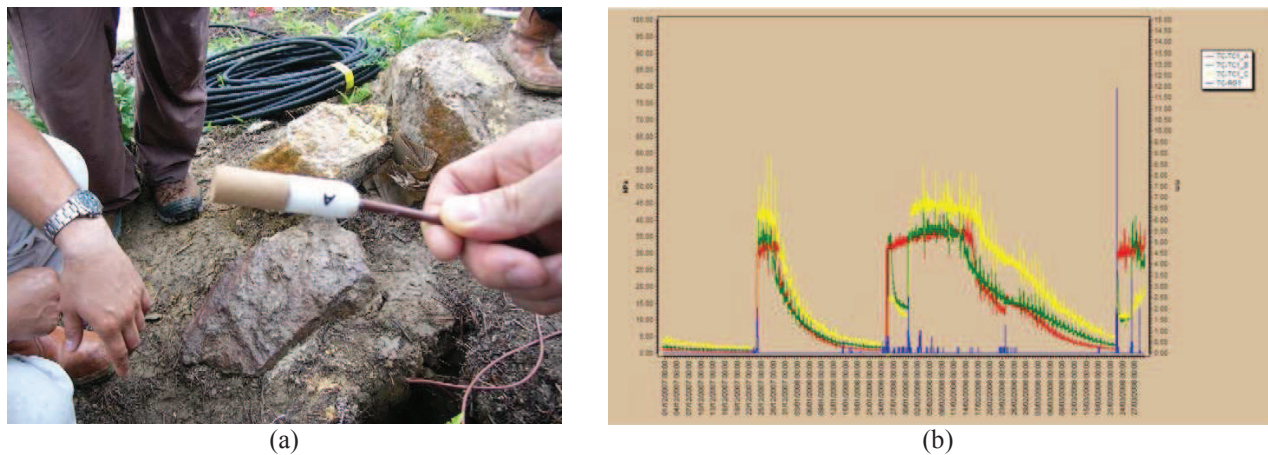


Figure 9: TCS Sensor (a) Porous Ceramic Tip and (b) Preliminary Monitoring Results

A TCS sensor consists of a heating element and a thermocouple embedded in the middle of the porous ceramic part of the probe, Figure 10(a). To calculate the soil suction, a 50 mA current is excited to the heating element for about 30 – 90 seconds and the thermocouple measures the rise of the temperature. The magnitude of the temperature rise varies in accordance with water content of the porous ceramic matrix, which changes as the surrounding soil wets and dries. Soil suction is inferred from previously determined calibration coefficients between the heat dissipation and soil suction. The calibration of the TCS sensors was carried out in research collaboration with the Hong Kong University of Science and Technology (Ng & Chen, 2008). Preliminary data showing the response of soil suction with respect to rainfall is quite promising, Figure 10(b), although more meaningful interpretation will require data of longer monitoring period.

## 7 WATER CONTENT TIME DOMAIN REFLECTOMETRY

A Water Content Time Domain Reflectometry (WTDR) probe comprises two 30 cm long stainless steel rods connected to a circuit board which is linked to a data logger by a shielded four conductor cable to supply power, enable probe, monitor the output and grounding, Figure 9(a). The principle of WTDR is that an electromagnetic (EM) pulse will be triggered from the circuit board to propagate along a pair of stainless steel rods to their ends where the pulse will be reflected back. The circuit board then detects the reflected EM pulse and triggers the next one. The velocity of the EM pulse depends on the dielectric permittivity of the

surrounding soil in such a manner that as the water content increases, the propagation velocity will decrease because it will take time for the water molecules in the soil to get polarized. Hence, the return period of the two-way wave propagation time is empirically related to water content using a calibration equation, with the lower and upper bounds of return period of 14  $\mu$ s and 42  $\mu$ s for the probe rods in air and completely immersed in tap water.

The probe can be inserted to the required depth at the bottom of a hole formed by hand auger or buried at any orientation to the ground surface. The installation method can affect the accuracy of the measurement as the probe rods should be kept as close to parallel as possible to reduce interference of wave propagation along the rods. For vertical installation in very dense soils, a probe insertion guide can be used to maintain the parallel orientation of the rods during insertion.

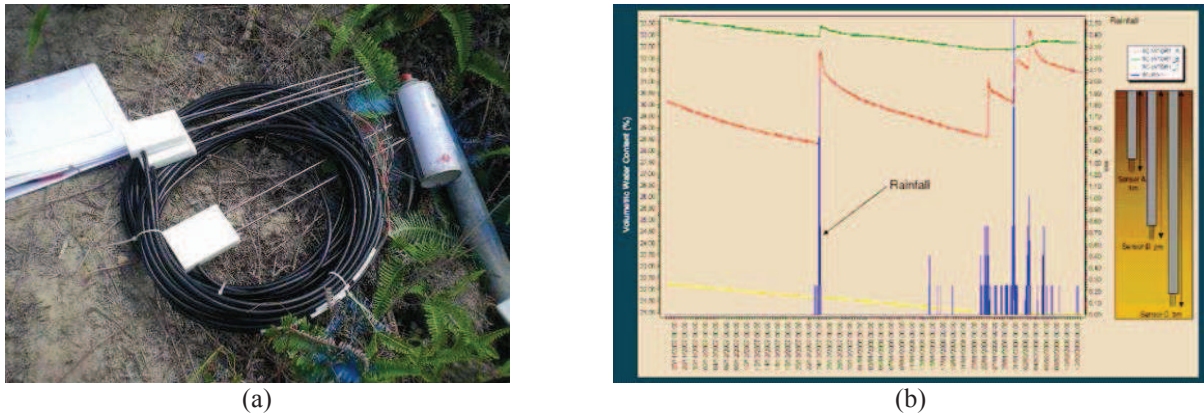


Figure 10: WTDR (a) Stainless Steel Rods, Circuit Board and Four Conductor Cable and (b) Preliminary Monitoring Results

Monitoring arrays, including 3 number of WTDR probes and conventional jet-fill tensiometers (JFT) were installed at a number of locations in order to monitor how changes in matric suction and volumetric water content within the shallow soil profile during periods of intense rainfall. Preliminary data indicating good correlation between the response of the water content and rainfall is shown in Figure 9(b). In addition, the results of adjacent WTDR probes and JFTs will also allow the Soil Water Characteristic Curves (SWCC) to be determined under the in-situ conditions and compared with those measured in the laboratory. SWCC is a plot of the relationship between volumetric water content and soil suction under several cycles of wetting and drying. The method of testing to determine these relationships was discussed in detail by Ng & Pang (2000).

## 8 INSTRUMENTATION MONITORING DATABASE SYSTEM

One of the key component of the monitoring project is the Instrumentation Monitoring Database System (IMDS) which was designed with the necessary computer hardware and software to collect, store, analyse and present the real-time monitoring data automatically. The total storage capacity of the IMDS is such that it can handle monitoring data from an additional 6 monitoring sites (i.e. 10 sites in total), each with an average number of 60 instruments installed. The IMDS normally collects data at 15-minute intervals but is capable of retrieving data at a maximum frequency of 5 minutes, although the instruments themselves have far higher frequency capabilities should this be required. The IMDS performs validation checks on the monitoring data within 96 hours of data collection.

The user interface for the database server of the IMDS is of critical importance as this forms the main access portal through which the data is retrieved and visualised. To this end, the database server facilitates internet accessibility and combines Geographical Information System (GIS) compatible platforms to allow the data to be visualised in a user specified manner. Monitoring data for the various sites can be accessed through site specific home pages that present both the site setting, in terms of digital ortho-photographs, topographic survey plans, landslide features etc., as well as the as-built surveyed locations of all sensors installed at the sites (Figure 11). Use of a simple layering structure facilitates the availability of any desired combination of viewing options. The IMDS also allows the monitoring data to be exported in a variety of formats, from instrument-specific Excel tables to automatically generated PDF reports for each site covering a predefined time period. Such automated protocols greatly ease the efficiency with which the data can be handled.



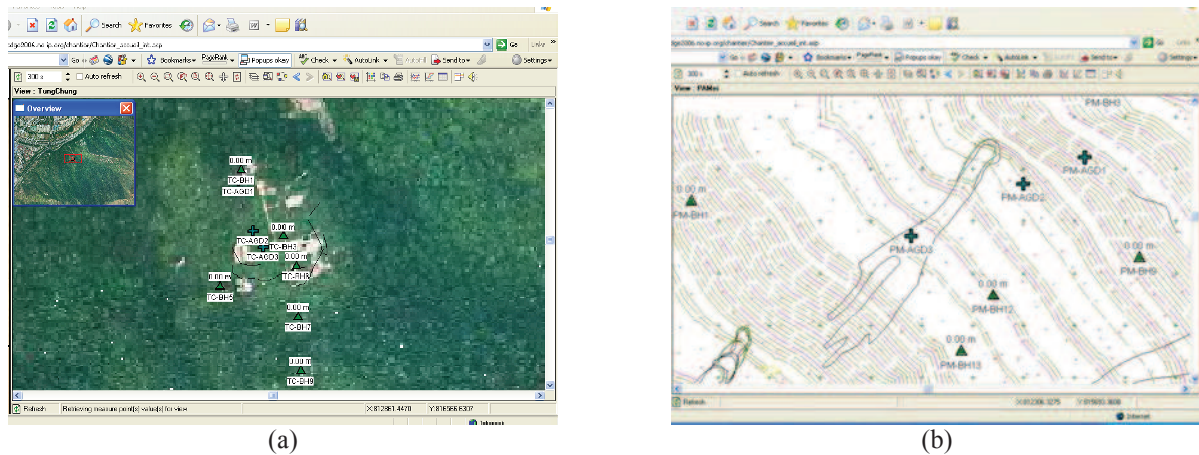


Figure 11: Example of the User Interface for the IMDS (a) Digital Ortho-photo Background and (b) Topographic Survey Background (both with landslide features overlain)

The primary control mechanism for the collection, initial storage and transmission of the monitoring data was achieved by a number of dataloggers each of which is connected to a cluster of instruments in accordance with the technical specification of this instrumentation project. Wireless data transmission was used as far as practicable in this project to reduce the use of cables, which are vulnerable to lightning strikes (Shoup, 1992) and damage from other factors such as human activities, roaming animals and hill fires. The monitoring data are transmitted from the monitoring sites back to the IMDS typically by means of GPRS (General Packet Radio Service) modems, Figure 12(a).

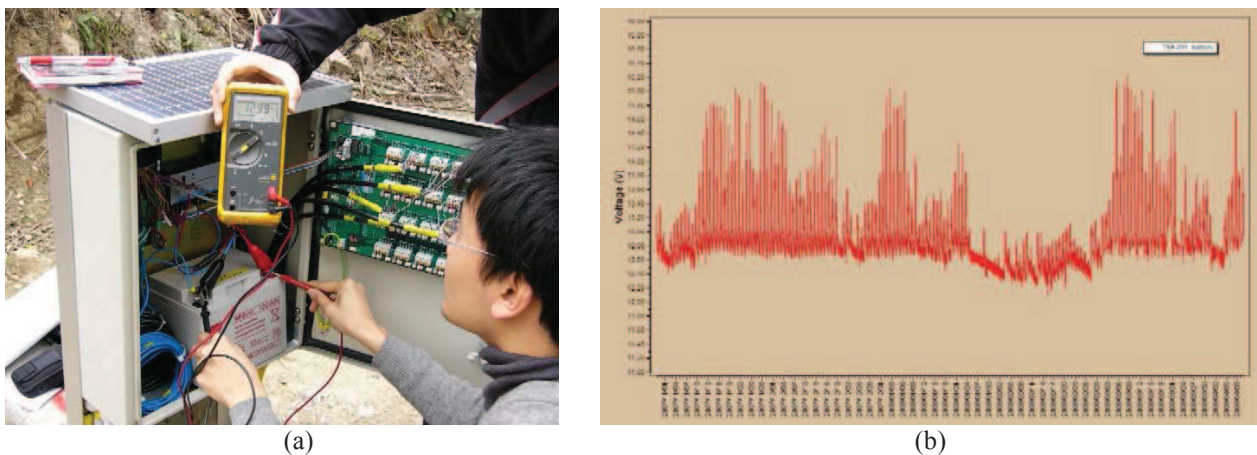


Figure 12: Typical Setup of Datalogger (a) A4-sized Solar Panel, 12V Backup Battery & GPRS Modem & (b) Voltage Status of a 12V Backup Battery Including the Effect of the Long Cold Spells in early 2008

All the dataloggers are capable of collecting, storing, and transmitting the monitoring data at 5-minute intervals for a period of 7 days in accordance with the particular specification of this instrumentation project. Thus, the dataloggers are powered by solar panels with provision of secondary battery backup of at least 168 hours capacity, assuming that the data are collected and transmitted at 5-minute intervals. Recent site inspections after the long cold spells in early 2008 confirmed that all the backup batteries had been adequately charged by the A4-sized solar panels (Figure 12).

## 9 FUTURE WORK

As the installation of all the instruments was completed in late March 2008, only limited results are currently available for review and the content of this paper has largely been confined to the purpose and intent of the instrumentation carried out.

Given that the instrumentation project has a monitoring period of 24-months after installation, the data currently being obtained will provide a reliable set of baseline conditions that can be used for comparison against those fluctuations and movements recorded during the 2008 and 2009 rainy seasons that occur during Hong Kong's summer time. The performance of the state-of-the-art instruments installed, the technical knowledge on slope instrumentation, the results of the future monitoring works, and interpretation thereof, will therefore be analysed and assessed at the end of the monitoring period.

The experience gained from the technical specification of this instrumentation project and the procurement of the instrumentation contract will be beneficial for planning and designing future instrumentation and monitoring projects. The knowledge and experience of the IMDS of this project will also help providing a basis for further enhancement of our capability in setting up a prototype real-time instrumentation network in Hong Kong.

## ACKNOWLEDGEMENTS

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