Real-time monitoring of ground movement and groundwater conditions associated with natural terrain landslides in Hong Kong

La surveillance en temps réel des états au sol de mouvement et d'eaux souterraines s'est associée aux éboulements à Hong Kong

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ABSTRACT

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 the design of slope stabilization 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. As instrumentation techniques continue to improve and practitioners gain a better understanding of the possible influence of progressive slope deterioration, it is anticipated that slope 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, the Geotechnical Engineering Office (GEO) of Hong Kong is undertaking some relevant technical development work to test the performance of various instruments and arranging pilot instrumentation schemes to set up a prototype real-time instrumentation networks in Hong Kong.

In 2005, Ove Arup & Partners Hong Kong Ltd (Arup) was commissioned by the GEO to undertake the detailed design and installation of geotechnical instruments for real-time monitoring at several selected hillsides, with particular emphasis on monitoring ground movement and hydrogeological conditions. The field instrumentation works were completed in late 2007 and the monitoring data collected thus far includes records from several notable rainstorms in 2008. A wide range of conventional and state-of-the-art geotechnical sensors (e.g. in-place inclinometers, ground movement Time Domain Reflectometry (TDR), and multi-antenna GPS), real-time data communication and geotechnical data processing system were 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

RÉSUMÉ

La profession géotechnique à Hong Kong est au courant de l'utilisation de l'instrumentation géotechnique comme outil moulu de recherche pour l'évaluation de stabilité des pentes et la conception des mesures de stabilisation de pente. L'instrumentation géotechnique a également aidé la collection de données de champ pour la recherche et le développement projette que plus loin notre arrangement du comportement de pente à Hong Kong. Pendant que les techniques d'instrumentation continuent à s'améliorer et les praticiens gagnent un meilleur arrangement de l'influence possible de la détérioration progressive de pente, on le prévoit que l'instrumentation de pente pour la surveillance d'exécution à long terme du développement d'éboulement à différents emplacements deviendra plus fréquemment utilisée à Hong Kong. Pour se préparer à cette tendance, le GEO entreprend un certain travail de développement technique approprié pour examiner l'exécution de divers instruments et arrange les arrangements pilotes d'instrumentation pour établir un réseau en temps réel d'instrumentation de prototype à Hong Kong.

En 2005, Ove Arup & Partners Hong Kong Ltd (Arup) été commissionné par le GEO entreprendre la conception détaillée et l'installation des instruments géotechniques pour la surveillance en temps réel à plusieurs flancs de coteau choisis, avec l'emphase particulière sur le mouvement au sol de surveillance et les conditions hydrogéologiques. Les travaux d'instrumentation de champ ont été terminés vers la fin de 2007 et les données de surveillance rassemblées jusqu'ici incluent des disques de plusieurs tempêtes de pluie notables en 2008. Un éventail de sondes géotechniques conventionnelles et du dernier cri (par exemple inclinomètres sur place, de réflectométrie au sol de domaine de temps de mouvement (TDR), et de multi-antenne GPS), le système de traitement de données de transmission de données et géotechnique en temps réel ont été installés. Ce document présente le fond, les détails techniques appropriés de l'arrangement d'instrumentation (points culminants y compris des principes de base des certains des instruments innovateurs adoptés), les résultats rassemblés et intérimaires de données

Keywords : innovative monitoring techniques, real-time slope monitoring system

1 INTRODUCTION

Over the past 50 years, Hong Kong has seen a rapid development of its urban area and currently has a population of over 7 million people within a land area of only 1,100 km^2. The development pressure resulting from continued population growth and a limited land area has led to intensive urbanisation of the lower portions of the hillsides that cover much of Hong Kong (Malone, 1998). This encroachment into hilly terrain has resulted in an increased risk to both human life and infrastructure from landslides occurring from man-made slopes formed on the hillsides as well as landslides from the natural terrain areas overlooking them.

On average, about 300 landslides are reported in Hong Kong every year (Ho & Lau, 2007), usually occurring during or soon after periods of heavy rainfall. Whilst significant improvements have been made in slope safety standards and the reduction of risk from landslides on man-made slopes, the GEO has taken a pro-active approach to further reduce landslide risk in Hong Kong and, over the last 5 to 10 years, has increasingly shifted its focus towards addressing hazards from natural hillsides. This has included studies to develop suitable frameworks for the identification of landslide prone areas, through both qualitative and quantitative assessment, investigations of major landslide incidents, and more recently the application of sophisticated instrumentation systems to monitor slope behaviour.

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It has long been recognised that geotechnical instrumentation can be beneficial to slope engineering works, both in terms of providing information and warning of slope instability and for providing ‘health-checks’ to slopes where engineering works have been carried out. It is anticipated that slope instrumentation for monitoring landslide development at individual sites will become more frequently used in Hong Kong. To prepare for this trend, the GEO is undertaking relevant technical development work to test the performance of new instruments 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 July 2005 when the GEO engaged the services of Ove Arup & Partners Hong Kong Limited (Arup) to undertake detailed engineering geological and hydrogeological studies of three landslide prone areas, Figure 1, and design tailor made instrumentation and monitoring schemes specific to the predicted types of ground movement and groundwater conditions present at each site.

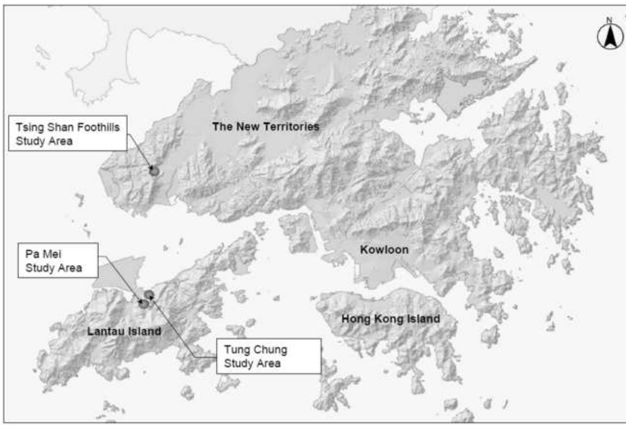


Figure 1. Location of Landslide Study Areas

2 INSTRUMENTATION STUDY SITES

The instrumentation study sites selected for the pilot scheme are discussed briefly in the following sections. The sites were selected due to the variety of geological / hydrogeological conditions anticipated and the differing landslide mechanisms present, 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 landslide at the Tsing Shan Foothills site comprises an active, elongate, very slow-moving translational earth slide with a basal shear surface at depths between 4 to 6 m. 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^3. Further details of the geological setting and landslide processes have been reported in Millis *et al* (2008).

Initial monitoring of landslide movement by means of an inclinometer was carried out by the GEO for the period 2002 to mid-2006 and deformation in the order of 200 mm was identified over that period. The surveys identified an annual movement rate in the order of 80 mm/year. The active nature of this site and its known propensity for deformation, especially during Hong Kong’s rainy season, meant it was an ideal candidate for the trial installation of a variety of different geotechnical instruments.

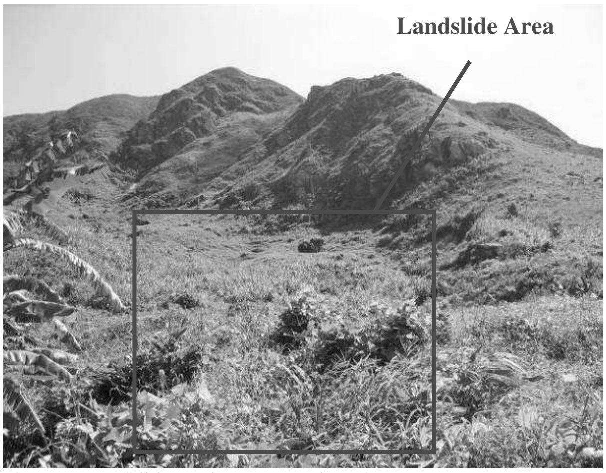


Figure 2. Landslide Study Area at Tsing Shan

2.2 *Tung Chung Foothills, Lantau Island*

The Tung Chung study site comprises a shallow, 3 m to 5 m deep, slump failure that appears to reactivate during the Hong Kong wet season, with small seasonal down slope movements observed. The failure mass is approximately 45 m across, moves along poorly defined rupture surfaces at 3 m to 5 m depth and includes an estimated 1,750 m^3 of material.

A notable back scarp has formed at the head of the landslide and lateral tension cracks and small thrust features are 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 likely resulted from short term loss of soil suction and transient development of high pore water pressures during rainstorms.

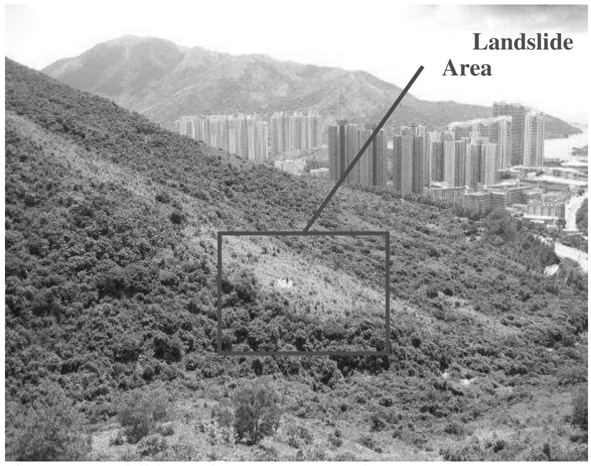


Figure 3. Landslide Study Area at Tung Chung

2.3 *Pa Mei, Lantau Island*

The site at Pa Mei differs from the previous study areas in that it was selected due to the high frequency of natural terrain landslides that have occurred within it, rather than due to evidence of any progressive type failure. These failures, the locations of which are presented on Figure 4, typically comprised shallow open hillslope landslides with volumes less than 100 m^3 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.

Such conditions do not readily lend themselves to slope deformation monitoring due to the ‘hit and miss’ nature of placing instruments at the exact location a future failure may occur. As such, the instrumentation for the bulk of this site area was focussed on monitoring the hydrogeological conditions, such as groundwater levels and changes in soil suction and moisture content, that lead to landslide initiation.

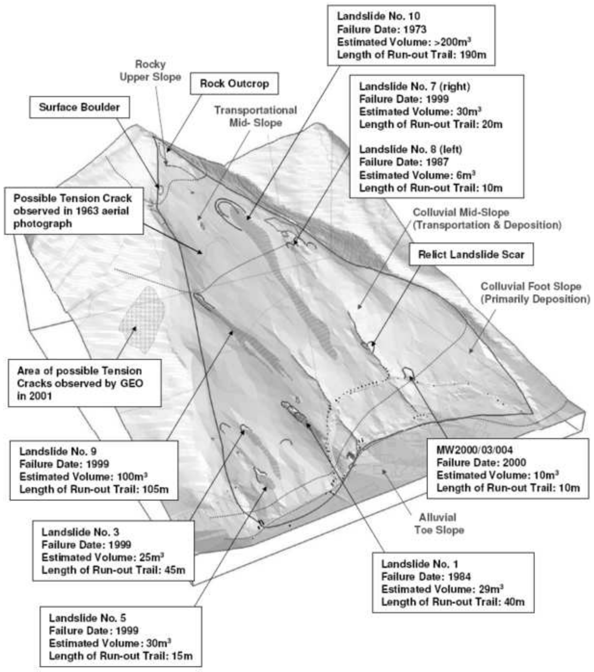


Figure 4. Block Model of Geomorphological Setting and Past Landslide locations for Pa Mei Study Area

3 GEOTECHNICAL INSTRUMENTATION FOR SLOPE MONITORING

Geotechnical instrumentation has been applied to slope engineering projects in Hong Kong since the late 1970s (Wong *et al*, 2006) and the Geotechnical Manual for Slopes (GEO, 1984) provides recommended good practice to which all slope engineering works in Hong Kong generally follow. The manual recommends that slopes be instrumented to provide information for design or construction control and for long-term monitoring of slope performance. However, it is widely acknowledged that it is '*impractical and ineffective to carry out instrumental monitoring of all slopes for the purpose of giving warning of impending danger*' (GEO, 2004). The extent of slope instrumentation works has thus far typically been limited to a small number of groundwater monitoring devices installed within Standpipe / Casagrande piezometers, which are rarely set up to allow real-time data acquisition.

Situations in which more complex instrumentation systems have been applied in Hong Kong, utilising a variety of deformation and groundwater monitoring devices, have generally been limited to detailed investigation of landslide sites following the identification of notable signs of distress or under research projects carried out by local universities or by the GEO. Highly detailed monitoring of groundwater conditions and ground movements on conventional slope engineering projects is not common.

The significant advances that have been made in the development of digital slope instrumentation tools and the provision of relatively stable, economical and easily accessible telecommunication of data over the last decade mean that the application of real-time slope monitoring have become a reality. Through a thorough review of commercially available geotechnical instruments and an in-depth knowledge of slope engineering in Hong Kong, a number of key areas where slope engineering projects could benefit from detailed instrumentation and automated monitoring are identified as follows:

a) Surface deformations;
b) Sub-surface deformations;
c) Groundwater pressures at multiple points throughout the geological profile;
d) Soil suction and moisture content; and
e) Other environmental factors such as rainfall / run off etc.

4 MONITORING OF SURFACE DEFORMATION

Surface ground movements have traditionally been measured through periodic surveys of monitoring points or prisms installed across a site, mostly by means of Theodolite and Electronic Distance Measures (EDM). The development of Robotic Total Stations, which essentially comprise automated versions of the above instruments, has led to major advances in the automation of such surveys but such devices rely heavily on 'line-of-sight' for the survey to be functional. Whilst this can work well for an un-vegetated site during fine weather conditions, the technique faces severe limitations for application in Hong Kong's densely vegetated natural hillsides, especially during adverse weather conditions when visibility is limited and the readings are often needed most.

With due consideration of the above factors, real time monitoring of surface deformation at the study sites is principally being carried out through the provision of crack meters across well defined tension cracks and scarps and the placement of automatic Differential Global Positioning System (DGPS) receivers within the landslide area. Quarterly manual surveys of a network of monitoring points are also being undertaken to facilitate field verification of the data obtained and allow further quantification of surface ground movements.

4.1 *Surface Mounted Crack Meters*

Crackmeters are devices that use displacement transducers to measure the one-dimensional displacement between two points that are experiencing separation, or sometimes closure. Surface mounted crack meters have been provided across well defined features within landslide areas such as tension cracks and shallow scarps.

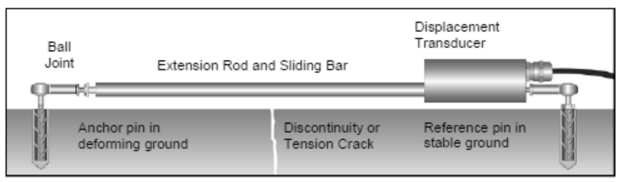


Figure 5. Schematic of Surface Mounted Crack Meter

The installed devices comprise vibrating wire displacement transducers (Figure 5) with a gauge length of 950 mm and a modified range of 300 mm. These were installed with anchor pins positioned at least 400 mm either side of tension cracks and embedded at least 500 mm to prevent minor surface erosion of the scarp feature influencing the readings. The sliding bar was positioned parallel to the slope surface and orientated perpendicular to the tension crack itself. Data recorded by the sensor allows the rate of movement between the stable ground above the tension crack and the displaced mass below to be determined and initial readings taken from both the Pa Mei and Tung Chung study sites indicate slope movements closely correlated to rainfall.

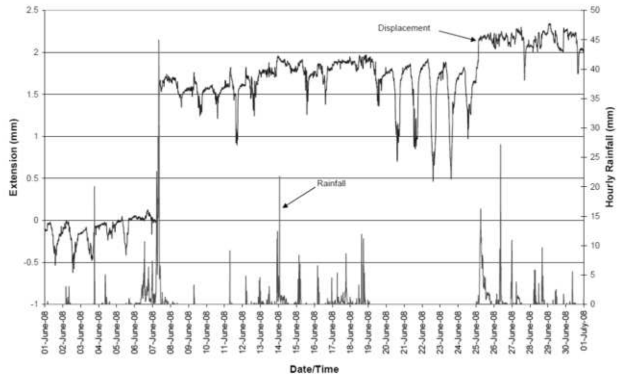


Figure 6 Initial Monitoring Results from Pa Mei

4.2 *Differential Global Positioning System (DGPS)*

The Global Positioning System (GPS) is a positioning system that utilizes a network of satellites orbiting the earth and transmitting radio signals back to the ground surface. The time taken for these signals to reach a GPS receiver can be used to calculate the distance from the signal source. By comparison of the time lags received from several different satellites, typically four or more, a GPS unit is able to determine its location in terms of longitude, latitude and altitude.

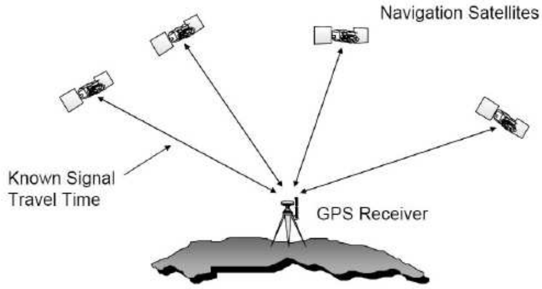
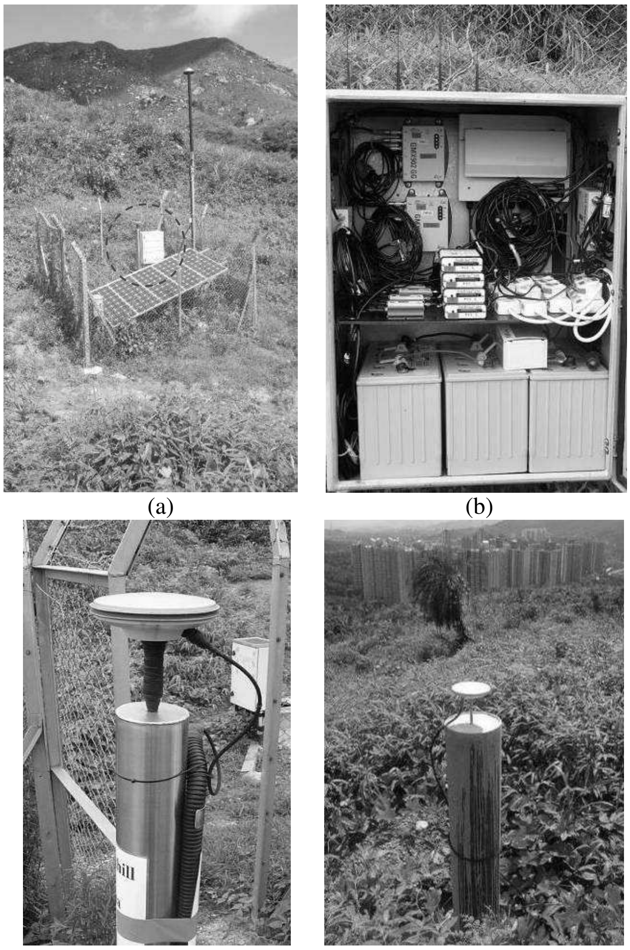


Figure 7. Schematic of GPS Monitoring Principles

The accuracy of the readings can be further improved by reducing the satellite navigation signal errors and combining the readings obtained with those from a local reference base station of known fixed coordinates, commonly referred to as Differential Global Positioning Systems (DGPS). The data obtained from the trial installations at Tsing Shan indicate that provision of local base stations improved the accuracy from 30 mm to about 10 mm.

Two types of GPS monitoring system have been installed at the Tsing Shan site. The first comprises a series of stand-alone DGPS monitoring units, whilst the second constitutes a multi-antenna monitoring system. The multi-antenna system includes a series of 5 antennae placed throughout the landslide body that are monitored by time switching through a single GPS receiver. This system was developed and installed by the Hong Kong Polytechnic University (HKPU) in research collaboration and is similar to those discussed by Ding *et* al (2002).

In order to ensure the functionality of the GPS instruments, both in terms of environmental hazards and general security, the receivers have been placed within a chain link fence enclosure with a lightning protection system to prevent theft or damage due to lightning strikes.



(a) (b)

(c) (d)

Figure 8. GPS Monitoring (a) Station (b) Receivers and (c) & (d) Antenna

Through collection and transmission of monitoring data at regular intervals, the movement path of the DGPS receiver can be plotted on plan and both the rate and direction of slope movement can be determined.

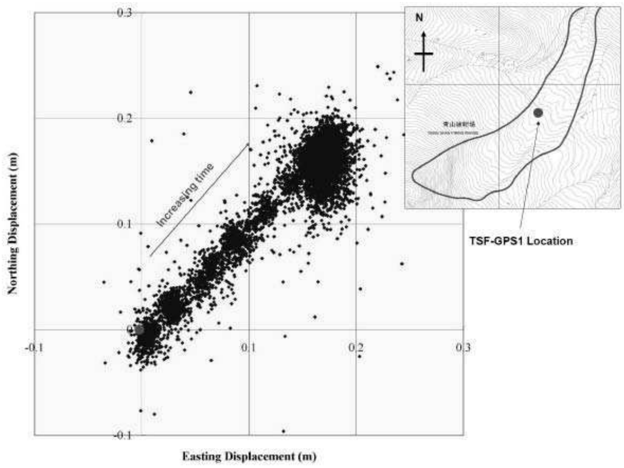


Figure 10. Coordinate Tracking Plot for DGPS1 at Tsing Shan

5 SUB-SURFACE DEFORMATION MONITORING

Sub-surface deformation monitoring is carried out to determine the depth and rate at which movement is occurring along and above the rupture surfaces. The principal means of automated sub-surface deformation monitoring employed for this study comprised the installation and monitoring of in-place inclinometers. In order to further explore the suitability of other potential monitoring methods, a number of drillholes with Time Domain Reflectometry monitoring were also provided.

5.1 *Inclinometers & In-Place Inclinometers*

Probably the most utilised geotechnical instruments for monitoring deformations within the sub-surface are inclinometers. These devices determine the degree of deformation along the length of pre-installed casings by measuring the degree of tilt induced within a probe as it is lowered down the casing with its wheels engaged in guide slots orientated both parallel and perpendicular to the anticipated direction of slope movement. The probe contains a gravity sensing transducer that is designed to measure the inclination of the probe with respect to vertical. The casings used are typically installed vertically so that the inclinometer provides data for defining subsurface horizontal deformation.

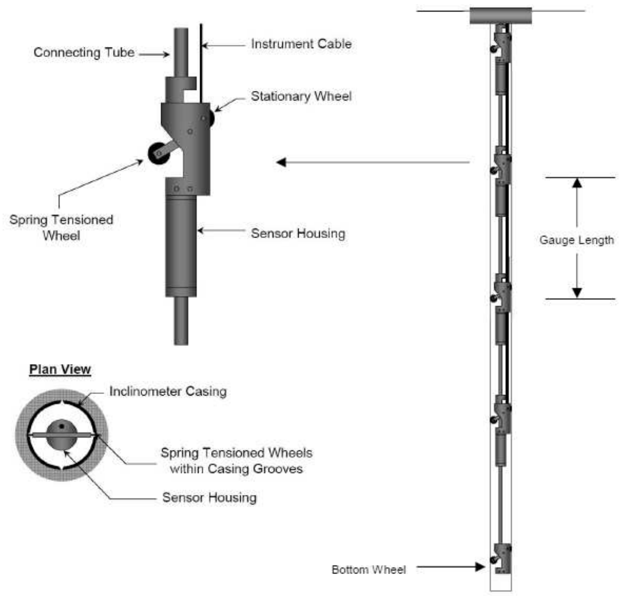
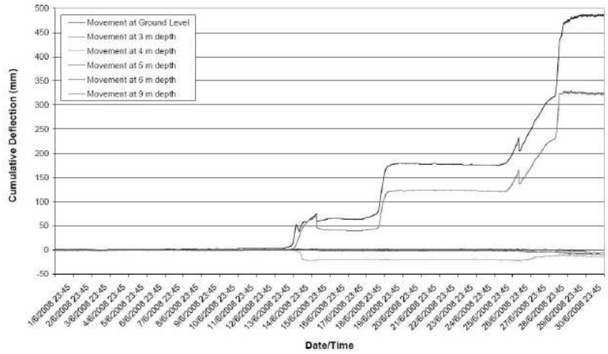
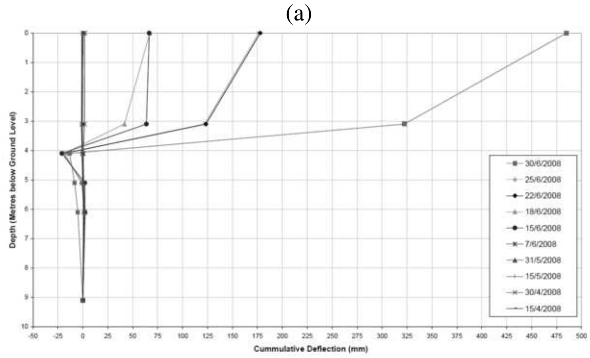


Figure 11. Inclinometer Monitoring System Schematic

Whilst it is ideal for an in-place inclinometer to have the sensors as closely spaced as possible to obtain a continuous sub-surface movement profile, such arrangements can be cost prohibitive. For this reason, the in-place inclinometers installed under the current project utilised a range of gauge lengths, between 1 m and 3 m, with the sensors at the shorter gauge lengths installed at the depths of most probable movement. The readings obtained to-date from the in-place monitoring system at the Tsing Shan Foothills site have largely been consistent with those previously obtained by manual monitoring and other nearby sensors (such as the DGPS), with the peak depth of deformation occurring at 4 m to 6 m below ground level. An example of the monitoring data obtained from one of the sensors at Tsing Shan during heavy rains in June 2008 is provided in Figure 12.



(a)



(b)

Figure 12. In-place Inclinometer data from Tsing Shan

5.2 *Time Domain Reflectometry (TDR)*

Time Domain Reflectometry (TDR) is a method of locating faults and breaks in a cable. In recent years this technique, which has conventionally been used by the power and communications industries to locate cable faults, has been modified 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. As the electrical pulse passed through the cable is timed, both the location and magnitude of any faults within the cable can be determined. In order to monitor any movement within a slope, a foam filled coaxial cable was grouted in place within a borehole and its integrity continually checked using a reflectometer, which generates the electrical signal passed through the cable. The characteristics of the test results are stored and, when plotted over time, reveal any changes should the slope move.

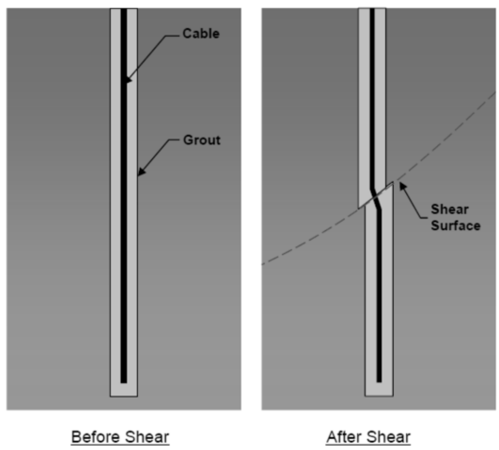


Figure 13. Schematic of Vertical TDR Monitoring System

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 foam filled 50 Ohm 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. The strength of the grout was kept sufficiently low that the grout backfilled had no anticipated reinforcing effect on the surrounding soil and will freely crack and deform.

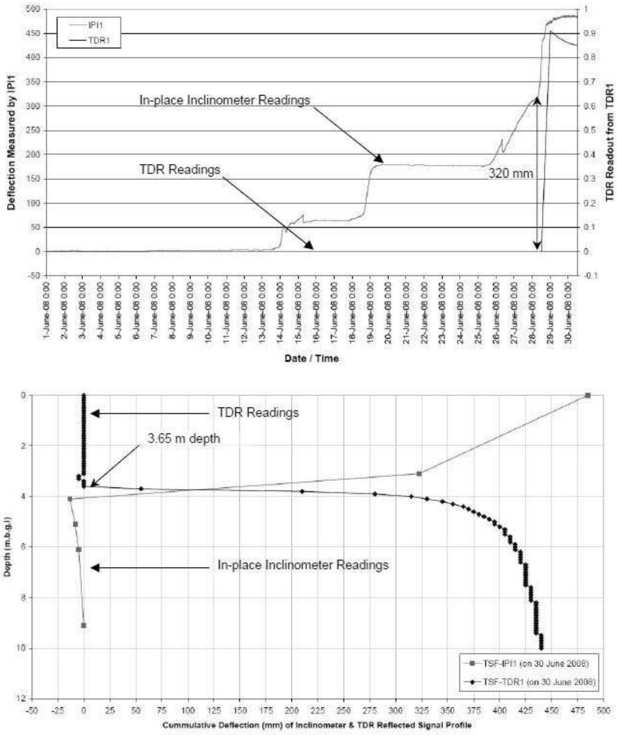


Figure 14. Comparison of TDR and In-place Inclinometer Data for adjacent Installations at Tsing Shan

As indicated in Figure 14, the system has yielded comparable results to those obtained from other nearby instruments. However, a notable delay in the onset of TDR movement is evident, with over 300 mm of movement detected by adjacent inclinometers before TDR movement initiated.

6 HYDROGEOLOGICAL MONITORING

The correlation between severe rainstorms and landsliding is readily evident in Hong Kong and a number of reports have been published by the GEO reviewing the annual relationship between them. Given the importance of the rainfall and its impact on slope stability, a large proportion of the instrumentation works implemented under the project focussed on hydrogeological monitoring. Discussion is provided below on the key elements of this monitoring, namely rainfall and groundwater pressures. Additional monitoring of soil moisture content and soil suction is also being undertaken but falls beyond the scope of this paper.

6.1 *Rainfall Monitoring*

The Hong Kong Observatory and GEO, currently operate a network of 110 automatic rain gauges throughout Hong Kong, collecting rainfall data at 5-minute intervals. Whilst this network provides good coverage of Hong Kong as a whole, site-specific rain gauges were provided at each site in order to supplement it and account for local rainfall variations associated with geographic and other effects.

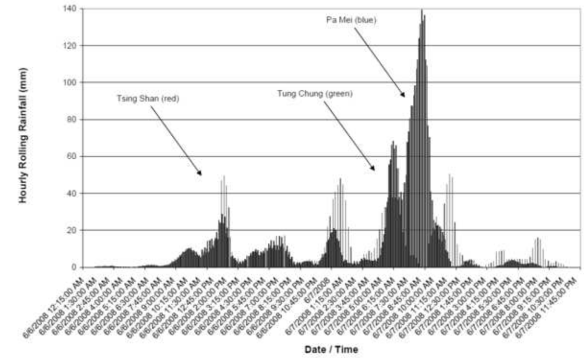


Figure 15. Project Specific Rainfall Data

6.2 *Groundwater Monitoring*

Groundwater monitoring is being carried out within a number of Casagrande piezometers, including pressure transducers within both single level and multi-level response zones (Figure 16). The tip depths and response zones have been designed to fall within areas thought to be of hydrogeological significance. Such areas include zones in which transient perched groundwater tables are thought to develop, i.e. the geological interfaces between colluvial and in-situ soils, zones of high permeability resulting from coarse grained highly decomposed strata and close to the soil/rock interface.

Figure 16. Pressure Transducer

The provision of these monitoring devices facilitates the capture of readings related to both transient (storm-specific) and seasonal changes in pore water pressure and subsequent assessment of how these relate to the ground movements recorded. An example of such monitoring data recorded is presented in Figure 17, which clearly highlights storm specific responses that would be missed by manual monitoring.

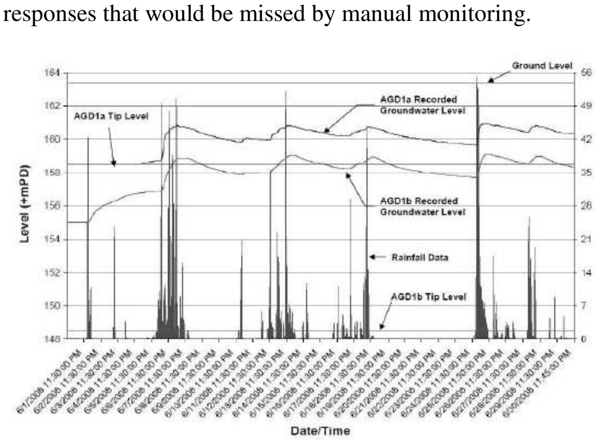


Figure 17. Groundwater Monitoring Results from Tsing Shan

7 DATA MANAGEMENT SYSTEMS

An Instrumentation Database Management System (IDMS) incorporates the components required to store, transmit, analyse and present the readings obtained from the various instruments. In order to achieve this a number of specific sub-systems were developed including the Data Acquisition System DAS), Data Transmission System (DTS), and the Database Systems (DS). A schematic layout of the interface between these sub-systems is presented in Figure 18.

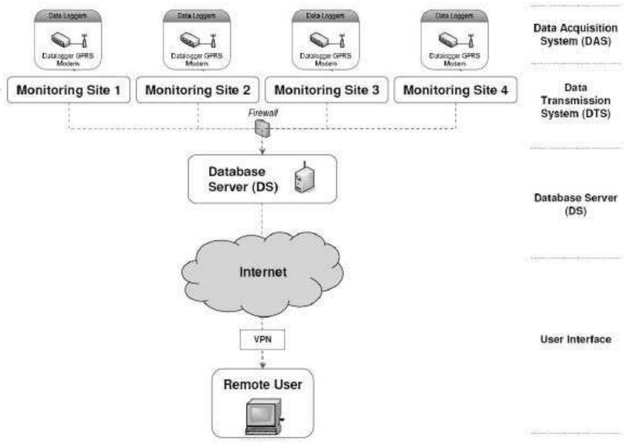


Figure 18. IDMS System Architecture

One of the driving forces behind the increased use of real-time slope monitoring systems is the advances that have been made in recent years in data handling and communications technology. The increased ease with which large volumes of data can now be handled means that a high frequency of monitoring data no longer results in an insurmountable task with regards to data storage, transmission, processing and interpretation. Additionally, the increased availability of wireless transmission technologies means that the need for substantial lengths of cables across a site, which are vulnerable to interference caused by lightning strikes (Shoup, 1992) and damage from a variety of other factors, are largely negated.

7.1.1 *Data Acquisition and Initial Storage*

The primary control mechanism for the collection and initial storage of the monitoring data was achieved through the installation of a number of dataloggers. Programming of the devices was undertaken using proprietary software to set both the monitoring and data transmission frequencies.

7.1.2 *Data Transmission System*

The data transmission system in use for the monitoring sites consists of a Wide Area Transmission System (Figure 18), whereby data for instrument clusters is transmitted from a local monitoring station. Each instrument within a cluster is located within 10 m of the monitoring station in order to minimize the use of cables. Instruments outside of this 10 m limit are provided with their own transmission equipment.

This system transmits the monitoring data back to the monitoring database at 15-minute intervals by means of GPRS (General Packet Radio Service) modems. Separate GSM (Global System for Mobile Communications) and SMS (Short Message Service) modems are also being used for data transmission from the groundwater monitoring devices due to the total system design for these devices, incorporating the transducer, data logger and GSM transmission system.

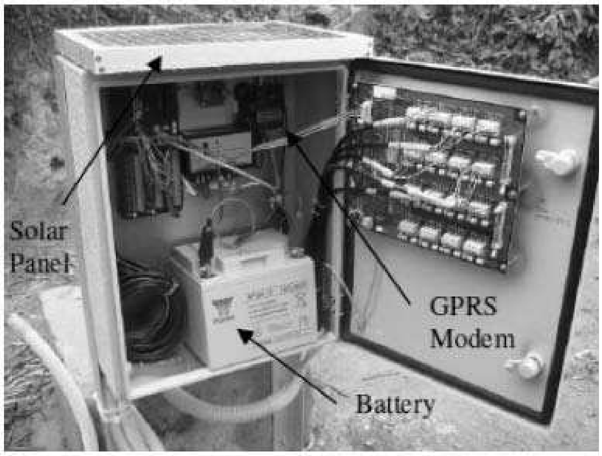


Figure 19. Dataloggers and Power Supply set-up for Monitoring Stations

7.2 *Monitoring Database System*

At the heart of the instrumentation project is the monitoring database system (MDS), which was designed and installed with all the necessary software and hardware to collect, store, analyse and present the monitoring data automatically. The MDS 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 MDS performs validation checks on the monitoring data within 96 hours of data collection.

Data security is implemented by means of physical and environmental security, network and communication security, and the built-in security features of the relational database management system (RDBMS). The MDS is located in a secure server room, which has strict control on temperature and humidity, and can be accessed by authorized persons only. Secure transmission of the usernames and passwords is carried out via the internet on secure sockets layers (SSL) of the web server. The RDBMS supports total data encryption and SSL, with all the data and passwords kept in a well encrypted/protected format.

7.3 *Graphical User Interface*

The graphical user interface for the database server is of critical importance to any remote real-time monitoring project as this forms the main access portal through which the data is retrieved and visualised. To this end, the majority of the systems adopted for large-scale monitoring works facilitate internet accessibility and often combine GIS compatible platforms to allow the data to be visualised in a user specified manner. Monitoring data for the various sites is accessed through site specific home pages that present both the site setting, in terms of digital ortho-photographs, topographic survey plans, landslide features etc. (Figure 20), as well as the as-built surveyed locations of all sensors installed at the sites. Use of a simple layering structure for the above data means that any desired combination of viewing options are available to the user. Graphical plots or tabulated pages of the monitoring data are accessed by clicking on any of the instrument locations and a variety of formatting options are available within these pages, including functions to reduce the data presented by taking the mean/median value over specified intervals of time.

The interface also allows data from various different instruments to be overlain on the same plot, such as rainfall and deformation, allowing easy comparison of relationships.

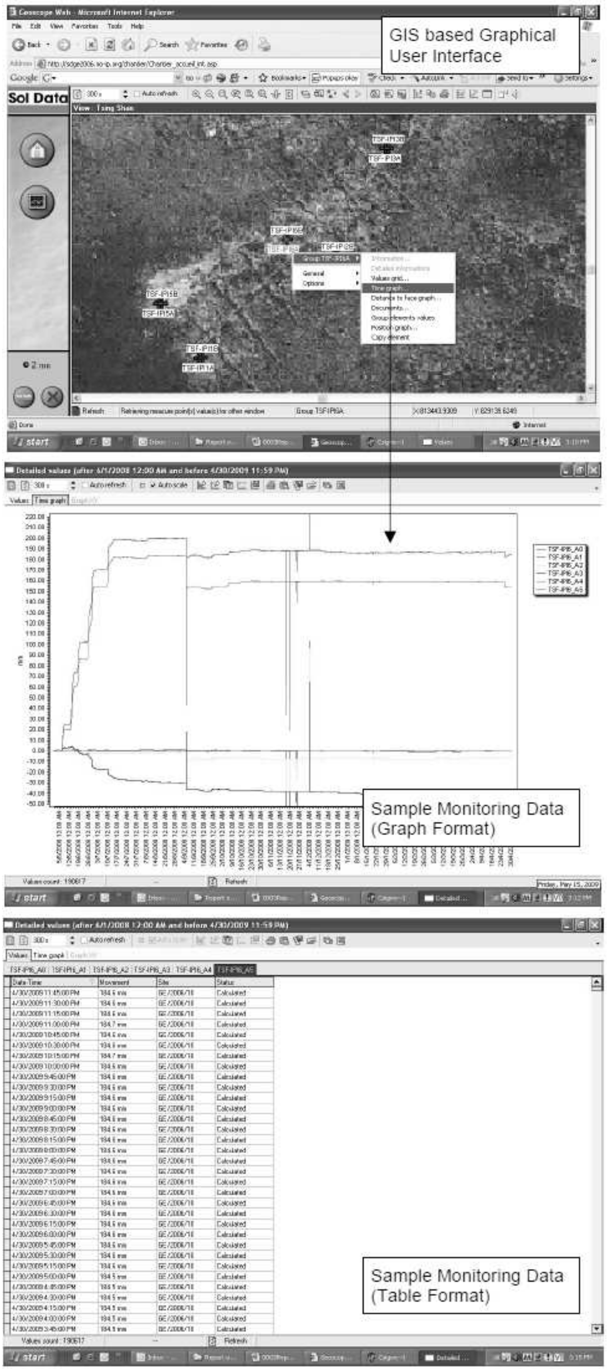


Figure 20. Screenshots of the Graphical User-Interface

7.4 *Data Export and Report Generation*

Whilst an internet accessible user-interface has obvious advantages in terms of data accessibility, there is typically still a need for hard copies of factual reports of the monitoring results to be produced. For this reason, the system developed on this Project allows 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.

8 FUTURE WORK

Monitoring of the instruments discussed in this paper will be on-going until December 2010. This will yield over 30-months of monitoring data, including three 'wet-seasons', upon which detailed assessments of instrument effectiveness can be made.

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REFERENCES

Anderson. M.G. 1984. Prediction of Soil Suction for Slopes in Hong Kong. GCO Publication No. 1/84, Geotechnical Engineering Office of the Government of the Hong Kong Special Administrative Region (China).

Ding X.L, Huang D.F, Yin J.H, Chen Y.Q, Lau C.K, Yang Y.W, Sun Y.R, Chen W, He X.F, 2002. Development and Field Testing of a Multi-Antenna GPS System for Deformation Monitoring. http://gps.hhu.edu.cn/jcxt1.files/8.pdf

Dunnicliff J. 1988. Geotechnical Instrumentation for Monitoring Field Performance. John Wiley & Sons, New York (USA).

Geotechnical Engineering Office. 1984. Geotechnical Manual for Slopes. Geotechnical Engineering Office of the Government of the Hong Kong Special Administrative Region (China).

Geotechnical Engineering Office. 2004. Information Note 12/2004: Instrumental Monitoring of Slopes. Civil Engineering & Development Department of the Government of the Hong Kong Special Administrative Region (China).

Ho K.K.S, Lau J.W.C. 2007. Learning from Slope Failures to Enhance Landslide Risk Management. Pre-prints of Papers from Conf. on Engineering Geology in Geotechnical Risk Management, Hong Kong (China), 45-83.

Kane W.F. 2000. Monitoring Slope Movement with Time Domain Reflectometry. Presented at: Geotechnical Field Instrumentation: Applications for Engineers and Geologists, Seattle (USA).

Lau, K.K.W., Sun, H.W., Millis, S.W., Chan, E.K.K. & Ho, A.N.L. (2008). Application of Innovative Monitoring Techniques at Four Selected Natural Hillsides in Hong Kong. Proc. HKIE GD Annual Seminar on Application of Innovative Technologies in Geotechnical Works.

Lumb. P. 1962. Effects of Rainstorms on Slope Stability. Proc., Symposium on Hong Kong Soils, Hong Kong (China), 73-87.

Millis, S.W., Ho, A.N.L., Chan, E.K.K., Lau, K.K.W. & Sun, H.W., (2008). Engineering Geological Assessment and Real Time Monitoring of a Large Slow Moving Landslide at Tsing Shan, Hong Kong. Proc. International Slopes Conference Malaysia 2008, Kuala Lumpur, Malaysia.

Parry. S. Campbell. S.D.G. 2003. A Large Scale Very Slow Moving Natural Terrain Landslide in the Leung King Valley. GEO Geological Report GR2/2003. Geotechnical Engineering Office of the Government of the Hong Kong Special Administrative Region (China).

Shoup D. 1992. Protecting Geotechnical Sensors and Cable from Lightning Damage. Sensors in the Real World. Slope Indicator (USA).

Wong H.N. 2006. Evolution of Slope Engineering Practice and Landslide Risk Management in Hong Kong. Proc. of the International Conference Slopes, Kuala Lumpur, (Malaysia).

Wong H.N. Ho K.K.S. Sun H.W., 2006. The Role of Instrumentation in Landslide Risk Management: Hong Kong Experience. Proc. of the Conference on Landslide, Sinkhole, Structure Failure: Myth or Science, Ipoh, (Malaysia).