Remote instrumentation of Itanhanga Hill

J A R Ortigao[1], R d'Orsi[2], H Brito[2], C Szendrodi[3] & A C Lobo[3]

2nd PSL Pan Am Symposium on Landslides

Rio de Janeiro
1997

[1] Terratek Ltd

Av Pres Wilson 165 / 321
20030-020 Rio de Janeiro, Brazil
tel +55-21-8218 8315
fax +55-21-2533 2077
ortigao@terratek.com.br

www.terratek.com.br

[2] GeoRio, Rio de Janeiro

[3] Insitutek Ltda, Rio de Janeiro

ABSTRACT: The Itanhanga Hill slope has a record of accidents during severe rainfall that stroke the City of Rio de Janeiro in 1967, 1988 and 1992. In these occasions, mass movements occurred and caused severe damage to three houses, pavements and walls. A partial study was, then, carried out by the Government, and further studies were suggested. Following these recommendations, the City Government Geotechnical Office (Geo-Rio) responsible for slopes carried out since 1996 a comprehensive study on the problem. It consisted of site investigation and the deployment of remote instrumentation to obtain data on the mass behaviour, especially during rainfall. Site investigation consisted of detailed surveying, geological investigation, surface mapping, geophysical investigation and boreholes. The instrumentation consisted of three instrumented stations with automatic inclinometers, piezometers. All three stations send the data via radio to a master station located at the site. The Main Station is connected through a dedicated telephone line to the central computerised station at Geo-Rio headquarters. This paper describes the studies carried out so far, the instrumentation system and preliminary results.

RESUMO: A encosta do Itanhagá sofreu movimentos durante chuvas fortes que caíram sobre o Rio de Janeiro em 1967, 88 e 92, com danos a várias casas, pavimentos e muros. Um estudo parcial foi realizado pela Geo-Rio logo após aquelas chuvas. Em 1996, os estudos foram retomados e consistiram em investigações geotécnicas, instalação de instrumentação remota para obtenção de informações sobre o comportamento da encosta durante chuvas. As investigações consistiram em topografia detalhada, mapeamento geológico, geofísica e sondagens. A instrumentação constou de três estações com leitura automática de inclinômetros e piezômetros. As estações enviam os dados através de rádio para uma estação concentradora no local, que por sua, vez envia todos os registros via modem e linha privada telefônica para a Estação Central localizada na Geo-Rio. Este artigo descreve os estudos realizados até o momento, a instrumentação e os resultados preliminares.

INTRODUCTION

The Itanhanga Hill slope, in South Rio de Janeiro, is a nice area, occupied by high quality houses. The first record of mass movements occurred in 1967 when severe rainfalls stroke Rio de Janeiro.

In the early seventies, the Geotechnical Institute of Rio de Janeiro, today’s Geo-Rio, carried out the first studies in the area comprising a few boreholes and the installation of two inclinometer tubes. Field monitoring took place for two years, until the mass movements ceased.

In 1992, once again heavy rains caused mass movements and cracks in several houses and damaged walls on the Itanhanga Hill. Another site inspection was carried out, leading to recommendations of further and a comprehensive study. Therefore, in 1996-97,

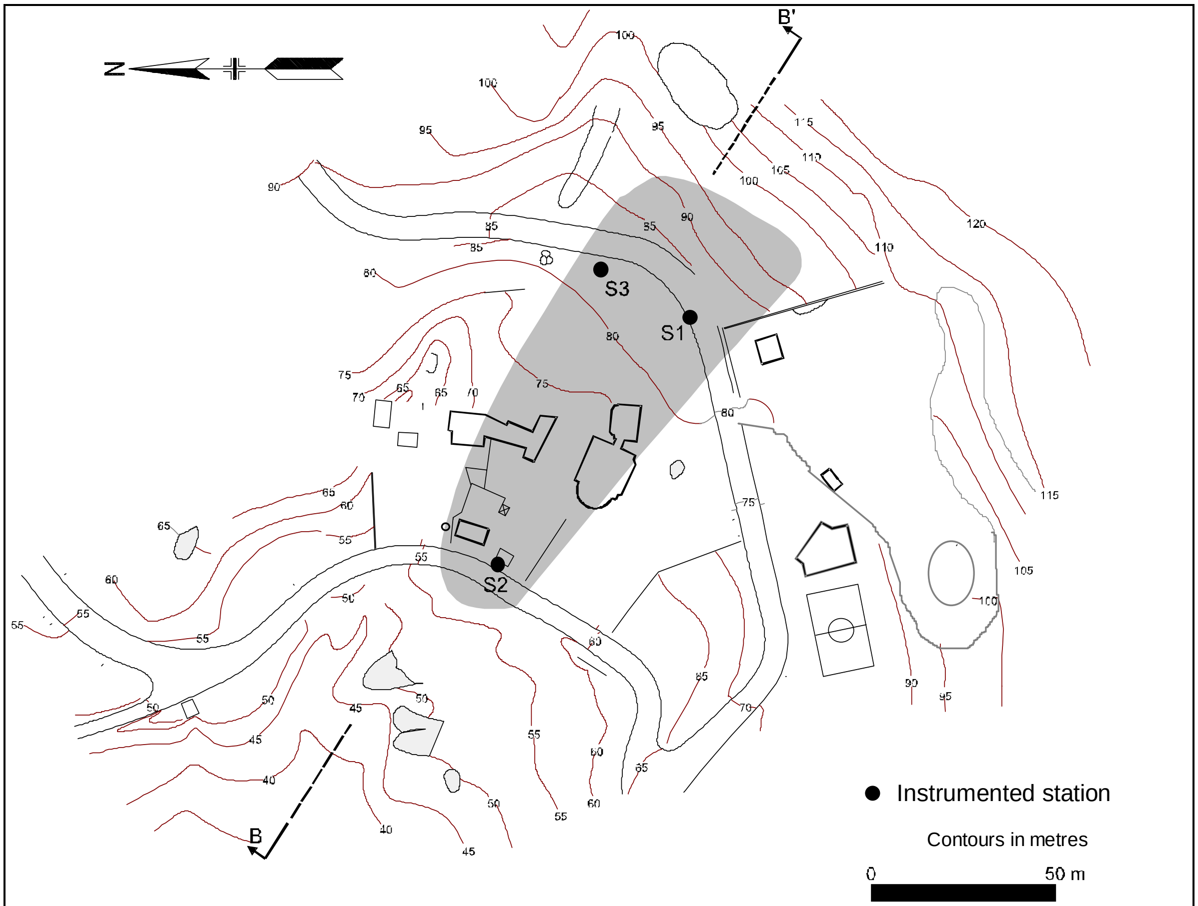

Figure 1 Itanhanga Hill slope map

the following investigations were conducted: geophysical and topographic surveys, geological photo interpretation and field surface mapping, boreholes and automated field instrumentation.

This paper gives a brief description of the results already achieved and the on going site automatic monitoring results.

Geology and soil profile

The works on the Itanhanga Hill were resumed in May 1996. Detailed surveying and mapping in the 1:500 scale and geological interpretation was carried out and a summary of the results is presented in Figure 1. The shadowed area in this figure corresponds to the zone affected by slope movements, as a results of plotting the damages to constructions, walls, tilting of trees and poles and pavements. The results of the site investigation and the boreholes are summarised in the cross section presented in Figure 2.

The region has a characteristic geology of the Serra do Mar gneisses. The rock steep scarp is intercepted by soils at the elevation 110 m (Figure 2) which present a low inclination averaging 15 degrees. The main lithology consists of biotite quartz microcline augen gneiss. The foliation is wrapped around the relative large eye-shaped feldspars in stream-line fashion and aligned in the NW-SE direction, dipping at 20 to 35 degrees NE. The exposed rock is sound to poorly weathered and presents few sub-vertical joints.

The damages caused by mass movements consisted of misalignment of kerbs, electricity poles and trees and wall and floor cracks, which were detailed recorded in resulting map. They seem to be aligned, as indicated in Figure 1, indicating a tongue of mass movements.

The soil profile in Figure 2 shows a gentle slope with a inclination averaging 15 degrees, with several man-made plateaux and light constructions of one to two-story houses. Descending from the rock scarp, the rock has

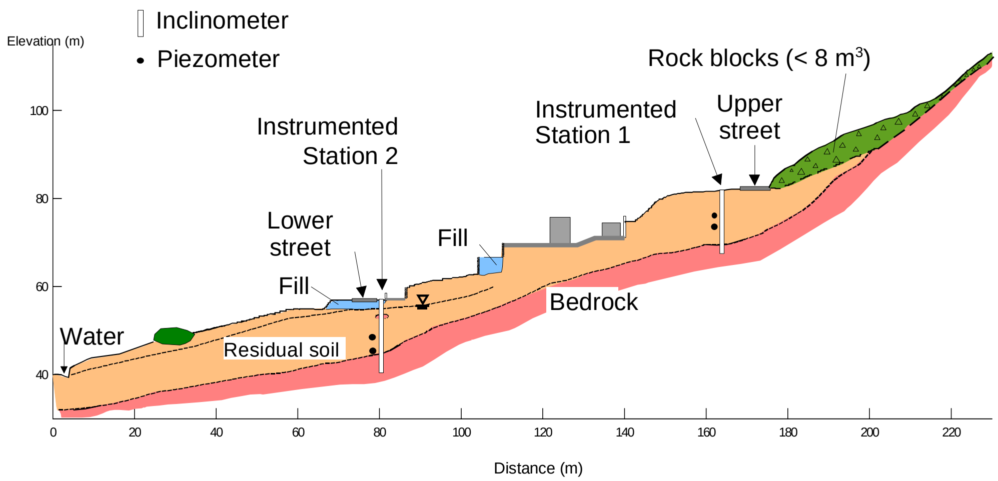

Figure 2 Cross section BB'

been toppled with a layer of colluvium that also extends on the residual soil, reaching the Upper Road (Rua Engenheiro Pires do Rio).

Initial investigation led to preliminary conclusion that the movements occurred in the colluvium. Further investigations have shown that the residual soil is up to 10 m deep and very little or no colluvium. Therefore the movements might have occurred in the residual soil layer.

The fill or colluvium layer is thin and in the order of 1 m deep only. The residual soils are up to 10 m thick and very dense, reaching SPT *N* values of over 30, overlying fractured rock. The boreholes indicated the presence of corestones surrounded by soil.

Rock blocks with volumes ranging from 1 to 8 m^3 can be spotted on the colluvium.

The water level at the time of the site investigation was around 3 m below the ground level at the lower part of the slope, but it was not found at the upper part of the slope. Residents in the area informed that a well close to the Lower Street overflows after severe and long duration rainfall periods.

STABILITY ANALYSES

Preliminary stability analyses of the Itanhanga Hill slope were carried out in order to assess if the observed instability could be simulated with estimated high pore water pressures and evaluated soil parameters. At this stage, since no laboratory testing has been carried out, the angle of friction of the soil was taken in the range 28 to 30 degrees and the effective cohesion, from 5 to 10 kPa. The soil unit weight was taken as 18 kN/m^3.

Table 1 Stability analyses

Run	Slip surface	Method	Phreatic line	c'	ϕ'	FS
				kPa	deg	
Itnhga1	circle	B	observed	10	30	2.110
Itnhga2	circle	B	max	10	30	1.515
Itnhga3	circle	B	max	5	28	1.226
Itnhga4	polygon	J corrected	max	5	28	1.144
Itnhga5	polygon	J corrected	max	5	28	1.217
Itnhga6	polygon	J corrected	observed	5	28	1.856
Itnhga7	polygon	J corrected	observed	5	28	1.979

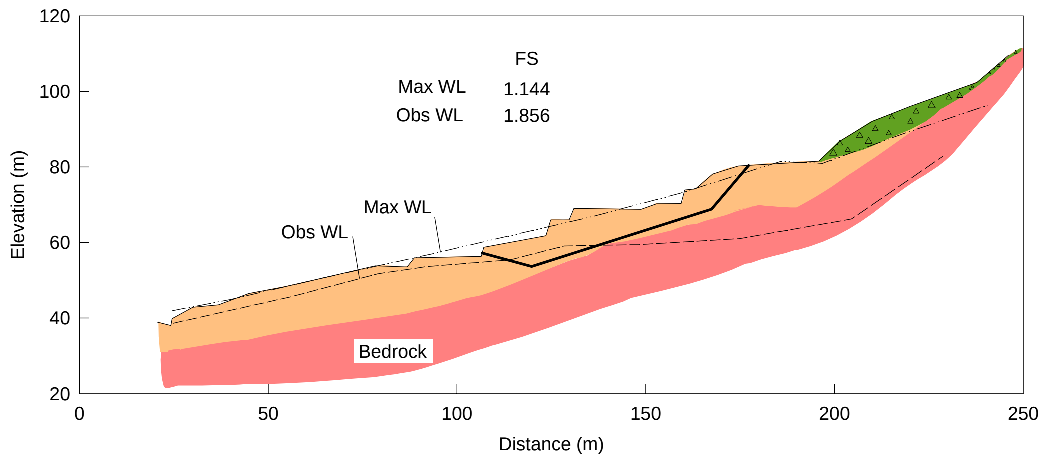

Figure 3 Results from the stability analyses

The analyses were carried out with Bishop and Janbu (corrected) methods of analysis using Rstabl computer program (Ortigao et al, 1995). Circular and polygonal slip surfaces were tried.

Two phreatic lines were considered, one based on observed water levels in the dry season and another estimated probable maximum values that may occur in the wet season.

A summary of the results and the calculated factor of safety (FS) is given in Table 1. The critical slip surface for estimated maximum pore pressures at the rainy season is shown in Figure 3. The resulting FS was low as 1.144, which may explain the cause of the problem.

INSTRUMENTATION

The automated instrumentation designed for the Itanhanga Hill consisted of piezometers, inclinometers and surface marks, of the type already used by Ortigao et al (1994). The instruments were deployed in three stations, as indicated in Figure 1. Each station comprised two piezometers and one inclinometer tube. The surface marks will be installed yet in 1997 and will not be discussed here. The measurements at the Itanhanga Hill are related to rainfall through an automated raingauge installed nearby and discussed by d'Orsi et al (1997) in another paper to this conference.

Piezometers

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

Piezometer

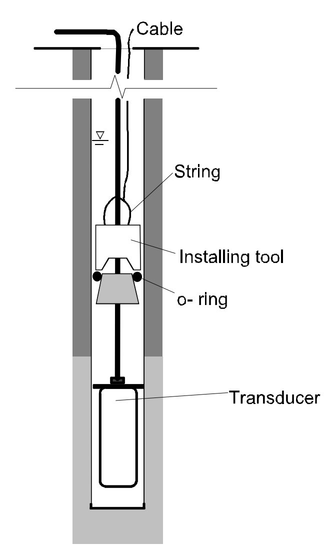

Figure 4 Piezometer

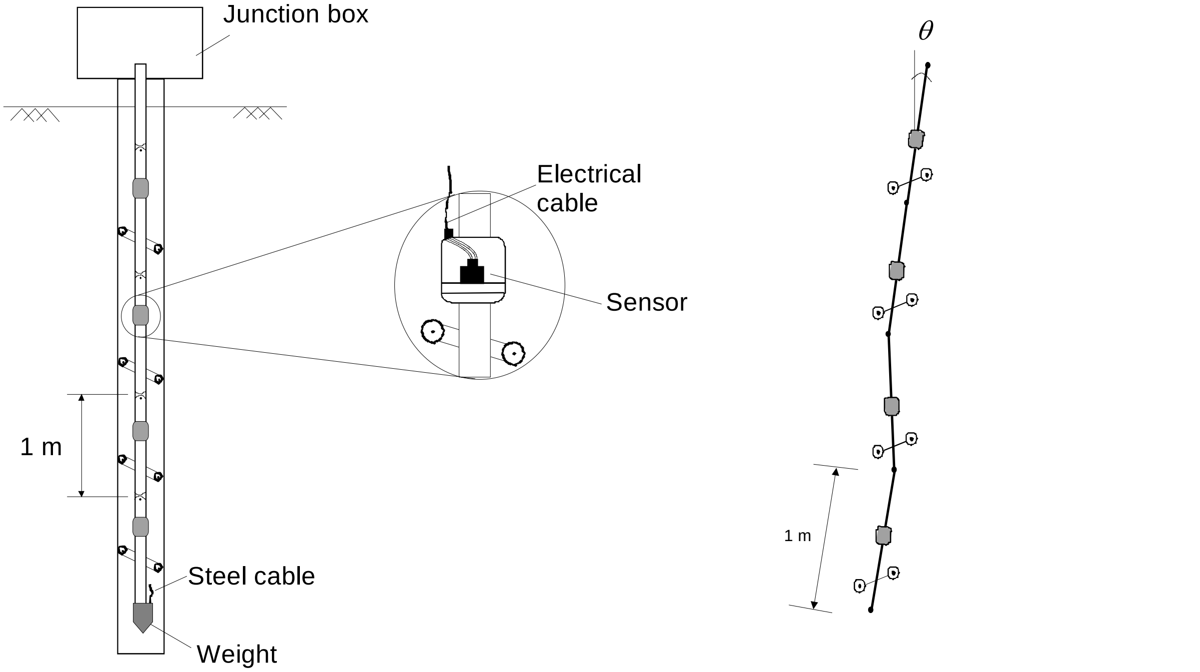

Figure 5 Cliper*: permanent inclinometer*

checking.

A mechanical cone packer, also shown in Figure 4, 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.

The Cliper

The *Clipe*r (*Permanent Inclinometer*), described in Figure 5, has the function of continuously detecting underground movements. It consists of a train of very accurate tiltmeters installed in a conventional inclinometer access tube. The tiltmeters are liquid level gauges used for more than three decades in the aeronautics and military industry, but only recently have found applications in geotechnical instrumentation (eg, Ortigao et al, 1993, Campanella et al, 1994). The principle of operation is described in Figure 5

The tilt gauges are tiny glass phials containing an electrolytic liquid and 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. The tilt gauges employed in the Cliper are of a new generation ceramic gauges with much higher accuracy, of the order of a few seconds of arc and long term stability.

They produce a square wave with an amplitude of ± 5 V and a frequency of 1 kHz, which can be conditioned to ± 0-10 V DC signal, appropriate for hooking up to the data acquisition system.

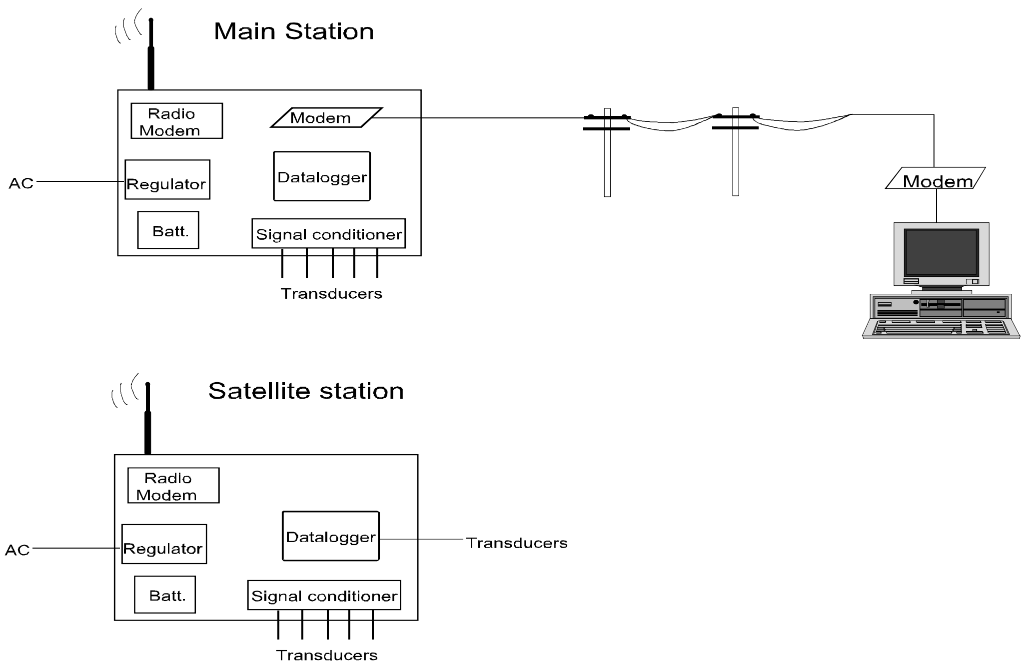

Figure 6 The data acquisition system at the Itanhanga Hill.

The gauges are placed in appropriate plastic housings, 40 mm OD, and connected to 1 m long, 20 mm OD, plastic PVC tubes containing spring-loaded and self-aligning inclinometer wheels. These wheels keep the instrumented centred in the inclinometer tube and aligned along selected appropriate movement axis.

The deepest Cliper element is connected to a safety 1 mm OD galvanised steel cable, to be used to retrieve the instruments for checking and calibration.

DATA ACQUISITION

The data acquisition system on the Itanhanga Hill slope is completely automated. The system comprises a Main Station at the slope and two Satellite Stations (Figure 6).

The dedicated data acquisition board has a central processing unit (CPU) with an internal clock running at 12 MHz and 12 bit analogue-digital (AD) converter. It comprises a 32 kbyte E2PROM and 32 kbyte RAM. The processor is an Intel 87C51FB with internal EPROM of 16 kbytes and internal watch-dog system that automatically checks the system at time intervals of 65 ms and if any fault occurs, it resets the CPU. This board has eight 4-20 mA channels or up to ten 10 V channels.

The data received at the Satellite Stations are transmitted to the Main Station on site via an analogue modem-radio UHF set operating at the frequency of 453.1 MHz with a transmission rate of 1200 baud/s. The Main station sends the data via modem and telephone lines to the Central Station located at Geo-Rio headquarters.

Each station is powered from main supply, but in case of electricity shut-down, it has a 12 V battery and a battery charger capable of running the system for more than a week.

The data acquisition system has the following protections. The physical protection comprises a all-weather sealed steel housing for the electronics. The electric surge protection comprises appropriate grounding and the AD channels are protected by a sequence of metallic oxide varistors that short-circuit to the ground when the voltage exceeds 11 VDC.

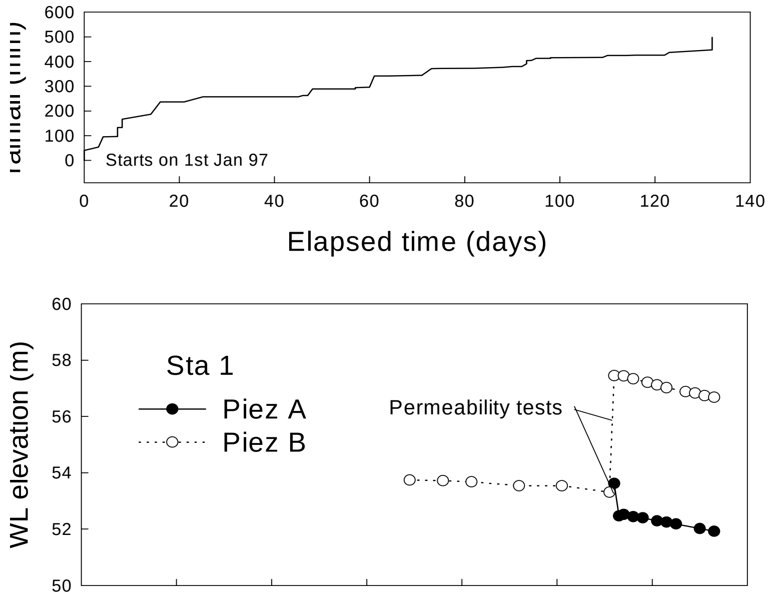

Figure 7 *(a) Rainfall, water level and (b) permeability tests*

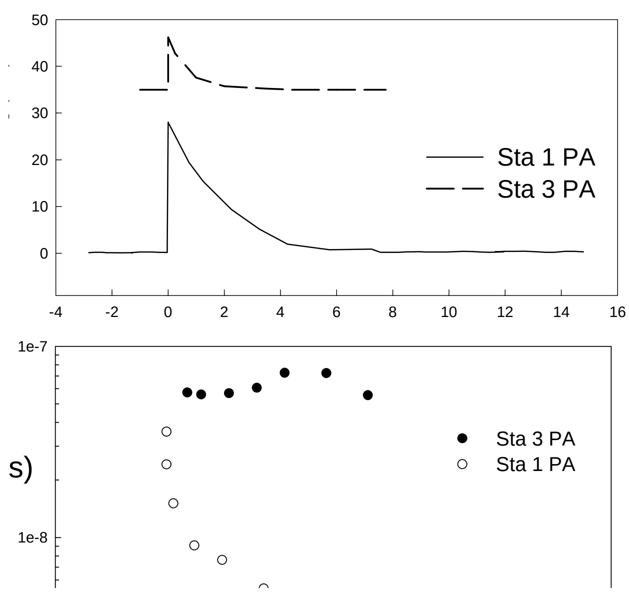

Figure 8 In situ permeability tests through the piezometers

PRELIMINARY RESULTS

Only a limited amount of data were obtained since the data acquisition system was installed in February 1997. No main rain-induced event or displacements were recorded up to the current time (May 1997). Figure 7a presents accumulated precipitation from 1st of January until 15th of May and Figure 7b shows water level records in two piezometers of Station 1 (Lower Street) from the start of measurements. A few days after data recording started, the water level in the piezometer access tubes was raised by filling it up with water, as showed in this figure, in order to evaluate the soil permeability around the porous tip, also as a test to instrument itself. After dissipation of the test excess porepressure, the reading in piezometer *A* seem to be decreasing due to lack of rainfall in the last month. Piezometer *B* did not dissipate rapidly, but at the same rate as in instrument *A*.

The results of a few permeability tests were plotted in Figure 8a. Permeability values are indicated in Figure 8b, they were calculated through standard procedures given elsewhere (*e.g.*, Ortigao, 1995).

The measurements on this slope will continue for a long period.

CONCLUSIONS

The geotechnical studies carried out at the Itanhanga Hill slope indicated that the estimated rise of porewater pressures during severe rainstorms can decrease the safety factor to a value close to one and trigger mass movements.

The automatic instrumentation is part of a comprehensive automated system which development was supported by Geo-Rio since 1991 (Ortigao et al, 1994). The piezometer packing device was redesigned. The Cliper has many developments since its first units. Electrical surge protection has been considerably upgraded and expected to perform better than its previous versions. An electronic system of surface marks to measure horizontal movements is under final development and its expected to be deployed in 1997.

The measurements and studies described here will continue for at least four years.

An additional site investigation is planned and will include sampling and laboratory tests.

ACKNOWLEDGEMENTS

The first author finalised this paper while at City University of Hong Kong, as Visiting Fellow to the Department of Building and Construction.

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