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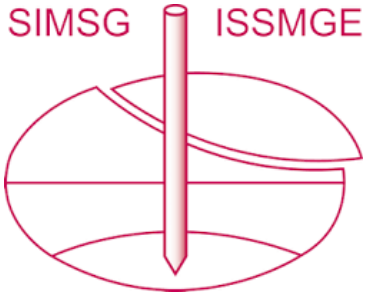

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Slide interacting with a buried pipeline in southern Brazil

Glissez agir l'un sur l'autre avec une canalisation enterrée au Brésil méridional

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ABSTRACT
Serra do Mar is a narrow mountain range along the South and Southeastern coast of Brazil. Mass movements of colluvium have been analysed since the 1940s by several authors. The slope discussed in this paper is located in the State of Paraná, South Brazil, where a buried pipeline was severely damaged due to the movement of a colluvium. The displacements were monitored using inclinometer, along with piezometers and a pluviometer. Deep sub-horizontal drains, which reduced the velocity of the movement, were installed to stabilize the slope. The paper illustrates the behaviour of such masses, and the use of deep horizontal drains as an efficient stabilization measure.

RÉSUMÉ
Serra do Mar est une gamme étroite de montagne le long du sud et de la côte du sud-est du Brésil.Des mouvements de masse se produisant sur des pentes ont été analysés depuis les années 40 par plusieurs auteurs.La pente discutée en cet article est située dans l'état de Paraná, Brésil du sud, où une canalisation enterrée était due sévèrement endommagé au mouvement de la pente. Les déplacements ont été surveillés en utilisant l'inclinomètre, et les mesures de piezometer et de pluviomètre prises.Des drains profondément secondaire-horizontaux, qui ont réduit la vitesse du mouvement, ont été installés pour stabiliser la pente.

1 INTRODUCTION

In Brazil, oil, gas and their by-products are carried through underground pipelines, over long distances and crossing a wide variety of geomorphologic units. These structures undergo every process involving foundation ground. Due to their length, some stretches cross geologically unstable areas which may jeopardize its integrity (Soares & Musman, 2001).

Soil creep is common in colluvial deposits. Very often it is imperceptible, since it causes no great damage. In underground rectilinear structures, such as pipelines, when crossing areas where this kind of movement occurs, they undergo stresses that may cause serious damage. This paper discusses a case where a 93 km oil pipeline, buried at an average depth of 3.5 m, and that was severely damaged by the movement of the slope, causing its rupture.

The slope is being monitored since June 2000 by means of inclinometers, piezometers and a pluviometer. Recently, a real-time monitoring system was installed on the slope and in the pipeline. Displacement speeds of up to 1.4 cm/day and artesianism in one of the piezometers were noted, before undertaking works to stabilize the slope, which consisted of surface and deep sub-horizontal drains. The slope movements are accelerated according to the oscillations of the piezometric level, relating to local heavy rainfall (annual average over 1800 mm) and other hydrogeologic contributions.

The steps taken to stabilize the slope have been efficient, reducing the movements measured in the inclinometers.

This paper discusses the development of slope movements, relating them with pluviometry and piezometry, as well as empirical correlations between displacements, displacement speeds and pluviometry.

2 GEOLOGICAL SETTING

The slope is located in the State of Paraná, in the Serra do Mar range, with presents a predominance of gneisses and granites, with varying degrees of resistance to weathering, crossed by fault systems and regional fractures cutting the formations, and creating a profile of alteration characterized by a layer of saprolitic soil under thick deposits of transported soil (Nunes, 2000).

The mountainous relief generally presents rocky outcrops at higher elevations. The presence of boulders and blocks of rock of various sizes, originating from slides and successive falling of the slopes, amidst a silt, sandy colluvial matrix, can be seen along the river beds, talus deposits, foothills and valley bottoms.

The colluvial soils are clayey-sandy, with a large quantity of angular quartz and feldspar fragments. They are found in heterogeneous deposits, with variable horizontal and vertical permeability. There is the possibility of more severe deformations during periods of heavy rainfall.

The slopes of the Serra do Mar are steep and together with the local heavy rainfall contribute to form a deep weathering profile. The annual rainfall can be over 1,800 mm. In this environment, the soils undergo processes of surface slides or deep slides in talus-colluvial deposits, generally as a soil creep.

3 SLOPE CHARACTERISTICS

The geotechnical profile in this site consists of a colluvial soil deposit made up of saturated silty clay, with the presence of boulders, varying in thickness from 11 m to 21 m, overlying a layer of residual soil consisting of sandy silt, with a thickness of 5 m to 7 m over altered migmatite rock.

The topography map is showed in Figure 1 and the cross-section of the slope presented in Figure 2 consists of a colluvial layer with N_{SPT} between 3 and 10, varying in colour; just below, a young residual soil (saprolitic soil), with N_{SPT} over 10 and increasing with depth, and then altered migmatite. The average slope is 13º. The horizontal displacements of inclinometers 1, 4 and 5 before pipeline rupture are showed in the Figure 2.

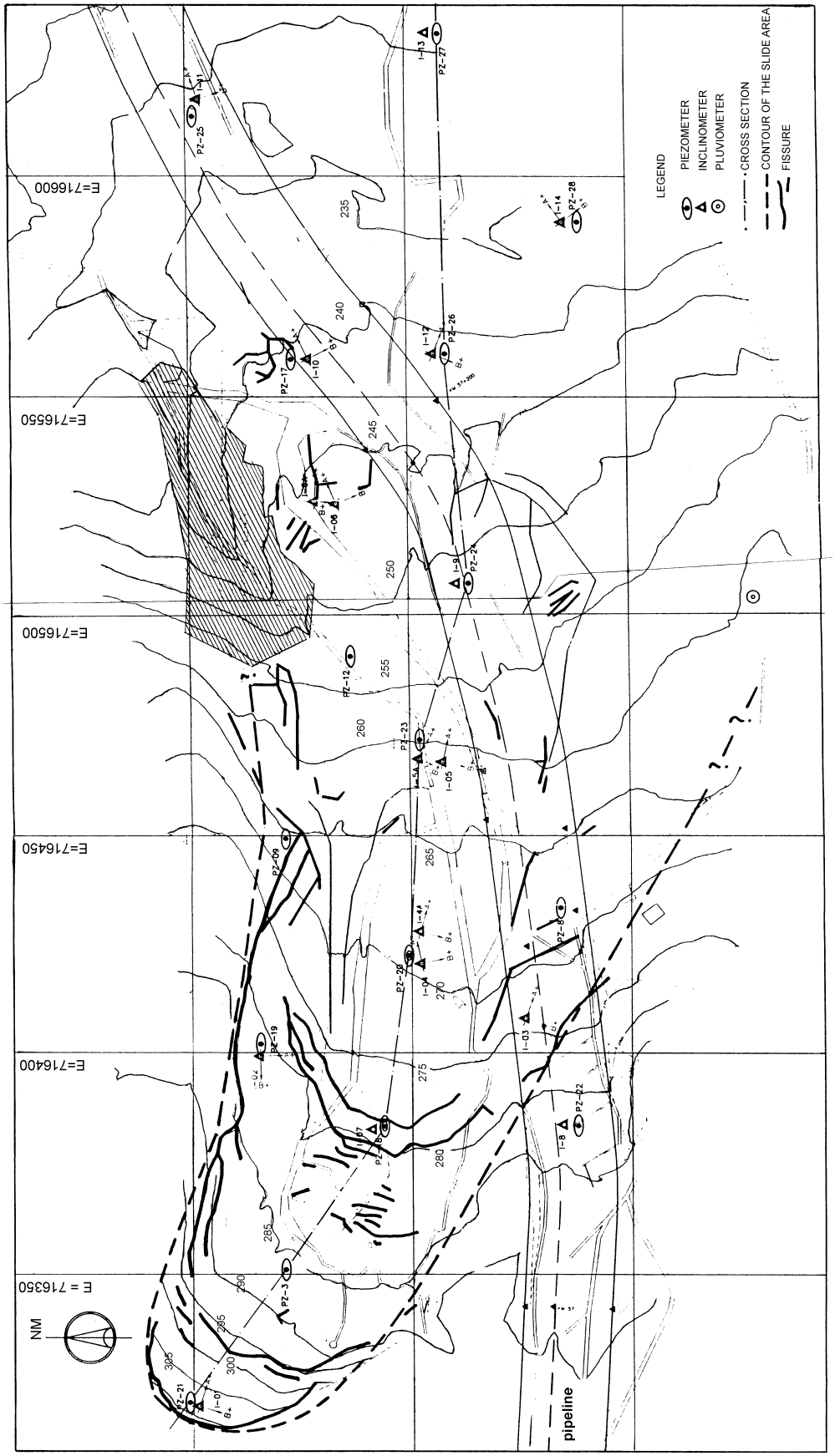

Figure 1 - Topography map

4 INSTRUMENTATION

The instrumentation for monitoring the slope movements consisted at first of six inclinometers, 12 piezometers and one pluviometer. The region has heavy rainfall, especially in January and February.

The Casagrande standpipe piezometers were installed in boreholes. The position of some inclinometers and piezometers can be seen in Figure 2. Piezometers PZD-18 and PZD-20 are double, so that one bulb is installed in colluvial soil, and the other in residual soil. The readings were begun in September 2000, and piezometer PZ-3 showed artesianism, evidenced by the outpour of water from the piezometer top.

The inclinometers were installed in May 2000 and the first readings made in October that same year. Inclinometer I-01 showed a displacement of 17 mm at a depth of 5 m, indicating movement of the colluvium. In inclinometer I-04 and I-05, the displacements were 25 mm and 20 mm respectively, and could not be used later due to severe deformations of the reading pipes due to the large movements that led to the rupture of the pipe. They were later substituted. Inclinometer I-06 showed displacements of 180 mm in February 2001. The position of inclinometer 6 is presented in the Figure 1, but it isn't in cross section of Figure 2.

The planned slope stabilization works were not completed, only the surface drainage had been done, when in February 2001, after a period of heavy rainfall, the movement of the slope accelerated, causing increased stress on the pipeline, until its rupture. Part of the pipe remained in a mass of firm soil, and the other accompanied the moved mass.

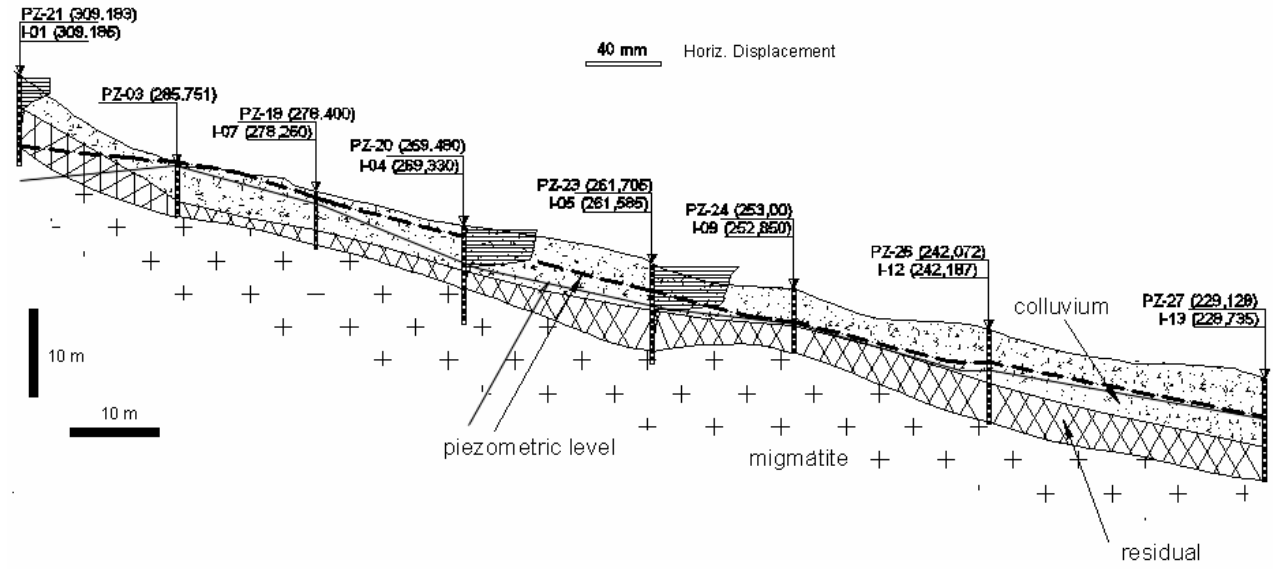

Figure 2 - Cross-section of the slope

Inclinometer I-06 shows a displacement velocity of 12 mm/day just after the rupture, as can be seen in Figures 2 and 3.

The design for stabilizing the slope comprised surface drainage and the installation of long, deep sub-horizontal drains. As a result of the flows of these drains, and piezometer readings, the design had to be uptdated with the installation of new drains to lower the groundwater until the velocity of the movement became very small.

The drains were installed in eight series, each consisting of 3 to 10 drains at different dates and positions. The average drain flow varied between 82 l/h (series A) and 250 l/h (series G). Figure 4 shows the average flows between March and December 2001. On examining the rainfall accumulated during the preceding seven days, and the average flow of all installed sub-horizontal drains (Fig. 5), it is found that there is a good correlation between both variables along time, where it can be seen that the flow of the drains has responded to the regional rainfall.

During the implementation of the stabilization design, another eight inclinometers were installed in order to have a better definition of the extent of the slide surface.

Inclinometer I-07, I-09, I-12 and I-13 (see Fig. 2) were installed after the sub-horizontal drains. The readings of inclinometer I-07 and I-09 did not reveal significant displacements, indicating efficiency in the slope stabilization measures. In July 2001, inclinometers I-12 and I-13 showed displacements. Piezometer PZ-26 installed close to inclinometer I-12 showed no rise in the piezometric level corresponding to the latter displacement, as can be seen in Figure 4. Other factors may contribute to the movement of the slope, and so follow-up of the instrumentation measurements must be ongoing.

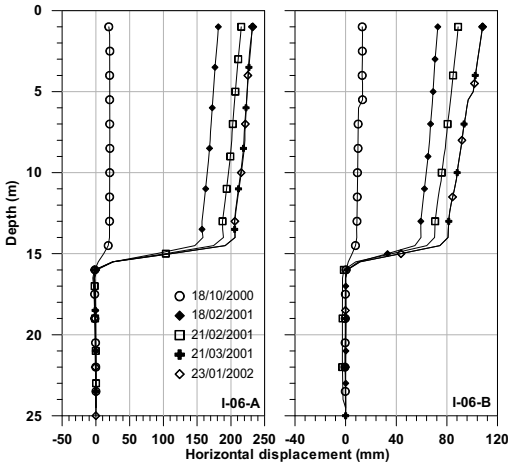

Figure 3 - Inclinometer data – I06

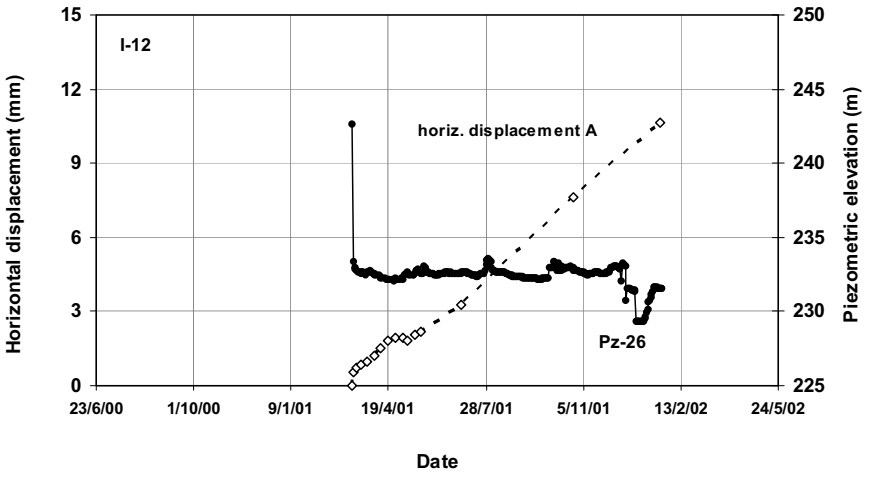

Figure 4 - Horizontal displacement and rate – I06

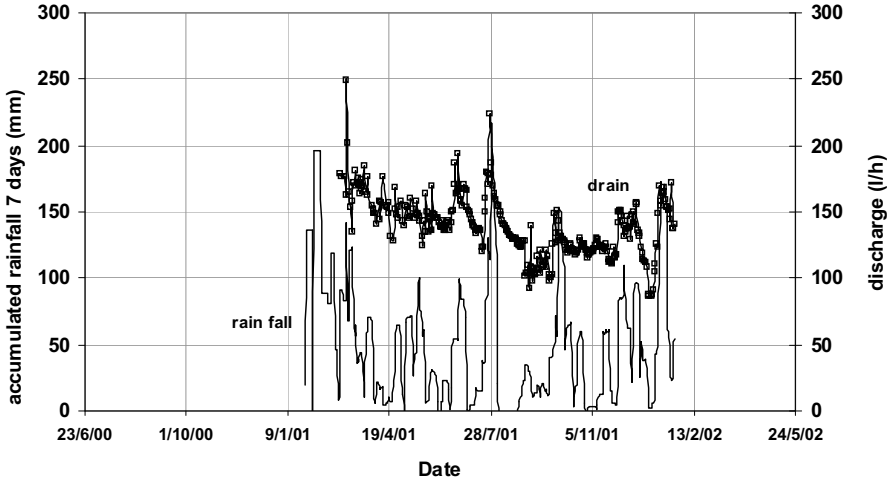

Figure 5 – Accumulated rainfall of 7 days and discharge

5 CONCLUSION

The soil creep mass movements occur imperceptibly in colluvial deposits, since they do not cause major damage. In rectilinear structures underground, such as pipelines, when they cross areas where this kind of movement occurs, they undergo strain that may damage their structural integrity.

This paper describes the case of an oil pipeline, 93 km long buried 3.5 m down, which was severely damaged, due to the movement of the slope, which caused it to rupture.

The region has heavy rainfall, mainly in January and February, one of the factors responsible for the slope's instability. Pluviometer was installed to record local rainfall and helped to interpret the slope movements and water discharge from the drains.

Instrumentation for monitoring the slope has proved adequate, allowing the accompaniment of its behavior of the slope after the stabilizing measures adopted.

The stabilization works included the installation of deep sub-horizontal drains and carrying out surface drainage and reshaping of the surface, which has proven efficient so far. The deep drainage system responds immediately to the occurrence of heavy rainfall, preventing the increase of piezometric levels inside the colluvium. This kind of intervention must be constantly reassessed, and requires an ongoing maintenance program and monitoring to guarantee the efficiency of the system.

ACKNOWLEDGEMENTS

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