Platform for integrated monitoring data management applied to an instrumented slope in southern Brazil

Plataforma para gerenciamento integrado de dados de monitoramento aplicada a um talude instrumentado no sul do Brasil

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ABSTRACT

The monitoring of slopes and geotechnical structures is fundamental for guaranteeing safety and improving the knowledge of soil behavior. This study evaluated the use of a platform for integrated monitoring data management applied to an instrumented slope.

The slope, known as “Morro do Boi”, is located in BR-101 highway, in Santa Catarina state, Brazil. The instrumentation was installed in 2012 during the execution of a stabilization system designed to contain an unstable soil mass, and allows the verification of positive and negative pore pressure, deformations of the soil mass and the precipitation. In addition, the structure, composed by passive anchors and flexible metal mesh, is monitored with crackmeters, strain gages and load cells. Until May 2018, the historical data comprising 6 years of monitoring was automatically registered by a datalogger hourly, with manual download. On June 2018, the remote dispatch of the data was implemented and the management of this information is done through a web-based platform. This tool has been extremely useful for the ease of visualization, data management and logistical efficiency, allowing the creation of a rapid alert system in cases of variation of some parameters that could trigger landslide.

Keywords: geotechnical monitoring, field instrumentation, data management.

RESUMO

A monitorização de declives e estruturas geotécnicas é fundamental para garantir a segurança e melhorar o conhecimento do comportamento do solo. Este estudo avaliou a utilização de uma plataforma para a gestão integrada da monitorização da-ta aplicada a um talude instrumentado. O talude, conhecido como "Mor-ro do Boi", está localizado na BR-101, no estado de Santa Catarina, Brasil. A instrumentação foi instalada em 2012 durante a execução de um sistema de estabilização concebido para conter uma massa de solo instável, e permite a veri-ficação da pressão positiva e negativa dos poros, as deformações da massa do solo e a precipitação. Além disso, a estrutura, composta por ancores passivos e malha metálica flexível, é monitorizada com fissómetros, strain gages e células de carga. Até Maio de 2018, os dados históricos, compreendendo 6 anos de monitorização, eram automaticamente registados por um registador de dados de hora a hora, com descarga manual. Em Junho de 2018, o envio remoto dos dados foi implementado e a gestão desta informação é feita através de um formulário de placa baseado na web. Esta ferramenta tem sido extremamente útil para a facilidade de visualização, gestão de dados e eficiência logística, permitindo a criação de um sistema de alerta rápido em casos de variação de alguns parâmetros que poderiam desencadear deslizamentos de terras.

Palavras-chave: monitorização geotécnica, instrumentação de campo, gestão de dados.

1 INTRODUCTION

Every construction involving soil or rocks are subject to encountering surprises, circumstance inevitable when working with materials created by nature, of which the knowledge about is intrinsically lower than that available for man-made structures. When affect a highway, a soil or rock movement can cause dramatic effects, both from the safety and economic point of view [6]. Therefore, to reveal unknowns and to reduce uncertainty inherent in geotechnical engineering, monitoring structural health before, during and after construction is fundamental. Besides, from a quality management perspective, monitoring is a critical part of the quality control and improvement process [3,10].

Dunnicliff [3] suggested 20 steps for planning a monitoring program. Step 18, to plan data collection, processing, presentation and interpretation, is the key to a successful result, since a large amount of data means nothing if it is not accurately analyzed and in a reasonable time. According to Mazzanti [6], the multi-temporal measurement of a parameter differentiates “measure” from “monitoring”. The remote monitoring system became a facility in the management of the data and is now used in many geotechnical constructions [1,4,5, 7, 10], allowing to obtain the important information reflecting the structural state of the project, which can help the engineers to evaluate the overall performance and accumulate experiences for similar projects in the future [5]. The conventional methods to acquire data require a number of field visits, involving costs. Although automatic online systems are expensive, they are more useful in high-risk areas [1].

This study aims to present the instrumentation plan and the monitoring system used in a densely instrumented slope in Brazil. The use of a web-based platform for data management allowed an easy and integrated visualization of the instrumentation records, besides the creation of an alert system for specific parameters.

2 SITE DESCRIPTION

The study is focused in a slope located in Santa Catarina state, Brazil, between the cities of Balneário Camboriú and Itapema, in km 140 + 700 of BR-101 highway (Fig. 1). The area presents historical records of soil movements with accumulation of debris in the highway, impeding the passage of traffic; in particular, one occurred in November 2008 after a heavy rainfall [9].

Fig. 1 Study area location.

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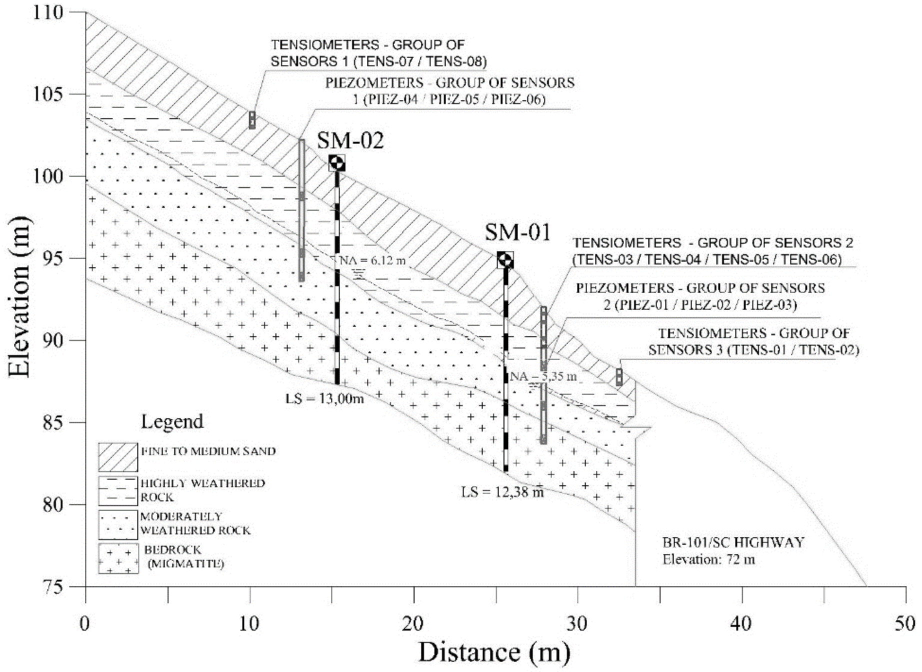
The authors.

The slope has inclinations between 1.0V:1.5H and 1.0V:2.0H and is at an elevation of 160 m above the sea level. In order to obtain more detailed information about the stratigraphy, two boreholes were carried out at the site, with interruption at 3 m bellow the bedrock (Fig. 2). It was defined that the slope is composed mostly by colluvial soil, composed by fine to medium sand, with thickness up to 3 m, high weathered rock with thickness between 2 and 3 m and moderated weathered rock with thickness between 3 and 4 m. Colluvial soils are heterogeneous, with a high degree of weathering and cohesion extremely low to null. Due to these characteristics, the area presents high susceptibility to shallow landslides.

Fig.2. Geological and geotechnical profile.



Sestrem *et al*. [9]

The geological structure is composed by two types of rocks: intrusive Nova Trento granites and Morro do Boi migmatites, which are affected by NE-SW and NW-SE shear surfaces and characterized by containing sub-horizontal fractures [9]. These characteristics facilitate water flow, maintaining the water level deep.

After the occurrence of several landslides due to heavy rainfall records in November 2008, the unstable soil mass was stabilized in its remaining position. The solution chosen was a passive anchor system combined with a flexible metal mesh. The purpose of the flexible metal mesh is to control the soil deformation and redistribute the solicitations to the anchor system. The structure has a fixing plate connecting the metal mesh and the passive anchors, avoiding puncture.

In order to monitor the structural performance of the stabilization system and to increase knowledge about geotechnical conditions and their influence on triggering landslides, an instrumentation plan was conceived. The instrumentation plan provides information about geotechnical, hydrological and environmental aspects, deformations of the soil mass and structural performance.

For the geotechnical and hydrological monitoring, the following instruments were used: 6 vibrating wire piezometers installed in depths between 3.90 and 8.65 m, to monitor positive pore pressure and water table; 8 conventional tensiometers with pressure transducer installed in depths between 0.50 and 3.00 m, to monitor soil suction and 2 conventional inclinometers, to monitor deformations of the soil mass.

The installation depths of the piezometers were chosen in order to monitor the high weathered rock layer, the interface between the layers of the high weathered rock and moderated weathered rock and in the interface between the moderated weathered rock layer and the bedrock. As mentioned, the water level is deep, around 5 and 6 meters from the surface, close to the interface between high weathered rock and moderated weathered rock layers and due to the fracturing of the layers bellow it, its depth does not tend to increase. Therefore, the shear resistance of the soil in the region is mainly controlled by the matric suction. To monitor soil suction in the shallow soil, the tensiometers were installed in the colluvial layer [8].

Regarding to the environmental aspects, the instrumentation plan provided the monitoring of rainfall with the use of a rain gauge able to register precipitation each 0.20 mm. Since rainfall is one of the greatest triggers of shallow landslides, specially in colluvial soils, its records are fundamental in the monitoring plan.

The stabilization system was monitored for the purpose of guaranteeing the safety of the structure and understanding soil-structure interaction. For this, the instruments used were: 4 load cells installed between the nail head and the metal mesh, to monitor the loading acting in the anchors; strain gages installed in 4 different nails with extensometers in 3 portions of the nail, to evaluate the load distribution along the steel tendon and 12 crackmeters installed in the metal mesh, to evaluate its deformation.

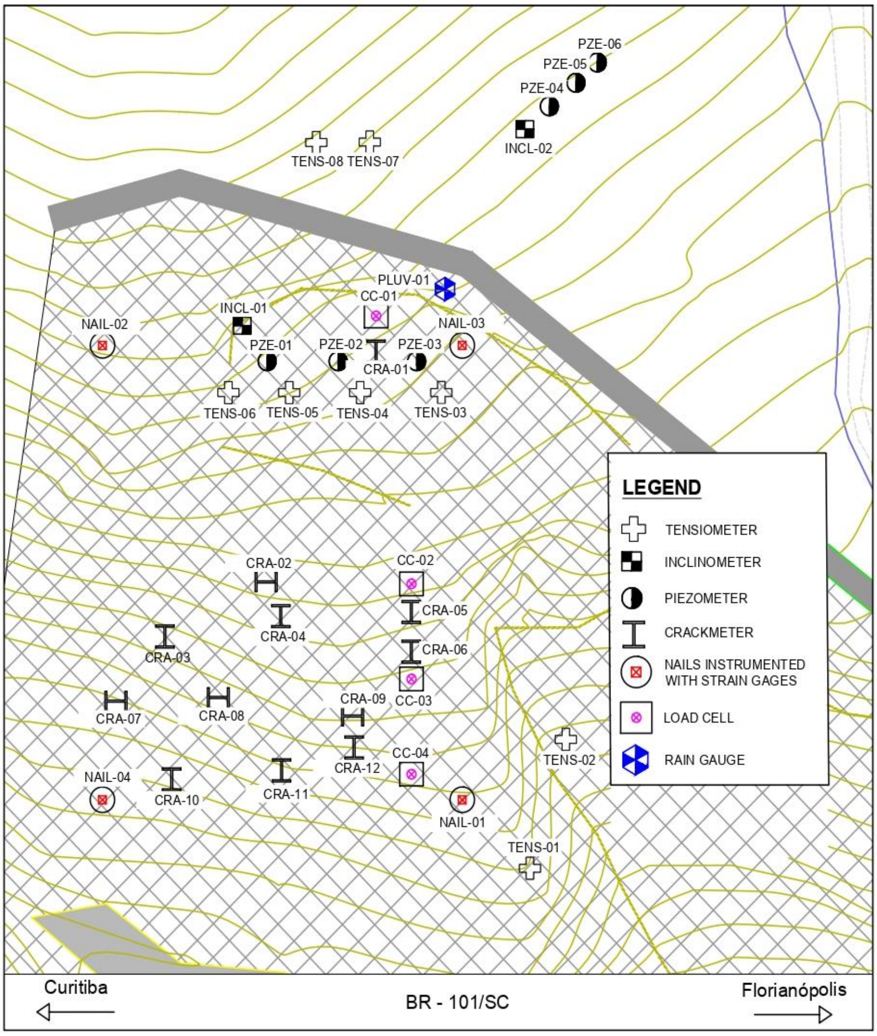
The instruments distribution is presented in Figure 3, the sensors were installed in 3 different regions, 2 inside the stabilized area and 1 upstream. The monitoring began in May 2012, with automatic data acquisition made through a datalogger with time intervals of 8 hours, except for the inclinometers. The interval of time for data acquisition was posteriorly changed in an hourly basis. The download of the data, until June 2018, was manual.

3 IMPLEMENTATIONS OF A WEB-BASED PLATFORM

The manual download of the data was performed for more than 6 years of the monitoring period. This activity required the displacement of a team to the slope, which is located 240 km away from the place where data processing is performed, to collect the records in the datalogger with a monthly frequency. After acquisition of the data, all the information was processed with the aid of spreadsheets. The amount of data is large, and the processing is different for each instrument, so this assignment took a considerably time. Besides that, the frequency of data acquisition was insufficient for an accurately analysis and interpretation, so the measures did not allow the creation of alert systems.

In June 2018, a web-based platform was implemented in the monitoring system with the purpose to facilitate acquisition, management and processing of the data. This remote accessing to the data was possible with the use of GPRS technology, which has a much higher data rate compared to other technologies as satellite and radio, and lower costs. Therefore, the information in the datalogger is now transmitted to an online platform, with the use of a GPRS modem. Also, the system is powered by a battery and a solar panel, allowing maintaining the system load at an adequate level for longer time without the need of an electrical network close to the site.

Fig.3. Instruments distribution.



The authors.

3.1 KEY FUNCTIONALITIES

The web-based platform allows the access to instrumentation data through an online page. The data is updated hourly and is available in the platform as soon as it is registered. Among the functionalities, it is important to highlight the possibility of insertion of equations to process the information registered by the instruments, converting this information into measurements automatically, and the insertion of validation values, with upper and lower limits, that can correct some reading with error. These measurements can be accessed through tables or graphs that can combine different variables, according to the preferences of the users, facilitating the visualization and management of data, which is the key of geotechnical risk management and disaster prevention [7].

Since data are collected every hour, it is easy to identify a problem in the instruments by the number of records. A page informs the number of records that should be stored and compares it to the real number, being possible to identify some failure. Besides, the battery level is registered, and an alert sign was created to inform, by sending e-mails to chosen users, when the level is low. This procedure permits the users to control the system operation. All system failures or problems throughout the monitoring period are recorded in a notes tab.

Another feature of the platform is the insertion of documents, such as manuals, maps and projects, which are available for access by all users. This facilitates the communication and integration between users related to the data management.

3.2 CREATION OF AN ALERT SYSTEM

The greatest advantage of a remote monitoring is the creation of alert systems. The alert can be related to the construction process, the structure performance or the prediction of disasters. In this study, the mainly alert system used is related to the prediction of rainfall events that can trigger landslides.

The hydrological monitoring, with piezometers and tensiometers, and the rainfall records, combined with the records of landslide occurrences around the study location, allowed the understanding of the mechanisms that can trigger landslides in the region. Thus, it was possible to create and alert system based on the monitoring data.

A pluviometric threshold was delineated to the area based on a methodology that fix values of hourly precipitation (mm/h) or one day accumulated precipitation (mm/24h) and correlate those to different scenarios of accumulated precipitation to find the best configuration for the curve that separates rainfall events that can cause landslides from those that are not a risk [2]. The best configuration for the study area was found to be the relation between accumulated precipitation in 24h (mm/24h or mm/1 day) and the accumulated precipitation in 72h (mm/72h or mm/3 days). In order to use this threshold as an alert system, the graph was delimitated in 4 different scenarios that correspond to the probability of landslide occurrences and procedures that should be adopted by the concessionaire of the highway. The curves related to the scenarios were defined based on the percentage of points in each scenario (Fig. 5).

The pluviometric threshold was inserted in the platform and is updated in the same frequency as the rain gauge, in an hourly basis. The "Current condition" scatter is related to the last reading of the instrument. In this manner, the possibility of landslide occurrence can be monitored through the position of this scatter on the graph. Each scenario is related to one level of criticality.

Besides the pluviometric data, it possible to monitor the behavior of the slope facing pluviometric events through the readings of pore pressure. Sestrem *et al.* [9] studied the precipitation influence on the distribution of pore pressure and suction in the slope studied. It was concluded that a three-day accumulated precipitation higher than 100 mm can cause an important reduction in suction profile. In general, the suction level is maintained above 20 kPa when this three-day accumulated is less than 100 mm, suction values bellow this can cause instability. Since the matric suction has such an important role in the shear resistance, it is also important to verify the response of the suction when a considerable amount of precipitation is recorded. The platform allows an easy visualization of this information through graphs that combine precipitation records and suction measurements.

An intense pluviometric event can cause not only a landslide, but also a deformation of the soil mass. This deformation may or may not change into a large-scale soil movement. The inclinometers readings are not automatized, so these instruments can not identify a deformation immediately. The sensors installed in the stabilization system, although can also be used for this. If a deformation of the soil mass occurs, the crackmeters will register a deformation of the metal mesh and the pressure cells and strain gauges will register an increase of loading, that can be accessed immediately.

Fig.4. Pluviometric threshold for “Morro do Boi”.

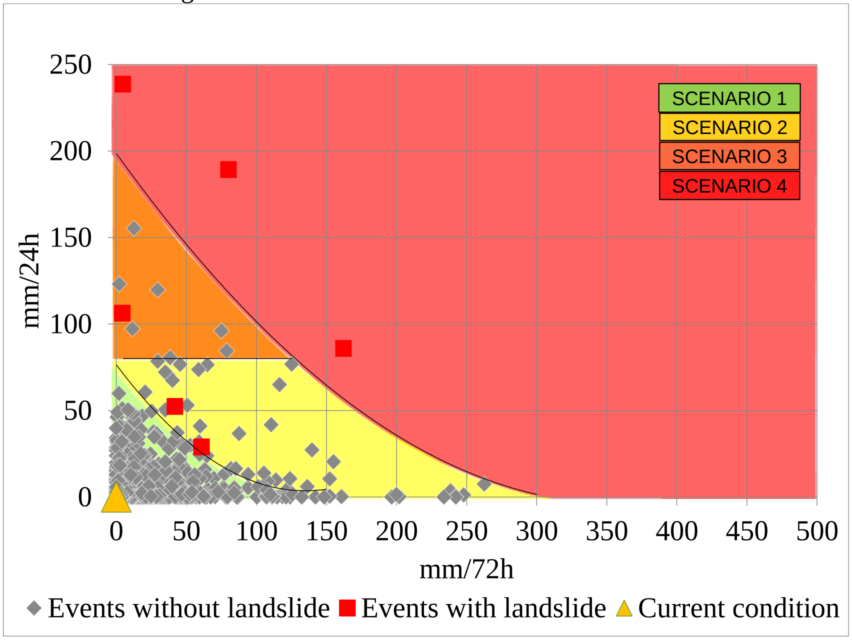


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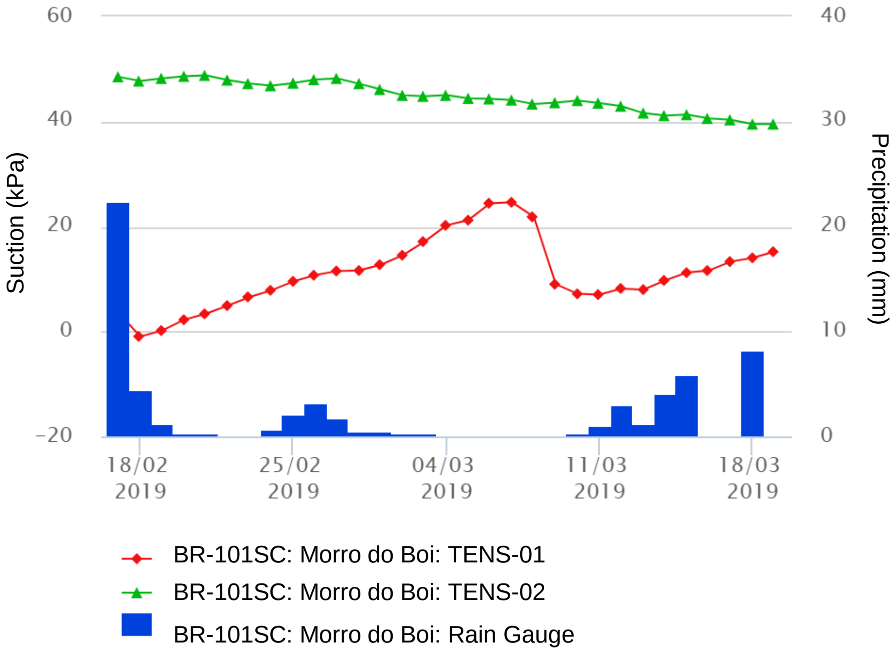
Fig.5. Example of graph available in the platform.



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4 CONCLUSIONS

The implementation of a web-based platform in the monitoring system of the slope located in “Morro do Boi” facilitated the data acquisition, excluding the need of displacement of a team to download it manually every month. Nonetheless, some procedures, as the cleaning of the rain gauge and the filling with water of the tensiometer’s tubes still demand a periodical accompaniment in the field. Considerable time is also saved with the automatic processing of the data, which can be visualized in tables or directly in graphs. Data management has been facilitated and can be done by different people in different locations at the same time.

An important accomplishment was the creation of an alert system with the pluviometric threshold. This is an easy and useful tool to predict slope failures induced by precipitation. The constant updating of the threshold is a good alternative to the geotechnical risk management and provides important information about the highway safety.

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