Application of Geotechnical Monitoring (Slope Monitoring and Early Warning System) for Risk Reduction in Philippine Infrastructure

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Abstract. The Philippines, an archipelago of more than 7,100 islands, and with a population of more than 100 million, is one of the counties most exposed to seismic hazards, being located in the Circum-Pacific Ring of Fire. It is also identified as one of the top 10 countries worldwide which are most vulnerable to the effects of climate change.

With a climate generally characterized by predominantly rainy season, many areas of high altitudes and characterized by thick residual soils and highly weathered rocks are highly susceptible to rainfall-induced or earthquake-induced slope failures. These failures may occur in populated areas without warning; thus, increasing the risks to the communities and essential utilities.

This paper presents the long list of the various geohazards in the Philippines, current efforts in the development of GIS-based regional hazard maps, and the current practice of conducting engineering geologic and geohazard assessment (EGGA) for critical projects – as part of disaster mitigation and risk reduction strategies. In few critical projects, geotechnical monitoring has been employed.

A case study involving the development of a slope monitoring program and early warning system for a power generation facility in the Philippines shall be presented. Monitoring equipment were installed, aimed at detecting slope movements and increase in pore water pressures – which became the basis for work suspension and evacuation of personnel working on or near slopes. The monitoring program proved to be effective as impending failures were detected, and the projects were completed without serious incident.

Keywords: Instrumentation · Geotechnical monitoring
Landslide mitigation · Risk reduction

1 Background

Roughly 90% of all seismic activities occur along a 40,000 km long horseshoe-shaped stretch called the Pacific Ring of Fire. This area consists of 452 volcanoes running along the southern tip of South America, Alaska, Japan, Philippines, and New Zealand.

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The Pacific Ring of Fire contains about three-fourths of dormant and active volcanoes in the world.

The Philippines, an archipelago of more than 7,100 islands, is one of the countries most exposed to seismic hazards. The country has 23 active volcanoes, 21 of which have historical eruptions according to the Philippine Institute of Volcanology and Seismology (PHIVOLCS). As a result, the country frequently experiences catastrophic events due to seismic and volcanic activities such as liquefaction, landslide and debris flow.

Aside from seismic and volcanic activities, other factors influence the susceptibility of the Philippines to such catastrophic events. With a climate generally characterized by predominantly rainy season, high amount of precipitation is experienced by the country year round, with strong typhoons occurring frequently, with an average of 20 typhoons per year passing through the Philippine Area of Responsibility (PAR). The highly-altered geologic formation of the Philippines also influences the hazards.

2 Hazard Mitigation and Risk Reduction

2.1 Risk Assessment

Risk is a function of three parameters: hazard, exposure and vulnerability. Hazard is a threat that can cause loss of life or damage to property. In the case of mountainous regions of the Philippines, the most common type of hazard is landslide.

Exposure refers to elements which have to confront a hazard. Exposure may be in terms of infrastructures and facilities - such as access roads, bridges, pipelines or buildings - and people, in the case of motorists travelling along access roads or occupants of buildings. Vulnerability refers to the capacity of a structure or facility, for example, to survive a hazard. Essential facilities located far from a slope are less vulnerable than those found along the base of a slope. Risk may be classified as low, moderate or high after taking into consideration the consequence of failure.

2.2 Risk Rating

Considering the three parameters of risk, the following ratings were generated, generally applicable for infrastructures exposed to landslide risk:

Low Risk is defined as an inconvenience that is easily corrected, not directly endangering lives or; Moderate Risk is defined as a more severe inconvenience, corrected with some effort, but not usually directed endangering lives or structures when it occurs; High Risk is defined as complete loss of roadways, important structures or complete closure of the way for some period of time. Lives are endangered during failure.

2.3 Disaster Risk

Since hazards are only threats that can cause loss of life or damage to property, it becomes a risk if two other parameters are present: exposure and vulnerability (Fig. 1).

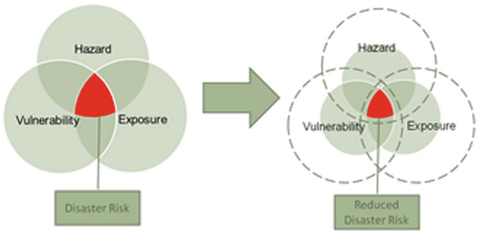

Fig. 1. Disaster risk parameters

2.4 Risk Objects

The three objects of risk are property, way of life and life. Their elements are subjective depending on the value system of the person, party or entity. For this risk assessment, the element of life pertains to the people; way of life pertains to the health status, public safety, livelihood, service, social and economic order and environment; property involves assets, physical structures, technical facility and system and land.

2.5 Disaster Risk Mitigation

Figure 2 presents the Disaster Management Steps that are taken to ensure the safety of life, way of life, and properties. Response refers to the emergency services and assistance rendered during or immediately after disasters. This is done to assess the disaster, to plan and pursue further actions. Rehabilitation, on the other hand, is to restore and improve the affected facilities, structures and/or livelihood of affected communities.

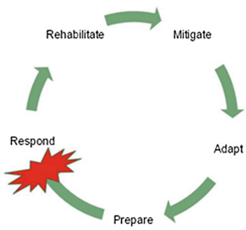

Fig. 2. Disaster management steps

Adapting to the natural environment such as site planning to anticipate potential problems is a proactive approach. An important part of the Disaster Management is mitigation, which can either be structural or non-structural in nature. These engineering measures reduce and/or prevent future damage related to hazards and disasters.

3 Hazard Mitigation and Risk Reduction

Instrumentation system for early detection of slope failure and monitoring of movements is essential in areas near essential facilities, and places where communities are exposed to slope-related geotechnical hazards. Slope monitoring through various instruments will be able to provide quantitative data on in order to constantly measure slope movements and thereby assess the stability of a slope. Lastly, it could help detect early signs of impending slope failure and can even send warning when the threshold parameters are exceeded.

The instruments used for slope monitoring measure several parameters that may be used to calculate the stability of the slope. The commonly measured parameters in slope monitoring are porewater pressure, deformation (directional and rotational), soils and rock stresses, temperature, and vibration.

Slope monitoring instrumentation systems may be classified into two groups, namely: contact and remote monitoring. The more traditional approach is the contact monitoring. It requires the instruments to be installed directly in the ground, either on the surface and/or at a certain depth below the surface.

In contrast, remote monitoring can collect data based on sensors installed far away from the site monitored. Some instruments may be partially remote such as sensors still required to be installed on the ground, but with considerable distance from the site monitored. Accordingly, fully remote instruments are available wherein no instruments are installed on site. Examples of different instruments used for remote monitoring are: Terrestrial Interferometric Synthetic Aperture Radar (TInSAR), and Light Detection and Ranging (LiDAR).

Remote monitoring will have no interaction with the ground or structure. While remote monitoring would have the advantage to cover a more extensive area of study and capability of increasing of the spatial information density, it would reduce the local precision of the monitoring point.

Usually, for sites with relatively small area/s of concern, it would be more practical to use the traditional contact monitoring. The case study presented in the next section utilized contact monitoring instrumentation system as early detection and monitoring system.

4 Case Study: Development of Monitoring Program as Early Warning System

4.1 Instrumentation

The monitoring instrumentation system used in the case study at a facility in the Philippines is composed primarily of data logger, MEMS tilt meters, soil moisture sensors, rain gauge, and an alarm.

Data logger is a device that records and stores data at a period of time. These data come from the external instruments and sensors attached to the logger. A computer connected to the data logger can view and process the collected data using a software.

MEMS tilt meters are instruments used to measure small and sudden movements or changes (in degrees) on the slope in terms of vertical and horizontal level. Tilt meters can measure up to ±15° tilt from vertical.

Soil moisture sensors measure the volumetric water content (in percentage) of the soil. These sensors monitor the saturation level of the slope at an approximate radius of 20 mm around the sensors.

Rain gauge (tipping bucket) is an instrument used to measure the amount of rainfall (in millimeters) in a period of time. Each tip on the rain gauge is equivalent to 0.254 mm rainfall.

An alarm is a device that activates when the data transmitted by the tilt meter exceeded the threshold values set for the said instrument.

4.2 Methodology

Installation of Monitoring System. One (1) data logger, two (2) tilt meters, three (3) soil moisture sensors, a rain gauge, a solar panel and an alarm are installed at the site of the study.

Data logger is placed in a temporary shelter, distant enough from the slope, to protect the logger from falling off and getting wet due to rainfall. Tilt meters and soil moisture sensors are installed at different locations (top, middle, and bottom portions) of the slope.

Tilt meters are attached to an angle steel bar which is embedded at the ground for stability. The orientation (x-axis, y-axis, and z-axis) of the tilt meters are properly set.

Soil moisture sensors are implanted completely deep enough (~0.5 to 1.0 m) from the ground surface. The rain gauge, solar panel, and the alarm are installed near the temporary shelter and the data logger. Rain gauge is elevated from the ground to collect rainfall properly.

All the instruments and sensors are then connected to the data logger by wires/cables and were calibrated to set the values to zero (0). This is to ensure the accuracy of the data to be recorded and collected (Fig. 3).

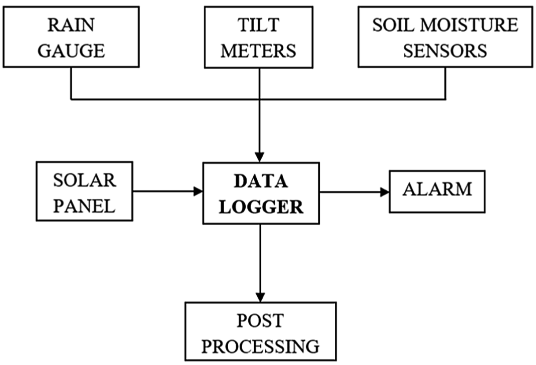

Fig. 3. Schematic diagram of the monitoring system

Monitoring Works. Monitoring of the slope is conducted on a daily basis. Prior to the daily monitoring, an initial 14-day monitoring (first phase) is conducted to derive the threshold values stated in the following subsection. Data are collected and analysed twice a day – one in the morning and one in the afternoon.

Data are presented graphically with corresponding interpretations. These are the basis for any work suspension and evacuation of staff working on the slope.

Threshold Values. Threshold values are set at the data logger for each of the instruments (Table 1). These are the basis of warning that a slope failure may potentially occur.

Table 1. Threshold values for each instrument

Instrument		Threshold
Rain gauge		15 mm/2 h
Soil moisture sensors	SM 1	14.00%
	SM 2	33.00%
	SM 3	23.50%
Tilt meters		>0.25% or <–0.25%

The threshold value for the rain gauge are based on the rainfall advisories of Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA). Three categories are included in the rainfall advisories; yellow warning (7.5–15 mm/2 h), orange warning (15–30 mm/2 h), and red warning (>30 mm/2 h). The monitoring system adopted the orange warning in which intense rain is observed and flooding is threatening.

For the soil moisture sensors and tilt meters, the threshold values are established based on the initial trend of the data on the 14-day monitoring. In case the threshold values for the soil moisture sensors were exceeded, resumption values are established to ensure that the area is generally safe before any work resumes.

4.3 Results and Findings

Based from the monitoring and analyzing of data, there are the instances where collected data exceeded the threshold values for any of the instruments.

One good example is the rainfall, and soil moisture data collected for four (4) consecutive days, from January 15 to 19, 2017, as shown in Fig. 4. During the first 12 h (January 15, 2017, 12:00 PM to January 16, 2017, 12:00 AM), accumulated amount of rainfall for any 2-h interval within the time period did not exceed the threshold value of 15 mm/2 h. Moreover, the soil moisture contents recorded for the three sensors did not exceed their corresponding threshold values.

However, during the succeeding hours (January 16, 2017, 12:00 AM onwards), the accumulated amount of rainfall per 2-h interval exceeded the threshold value of 15 mm/2 h. These increase of amount of rainfall can also be validated by the increase of values of the moisture sensors, which also exceeded their corresponding threshold

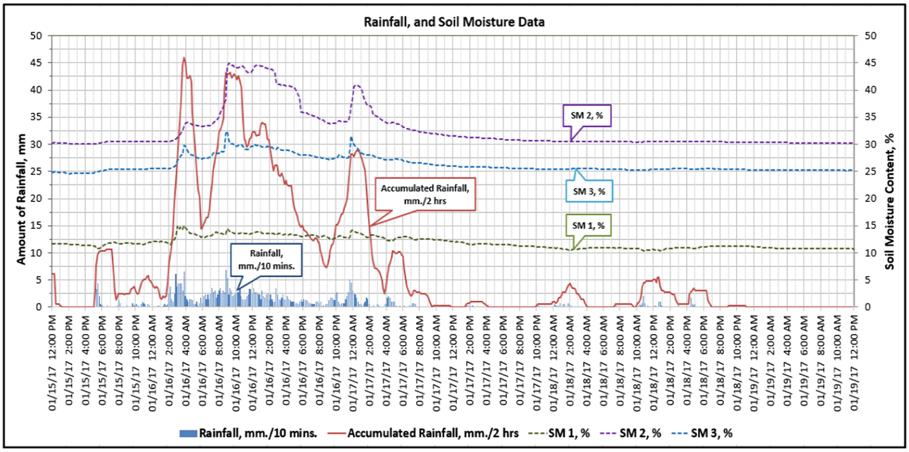

Fig. 4. Rainfall, and soil moisture content data for four (4) consecutive days

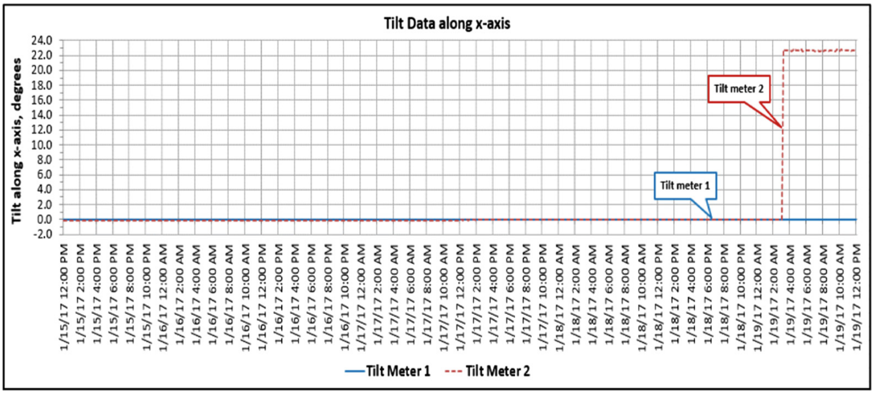

Fig. 5. Tilt data along x-axis for the two (2) tilt meters

values. The sudden increase of the values is largely due to the continuous rainfall caused by a tropical depression.

As for the tilt data along both x and y axis (Figs. 5 and 6), the threshold values of >0.25 or <–0.25 for the tilt, are also exceeded two (2) days after the recorded exceedance for the rainfall, and moisture content values. The data showed that there are sudden increase in the tilt values, which is an indication of a slope movement.

Prior to the sudden increase in tilt values, the graphs show that there are no (or minimal) changes/variations on the tilt data indicating that the slope is stable at that period of time.

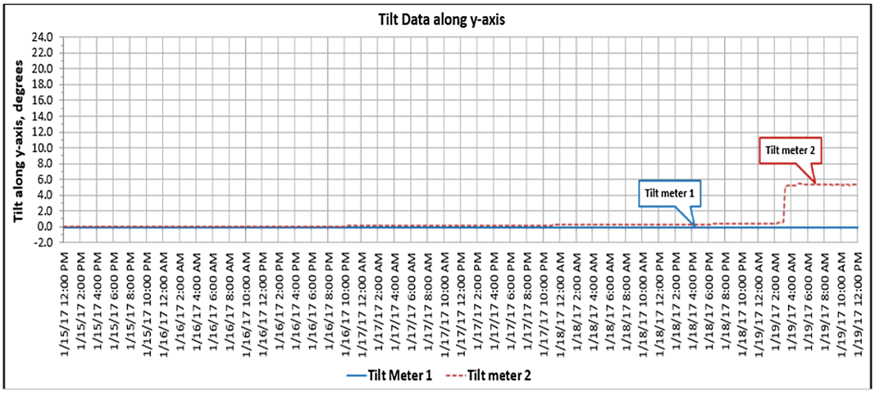

Fig. 6. Tilt data along y-axis for the two (2) tilt meters

True enough, a landslide occurred at the site which is a good validation of the data recorded. Slope works are recommended for suspension during the day threshold values exceeded and three (3) days following the exceedance.

Generally, the results and findings are used as the basis for any work suspension on the slope.

5 Conclusion

The paper presents the case study involving a slope monitoring system which was successfully implemented as an early warning system on an area with critical slopes. A 14-day monitoring program (first phase) was conducted to establish the threshold values. It also aimed at ensuring the general safety of personnel working on or near the slopes.

The threshold values initially established was deemed appropriate since landslides occurred when the threshold values were exceeded. Moreover, based on the data gathered, further analysis and evaluation is warranted to further optimize the threshold values, while ensuring safety along the slope.