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Short Communication

Analysis of slope stability by back-calculation along the Paute River Valley: application to construction of the Mazar Hydroelectric Project - Ecuador

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ABSTRACT

The Mazar Hydroelectric Plant is located in the Andes Cordillera in south-central Equator. The study area corresponds to the middle source of the Paute River Basin which is nestle in a narrow valley at about 2,000 metre above sea level. Many landslides are observed along the Paute River, including the historic case "*La Josefina*" which in 1993 moved a volume of soil and rock estimated at 25 million m³. For the construction of a large engineering project in this geological context characterized by many natural instabilities is essential to identify the spatial distribution of the landslide hazard. Furthermore, in order to obtain satisfactory results in timely with reduced costs, the use of back-calculation methods and techniques of geoprocessing are facilitators' tools. In this aspect, this paper presents the strength parameters of colluvium soils and rock horizon that form more superficially the slopes bordering the hydroelectric reservoir were determined by back-calculation and, to attest the reliability of the results, were compared with literature values. The factor of safety (FS) was calculated as a function of the degree of ground saturation and the groundwater level in regions above the reservoir, therefore, not submerged. The FS was also evaluated the seismic contribution applying acceleration coefficient K_h of 0.14 g and another overestimated (K_h = 0.28 g). The spatial distribution of the FS, through geoprocessing, resulted in maps of guidance character about the areas of lesser and greater stability for each simulated situation.

Keywords: Landslides hazard, Safety Factor, back-calculation, Andes Cordillera, hydropower plant.

INTRODUCTION

Operational decision in engineering geology can be influence not only by scientific knowledge but also cost and time to conduct the study or implement the recommendations. So, when it comes to stability analysis of slopes in the field of hydropower, flexible and versatile tools and low cost enabling diagnose the hazard by simulating the instability of some natural phenomena can be of great help to define the safest place for a large infrastructure project. In this purpose, this study presents a method to meet these goals by analyzing simulated geoprocessing behavior of embankments to the variation contributing parameters to slope instability which in context of the Andes, is the degree of saturation and seismic acceleration. The method does not dispense field inspections, in-situ or laboratory testing, nor the opinion of experienced professionals. This study proposed to map the spatial distribution of the slope stability condition in the region identified for the infrastructure development without significant cost or time.

Study Area

The proposed method was applied to the analysis of slopes located along the reservoir of the Mazar

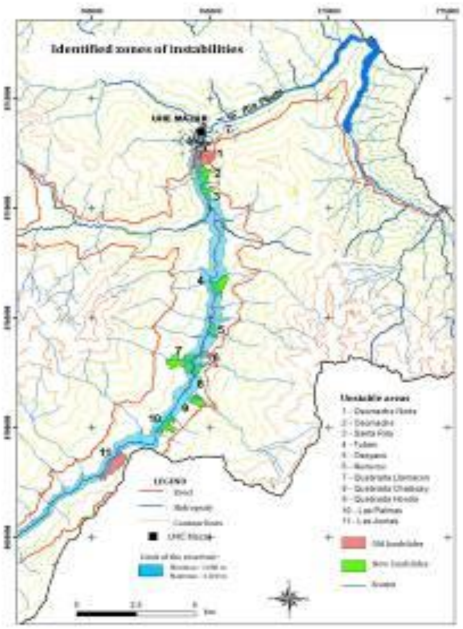

Figure 1. Previously identified zones of instabilities in the study area

Figure 2 Fractured shale and phyllite.

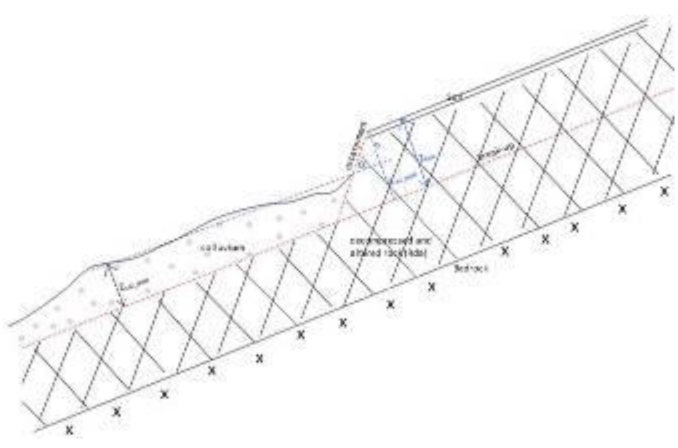

Figure 3. Model breaking soil and rock.

Hydroelectric Dam, located in Paute River near the city of Cuenca in the south-central Ecuador in Andes.

Geology

The geological context for the incision of Paute River Basin is strongly influenced by the Andes, resulting from subduction of tectonic plates Nazca and South American that his constant collision, promotes volcanism and seismic events. Along the Paute River, in the region near the dam of the Mazar Hydroelectric Dam, there are eleven large unstable areas affected by these movements, described by INECEL (1998) as highly dangerous: Osomache North Osomache, Santa Rita, Tuban, Osoyacu, Ñuñurcu, Llamacón, Chalacay, Quebrada Honda, Las Palmas and Las Juntas (Figure 1). In general, the region comprises two well defined lithological units: Alao - Paute and El Pan, characterized by metamorphic rocks, especially represented by strongly fracture interbedded shale and phyllite (Figure 2). The foliation typical of these lithologies and the presence of fractures, with high dip inclined towards the free face of slopes, especially on the right bank of the Paute River are factors promote slope failure. In the areas of slope instability the bedrock can be overlain by up to 28 m of colluvial material while outside the zones of instabilities a 2 m residual soil is more typical.

METHOD

To reach that goal, it is necessary to fulfill the following steps sequentially:

1) Define failure criterion.
2) Determine by back analysis, the shear strength parameters (cohesion (c) and friction angle (ϕ)) zones of slope instabilities.
3) Calculate the Factor of Safety (FS) of the slopes for different degrees of saturation (m) and seismic acceleration (K_h), and provide a spatial distribution using a geoprocessing tool such, as Nicole (2012).

Failure Criterion

The initial stratigraphy of the slope in the study area was composed of a thin (<2 m) layer of residual soil on decompressed and altered rock (Rda). Therefore, the failure surface which led to the large slope instabilities occurred over discontinuities present in this material, possibly along the foliation. The stability analysis for this morphological context considered the strength parameters determined for Rda, and the apparent dips of the most critical discontinuities in relation to the slopes. The depth of the failure plane perpendicular distance resulted from the top of the slope in relation to the plane of the surface of the body plus the height of the colluvium. For areas already unstable with significant colluvial soil cover, it was considered the plan limit a possible new event of instability as a horizon in colluvium in angle consistent with the terrain slope. Thus, the resistance parameters used for determining safety factor of these regions were angle of internal friction and for the cohesions colluvial soil. The thicknesses of these layers was compared equal to the height of the deposits (Figure 3).

Back-calculated shear strength parameters

By limit equilibrium theory, it is assumed that at the exact moment of rupture the Factor of Safety (FS) is equal to unity and null cohesion. With these values assumptions, calculate the friction angle (ϕ) by equation (Eq.1).

Eq.1
$$\tan\phi = \frac{\tan i_c * \gamma}{1{,}05*(\gamma - m\gamma_a)}$$

Where:

ϕ = friction angle; i_c = critical angle; γ = specific weight (natural or saturated soil/rock); m = degree of saturation; γ_a = specific weight of water.

In the case of movements triggered by seismic loading, it adds a factor to the FS calculation to account for the acceleration experienced. According to INECEL (1998), the event that triggered the original movements of unstable areas was of low magnitude (3.5 M), corresponding to an acceleration seismic (K_h) 0.05 cm/s^2. The ϕ was determined by back analysis for materials instabilities in both cases suggested break in both the horizontal decompressed and altered rock (Rda) and in colluvium under the following conditions of saturation (m): 10%, 50 % and 100%.

Factor of Safety

For the calculation of FS (Eq.2) considered the static condition (no earthquake), and the pseudo-static condition, with K_h equal to 0.14 g (typical expected earthquake) and 0.28 g (maximum expected earthquake). The Table 1 summarizes the different assumed conditions for the calculation conducted in this study.

Eq.2
$$FS = \frac{c + (Z\gamma \cos^2 i - Z\rho K_h \cos i \, sen i - \gamma_a h_2 \cos^2 i)\tan\phi}{Z\gamma sen i \cos i + Z\rho K_h \cos^2 i}$$

Where:

c = cohesion;
Z = depth of the rupture plane;
i = angle of slope gradient (for soils) and apparent dip critical (for Rda);
ρ = density;
h_2 = height of water level above the plane of rupture;
K_h = seismic acceleration coefficient.

The application of FS calculation for the entire area is only practical with the use of GIS tools. The software

Table 1. Conditions for analyzing the factor of safety

Degree of saturation (m)	Seismic condition		
	Static	Pseudo-Static	
10% 50% 100%	No earthquake	Typical expected earthquake (K_h = 0,14 g)	Maximum expected earthquake (K_h = 0,28 g)

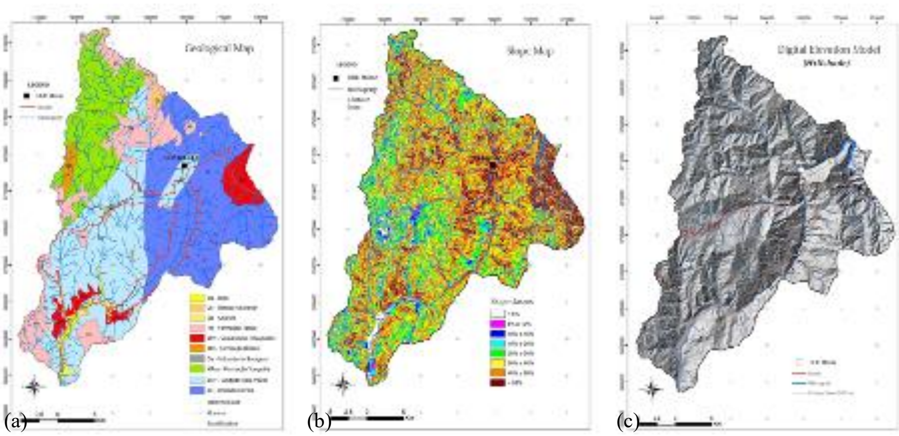

Figure 4. (a) The geology map,
(b) Slope map and
(c) Digitial Elevation Model of the study area.

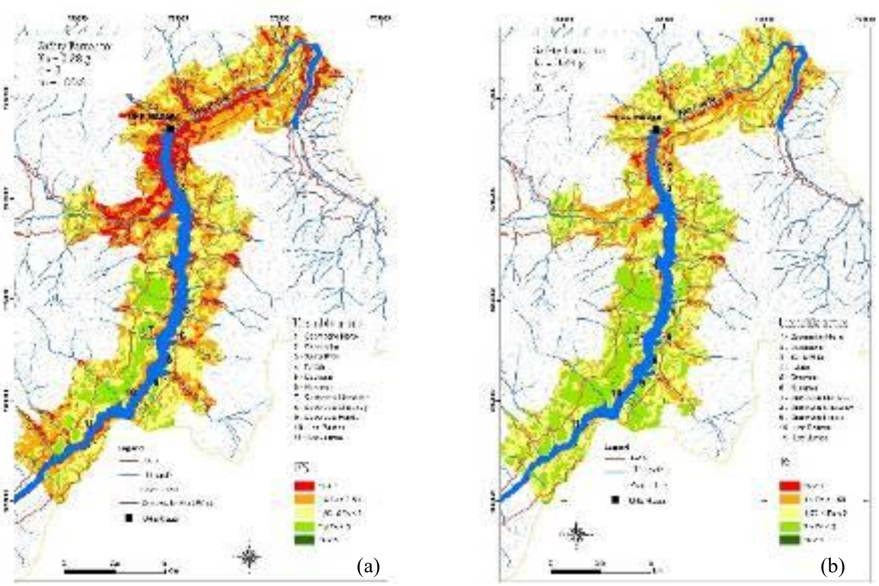

Figure 5. Spatially FS for assumed cases to cohesion zero, earthquake acceleration of 0.28, and different degree of saturation: 100% (a) and 1% (b).

ArcMap was used to create a database with attributes extracted from the area of geological map, digital elevation model and slope map (Figure 4). These were combined with back-calculated friction angles from the known unstable areas, and extrapolated to the dimensions of the area with similar geological characteristics. In the case of a large area, so that the results were best viewed spatially, the slopes were grouped into polygons with varying slope of 5% of each other, and divided into 8 slope stability classes. The resulting maps provide visual areas of spatial distribution of the landslide hazard.

Spatially FS for assumed cases to cohesion zero, earthquake acceleration of 0.28, and different degree of saturation: 100% (Figure 5a) and 1% (Figure 5b).

CONCLUSION

The methodology presented in this paper allowed to characterise the slope stability conditions over a large area based on back-calculated shear strength parameters of previous slope failures. The use of GIS software streamlined the calculation of the FS and it visualization over the study area. The results of the analyses demonstrated that, in the study area, water is the main factor influencing the slope stability conditions followed by seismic acceleration.

REFERENCES

Borchardt N (2012). Análise da estabilidade de taludes por retroanálise do rio Paute: aplicação nos estudos construtivos da Usina Hidroelétrica Mazar – Equador. Tese de Doutorado. Curitiba, PR. Editora da UFPR. 178p.

Enoki M, Kokubu AA, Ikeda Y (1999). Infiltration of rainwater and slope failure. In: Griffiths, Stokes and Thomas Eds. Landslides. p.27-35. Balkema - Roterdam.

Hoek E. Bray JW (1981). Rock slope engineering. 3. ed. London: Institution of Mining and Mettalurgy. 358p. Revised edition.

INECEL (1998). Proyecto Hidroeléctrico Paute Mazar. Licitación Proyecto Mazar – Volumen IV – Parte 11. Estudios de Factibilidad – Volumen 1 – Tomo 1 de 2.

Mostyn GR, Small JC (1987). Methods of stability analysis. In: WALKER, B. & FELL, R. ed. Soil slope instability and stabilisation. Cap.3, p.71-113.

Pyke R (1999). Selection of seismic coeficients for use in pseudo-static stability analysis. Lafayette, California.

Varnes DJ (1978). Slope movement types and processes. In: Landslides analysis and control. National Academy of Sciences. p.11-33. Washington.

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