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Early warning system for landslides caused by high intensity rains during the El Niño

Système d'alerte tôt pour glissement causées par les pluies intenses pendant El Niño

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ABSTRACT
Much geological and archeological evidence show that in the coast of Ecuador and Northern Peru, flourished ancient civilizations that later completely disappeared, by reason of intense rains and disastrous droughts. After El Niño phenomenon of the years 1997 and 1998, that destroyed towns, roads, agriculture in that region, the author has investigated the relationship between intense rain , its evolution and intensity, with the landslides occurred at the city of Guayaquil and other cities of the Ecuadorian coast, like base for a Early warning system. Many of the advances in the investigation were already presented by the author at several international meetings.
After many investigations a relationship was firmly established between the 24 hour rain , accumulated every ten days, and the accumulated media in the same period, acceptable results were found, they enhanced the powerful effect of accumulated rain and the increment of intensity of rain before the start of landslides, achieving a simple sensitive statistical method to identify the beginning of landslide with more than 24 hours of anticipation , these implies a simple and economical early warning, for regions of high population density and vulnerability to suffer landslides and avalanches due to extreme rain as occurs at Eastern Pacific Coast, due to El Niño.

RÉSUMÉ
Beaucoup de signes géologiques et archéologiques démontrent cela dans la côte de Équateur et Nord du Pérou, ils ont prospéré vieilles civilisations qui alors ont disparu, probablement à cause de pluies intenses et sécheresses désastreuses. Après le Phénomène El Niño des années 1997 et 1998 cela a détruit des villes, des autoroutes, et des plantations agricoles dans cette région, l'auteur a recherché sur les corrélations parmi les pluies intenses, son évolution et intensité, avec les glissements est passé dans Guayaquil et autres villes de la côte Équatorienne, comme base pour un Système d'Alerte Tôt. Beaucoup des avances sur cette recherche a déjà été présenté par l'auteur dans les plusieurs réunions internationales.
Comme culmination de cette recherche, après avoir répété beaucoup de corrélations, parmi la pluie de 24 heures dans Guayaquil accumulé chaque dix jours, avec le bas accumulé dans cette même période, nous pourrions trouver résultats plus acceptables et plus prometteurs qui ont confirmé l'effet puissant de la pluie accumulée et l'augmentation de l'intensité avant le commencement des glissements, accomplir une méthode statistique sensible simple pour identifier le commencement des fiches avec plus de 24 heures d'anticipation, et qu'il peut être un système pratique et bon marché d'alerte tôt, dans les régions très peuplées et vulnérables souffrir des glissements et des avalanches à cause de pluies extrêmes comme ce du El Niño dans le Pacifique Oriental.

1 INTRODUCTION

During the XX century El Niño has whipped 17 times with high intensity rains, at the coast of Ecuador. Today we know that El Niño with high intensity rains alternates with long periods of drought in this region, and we also know, for the Archaeology and the Geology that before the arrival of the Europeans in the XVI Century, El Niño phenomenon has acted strongly compared to the modern episodes at the recent period of history.

In 1998, the author established a classification of El Niño happened in the XX Century, based on the annual rains registered at Guayaquil, Ecuador, according to which is considered the period like El Niño when the rain is bigger to 1500 mm, this is, 50% on the annual rain average registered during 83 years approximately. Generally El Niño is generally developed in the in the months of the spring and of the southern summer, although it can last more than 8 months raining intensely. The maximum 24 hours rain, notwithstanding it is not very high (224.7 mm. At 18 April 1998), but the accumulated rain is on the average 3 times the media in the same period of time.

Contrary to what is believed, El Niño generated at the Pacific Ocean, does not enters in the Andean valleys, and only affects the occidental flanks of the Andes, up to 1000 m. of altitude over the sea level. In Figure 1 is shown the accumulated monthly rain of 17 Niños during the XX Century and the annual media rain at Guayaquil.

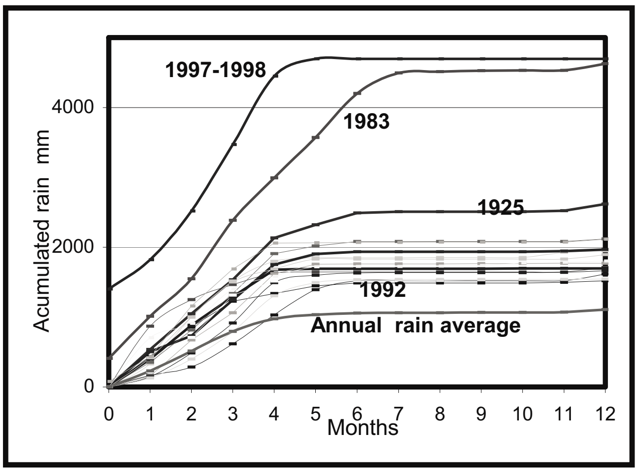

Fig. 1.Guayaquil. monthly rain of the 17 Niños of the XX Century and the annual average rain of Guayaquil.

During the initial high intensity rains at Guayaquil in the first months of 1997, landslides were produced in populated zones at Guayaquil, particularly in poor neighborhoods. With the spirit of reducing the risk, we achieve with success the Zonation on

Areas Susceptible to Rain-induced Slope Failure in Guayaquil City (Quito 1997), based in the method proposed by Mora and Vahrson, (1993), which was exposed by their authors at Guayaquil (1994).

Our aim was to achieve a method to warn the population in the future, about the initiation of the landslides, during the development of continuous storms. Something similar to what has been achieved at Hong Kong (Ishihara, K., 1997) and at others regions in the developed world. . It was as well as we discover that there was an important effect in the beginning of the landslides caused by accumulated rains and the effect of its intensity during 24 hours.

Notwithstanding, we were not satisfied with the results of such investigations before the year 2003, because the elected methodology, didn't represent a relationship average reasonably among the quick elevation of the pore pressure in the site, occasioned mainly by accumulated rain, versus the limit undrained resistance at shear, which were the detonating effect to initiate the landslides.

2 EL NIÑO REGION

Contrary to other wet regions with high vulnerability to landslides caused by intense rains, the coast of Ecuador and Northern Peru, up to the foot of the Andes, they prevail the years of low precipitation, with tendency to permanent drought. However every 5 years on the average, intense rains occur, two or three times bigger than the annual media, causing floods, high waves and landslides. This rainy period well-known as El Niño Phenomenon, due to its occurrence at Christmas, it may prolongs for several months, contrary to the tropical storms of the Caribbean and Centro America, that last only two weeks, just as it is observed in the Fig. 2, which is a comparison of the rain produced by the Hurricane Mitch, and that caused by El Niño.

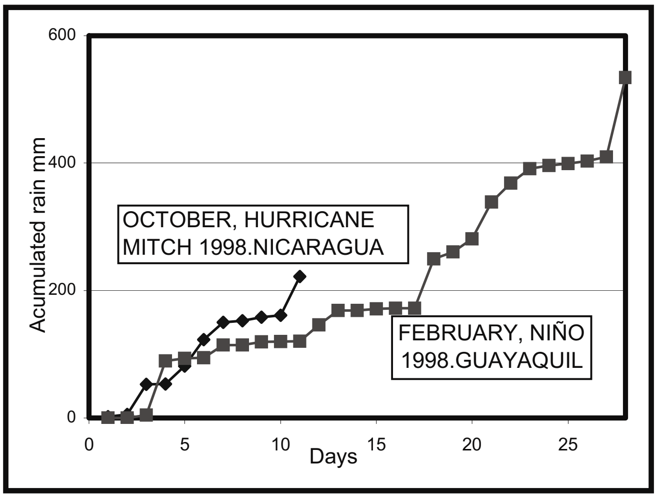

Figure 2. Comparison of the rain produced by the Mitch in 1998, and that caused by El Niño.

On other hand, the lands of the region are alluvial plains or coastal mountain ranges of marine origin, generally formed by soft, stratified sedimentary rocks, with sandstones, siltstones and shale, extremely weathered and fractured, whose water table remains deep until it elevates it quickly The Boy's rainy period, and it detonates a series of disastrous landslides.

In the Fig. 3 are shown a typical hillside of the coastal mountain range of the Ecuador that failed during The Niño of 1997-1998.

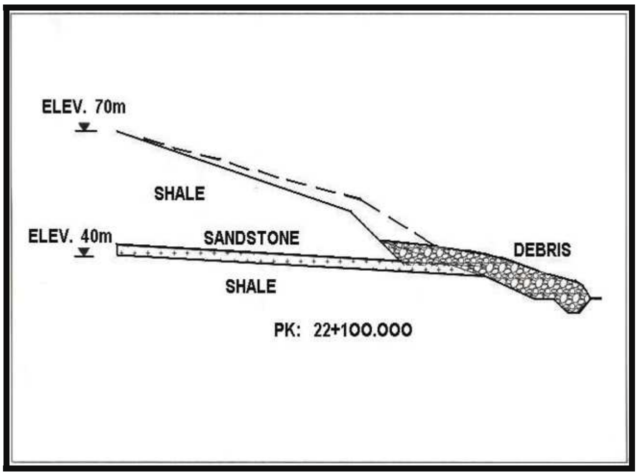

Figure 3 Channel Chongón – Playas, 22 Km., Ecuador. Slope failure adjacent to the channel, during El Niño 1997 – 1998.

3 THE METHODOLOGY.

At the 12TH. Pan American Conference on Soil Mechanics and Geotechnical Engineering, Boston 2003, the author presented (fig. 4), a consistent relationship, between the rains and the starting of the landslides during the rainy season of El Niño.

The information was registered at the Climatologically station in Guayaquil, which is representative in the region and has the longest register of rains since 1915.

$\Delta = P_1/T_1,\ (P_1 + P_2)/(T_1 + T_2),\ ......(P_1+...+Pn+Pn_{+1}) / (T1+...+T\,n + T\,n_{+1}).$ (4.1)

and

$\Sigma/\Sigma = P_1/P_{N1},\ (P_1 + P_2) / (P_{N1} + P_{N\,2}), ...(P_1+...+Pn + Pn_{+1}) / (P_{N1}+...+P_Nn + P_Nn_{+1})$. (4.2)

Where: P1,P2....Pn = accumulated rain of the period, every 10 days since the initiation of the rains (mm).; T1, T2...Tn = number of days at the period or the decade.; Pn1, Pn2,...Pnn = Media of the rain within the period, or the decade (mm).

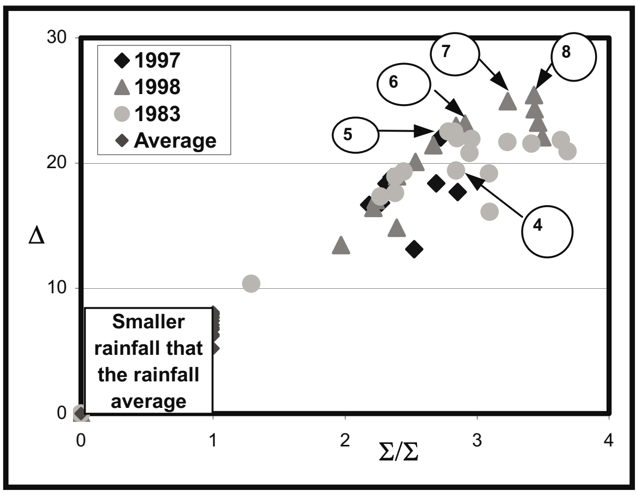

Figure 4. Guayaquil. Correlations of daily rains per decades, indicating the principal landslides that are detailed in table 1. 12 TH Panamerican Conference on Soil Mechanics and Geotechnical Engineering, Marín – Nieto L,. Boston 2003.

Table 1. Principals landslides at Guayaquil. El No 1983, 1997 – 1998.

	Place	Date of event
4	Cerro del Carmen	25/Ene/83
5	Mirador San Eduardo	25/Mar/97
6	Las Cabras, Duran	13/Dic/97
7	Cerro Azul	01/Abr/98
8	Puertas 4,10,14 Cementerio General	19/Abr/98

The final step was the creation of a simple figure, showing different sectors indicating levels of risk each one to landslide. In this figure, points of coordinates are plotted (Δ and Σ/Σ),.which corresponds to rains produced during the rainy seasons (fig 5), these points help us to follow the development of rain for several days or weeks, before the intervention of the triggering effect to start landslides.

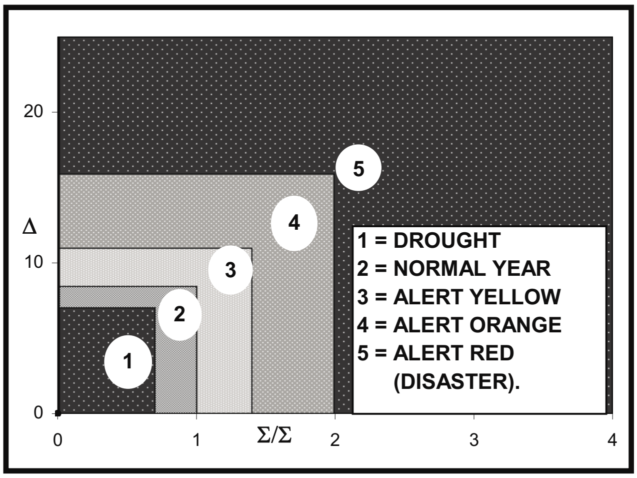

Figure 5. Guayaquil. Early warning level chart for landslides during El Niño.

4 CONCLUSIONS.

The methodology presented is based in the following fundamental hypothesis. The triggering effect for landslide occurs when, after a relatively dry year, the accumulated rain and the daily intensity of rain during El Niño, joint forces to create an undrained failure condition along the stratification and fracture of the rock. It is not usual that slope failures occur during an isolated rain of great intensity, because they do not corresponds to El Niño hydrology; isolated rains do not penetrate to the interior of the clay structure of the rocks in the region. This must be the reason why an important volume of daily rain must accumulate rapidly at the interior joints of the fractured rock, before the start of the initial landslides. Once this hydro-geotechnical condition is reached, the landslides continue until El Niño dissipates, or the Δ is diminished. Lastly, it is certain that the characteristics peculiar of the storms and the type of lands in each region, both create a particular condition to initiate landslides and floods.

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