Preliminary results of landslide characteristics due to rainfall in the city of Ensenada, Baja California, Mexico using physical modelling

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Abstract

The overall objective of this project is to produce maps identifying potential landslide hazard areas in the city of Ensenada, Baja California Mexico. In this paper we present the results of the granulometric analysis for 7 soil samples of different sites in the city that are subject to landslide or rock displacement hazard. We also present the tests done on the physical sliding model and a comparison between the sites and the model observations. The results show some consistency between the sliding model and the field observations.
Keywords: landslides, physical modelling, natural hazards.

1 Introduction

Landslides are known for its fierce consequences in the number of deaths. In Brazil, more than 500 people were reported to have died after torrential rains triggered mud avalanches in Teresopolis and neighbouring areas north of Rio de Janeiro; some of the areas were illegally occupied by houses built by their occupants on steep hillsides.

In Oaxaca, Mexico, on the 28th of January of 2011, a landslide devastated the State, mainly the town of Santa Maria Tlahuitoltepec leaving approximately 1500 houses with damages and 25000 victims [1]. On the North-western part of

www.witpress.com, ISSN 1743-3541 (on-line)
doi:10.2495/WRM110551

China, landslides triggered during August of 2010 had devastating consequences: up to 1000 deaths.

In the city of Ensenada, Baja California in Mexico, flooding occurs mainly because of the lack of storm drains, where landslides are mainly induced by the weight of the increased construction of low-cost housing developments with no impact studies beforehand.

A previous landslide study was done by Cruz-Castillo et al. [2], for a small sector of the Tijuana-Ensenada Toll Road, in the Ensenada county, indentifying that engineering works and anthropogenic factors are the main causes for the sliding; in addition, the geologic characteristics of the region indicate that it was subject to early sliding; however, in less than a year after the road was constructed, sliding occurred that caused the destruction of some houses that were built on top of the hill, which suggest that the main problem in this section was the decisions taken when constructing the Toll Road. Since that time, maintenance has become necessary to compensate for the continuous road subsidence. Other studies for the city have been published by Soares et al. [3, 4] where it is shown that lack of city planning is the main factor for the disasters caused by rain.

The general objective of this study is to compile all possible information on the sites in the city where it is known that landslides have occurred or where they are prone to occur, obtaining the basic soil studies and creating a mathematical model that characterizes the type and time at which a landslide may occur. The purpose of this article is to present the preliminary results of our findings, such as the basic soil studies and the slide model used as a first approach to characterize landslides for the city. We compare the physical model to what it is observed on the field as a first step forward for the city, in this field.

2 Description of the physical model

The physical sled model is composed by a wood support with option for different slopes allowing the flume to stand in the position chosen; our first inclination selections were 10˚, 16˚ and 20˚ used for the preliminary testing of the physical model; flume length is 1.5 m, and made from fibreglass (Figure 1).

The sled has a two way division for different soil comparison if needed. A mechanism for rainfall induction is made using a 20 litre water bottle with indicators at each litre; this gauge is connected to a pipe with holes at the bottom and to a mechanical valve which controls the velocity at which water falls over the soil set in the flume. A container is placed at the end of the sled for soil collection. The initial attempts with this model led to a fast soil runoff, so it was decided to glue rocks at the bottom of the fibreglass sled to make the model more realistic. As we decided on the sampling sites, we increased the slope configuration of the model; the current sled model allows a slope range from 10˚ to 80˚, with an angle increase of 10˚.

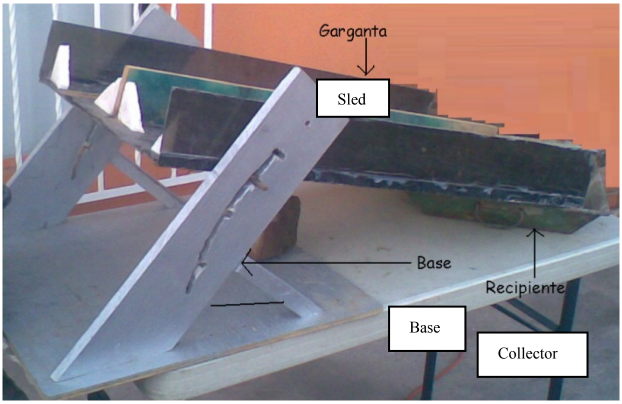

Figure 1: Preliminary sled model used as a first approximation for landslide analysis.

3 Method

3.1 Site selection

Site selection was done taking into account the regions in which we have observed landslides or a potential sliding hazard in the near future.

The first site is “Colonia 89” (Figure 2), a new housing development in which deep excavations are leaving steep slopes with risk of tear off by the weight of the overhead traffic.

Figure 2: Colonia 89 new housing development.

The second site selected is “Colonia Morelos I”. In this neighbourhood, we observed irregular settlements embodied on the hillside; if it continues to grow with no regulation, access to the homes will become almost impossible. At this location, the Terrazas El Gallo Hill and Colonia Morelos Hill converge forming a stream mouth towards the main street of the neighbourhood. City planners must consider debris and silt flow as well as mudslides (Figure 3).

Figure 3: Colonia Morelos I. One can observe the electricity pole in the middle of a stream bed.

Figure 4: Two houses adjoining the Esmeralda Beltway. Note part of the bottom of the houses with no support.

Our third selection is near the Esmeralda Beltway between Delante and Diamante Avenues. In order to make the relief road, heavy machinery and explosives were used, leaving some houses and buildings with high risk of falling (Figure 4). At this location, when it rains, big chunks of granite rocks fall into the Beltway, leaving the structures vulnerable without their natural support in which they were built. It also represents a hazard for drivers using the road.

The fourth section considered is the Neighbourhood "Praderas del Cipres". At this site a small rivulet flows carrying debris and silt into the Cipres stream;

Cipres stream does not flow into the ocean, it rather goes into the sewage system that already transports both domestic and rain water. This sewer is located at the corner of Boulevard Tecnologico and Avenida Reforma, right in front of one of the most populated High Schools of the city: CBTIS 41. Whenever it rains, the gutters overflow, making it impossible for the students to cross the street.

The Land Invasion called "Terrazas el Gallo" is not officially defined as a neighbourhood. Its houses are built on a steep hill (Figure 5). City planners have proposed that another Beltway for the city must be built in this section, so people who have taken over the land must be relocated, and this will lower the risk for this part of Ensenada.

Figure 5: Houses built on the "Terrazas El Gallo" land invasion.

Two more neighbourhoods were studied: "Colonia 17 de Abril" and "Colonia Arco Iris", both adjoining a river bank, and increasing in population by low-income residents. In general, people living to the east of the city, represent low-income resident. Figure 6 shows the location of the 7 sites selected for this study.

3.2 Analysis

Using a topographic map, slopes were calculated for the natural terrain without taking into account the works done. We proceeded to compare the calculated slop with the observed slope on the field. For this study, it was decided to work with the real, observed slopes. Soil was obtained approximately at a depth of at least 30 cm on undisturbed sites for each neighbourhood and soil testing was done at the Civil Engineering Lab of the Universidad Autonoma de Baja California, Ensenada Campus.

Gain size distribution was obtained as a first distinguishing property. The procedure used was a system of sieves with different mesh sizes, shaking the assembly of sieves by hand and obtaining the grain size diagram (Figure 7).

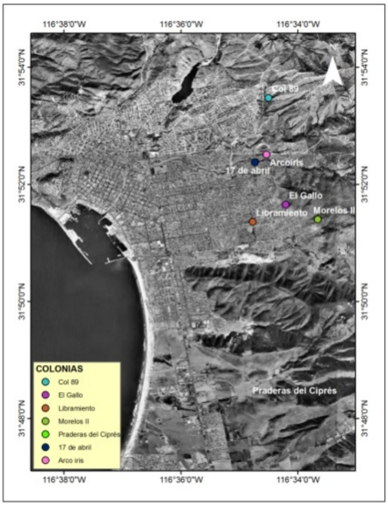

Figure 6: Location of the 7 sites studied.

Figure 7: Soil testing: grain size distribution and weight.

4 Results

Table 1 shows that sand predominates in the soils of the Neighbourhoods studied. This explains the visible erosion and the sliding tendencies as a result of the destabilization by the housing developments (some illegally built on the slope of the hills), and the cuts made for the construction of roads. At “Praderas Del Cipres” a Neighbourhood of recent creation, we found rocks and clay type material (Figure 8), making it a high risk location for landslides and rockslides, when it rains.

Tests done on the slab model reproduced coincides with the types of cracks found on the terrain studied. In particular, at “Praderas del Ciprés”, we found that clay material makes the rocks slide faster than the rocks collected from the “Beltway” subject to the model.

Table 1: Granulometric results for the sites studied.

Site	Location	Depth of collection of material (cm)	Granulometric Composition (%)	Slope Angle for the Model
1: Colonia 89	N 31^0 51.40' W 116^0 33.76'	30	Sand = 99 Silt = 1	45
2: Colonia Morelos I	N 31^0 51.40' W 116^0 33.76'	30	Gravel = 1.0 Sand = 72 Silt = 25 Clay = 2	27
3: Esmeralda Beltway	N 31^0 51.37' W 116^0 34.77'	50	Primary Rock: Granite	33
4: Praderas del Cipres	N 31^0 48.34' W 116^0 34.74'	30	Gravel = 5 Sand = 70 Silt = 25	23
5: Terrazas El Gallo	N 31^0 51.76' W 116^0 34.27'	40	Sand = 75 Silt = 22 Clay = 3	
6: Col. 17 de Abril	N 31^0 52.37' W 116^0 34.70'	40	Gravel = 2.0 Sand = 88 Silt = 10	45
7: Col. Arco Iris	N 31^0 52.73' W 116^0 34.71'	30	Gravel = 3 Sand = 95 Silt = 2	

Figure 8: Testing the soil of Praderas del Cipres.

5 Conclusions

Comparing the results obtained from the granulometric analysis and the model developed to reproduce the conditions in which landsliding occurs, we observe a match with the slope analysis and rock types and sediments carried out based on digital elevation models made by Soares et al. [3, 4].

Although this slide model produced results similar to those found on the field, it is imperative to make corrections for better simulation of the soil compaction and stabilizing due to the presence of vegetation.

This slide model is suitable as a first step for reconnaissance of the behaviour of landslides for the different parts of the city as no landslide inventory is available and will serve as a reference for the Headship of the Civil protection

Agency in the city of Ensenada, so it can implement response programs in case of a contingency produced by landslides in our rainy seasons.

It is important to note that this work was made by the authors with no financial or other type of support. The overall project has just been approved for financial support on December 2010. This will allow us to produce better results.

References

[1] FOTOtv. http://www2.esamas.com/noticierostelevisa/veracruz-inundacion-bajo-el-agua/210597/suman-11-cuerpos-rescatados-deslave-tlahuitoltepec

[2] Cruz-Castillo M., Luis A. Delgado-Argote. *Los deslizamientos de la carretera de cuota Tijuana-Ensenada, Baja California.* GEOS, Union Geofisica Mexicana. Vol 20, No. 4 p 418-432

[3] J. Soares, C. Garcia, L. Mendoza, E. Inzunza, F. Jaurregui & J. Obregon (2008). Slope instability along some sectors of the road to La Bufadora. In C. A. Brebbia & V. Apollo (Eds.), *Sustainable Tourism III*. Malta: WIT Press.

[4] J. Soares, R. Blanco, C. Garcia, E. Inzunza & P. Rousseau (2009). Flooding tendencies for the city of Ensenada, Baja California, Mexico. 1948-2004. In C. A. Brebbia & V. Popov (Eds.), *Water Resources Management.* Malta: WIT Press