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Altos de la Estancia: a Large Landslide Area in Bogota, Colombia- History and Remedial Measures

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Abstract

The Altos de la Estancia landslide area in Bogota, covers 82.8 hectares and is the 2nd largest unstable area in the city. It is located in the southwestern part of Bogota, Capital of Colombia, a city with 8.2 million people sited on a flat lacustrine clay deposit 500m deep at 2,600m above sea level and surrounded by mountains (Figure 1).

Figure 1- Altos de la Estancia- Location (INGEOCIM, 1998)

The landslide area is located in the mountainous poor district called Ciudad Bolivar and it has two large landslides: El Espino Landslide in the northern part and La Carbonera Landslide in the southern part, both limited by a central geological fault that runs along the Santo Domingo Creek (Figure 2)

Figure 2- Altos de la Estancia - General Morphology

In this paper, the Altos de la Estancia area is described with topography, geology, earthquake hazard and landslide hazard. Also a brief history of the evolution of the instabilities and a summary of the remedial measures carried so far are presented

1 ALTOS DE LA ESTANCIA- TOPOGRAPHY

The topography of the Altos de la Estancia area is a monoclinal sloping an average between 15° and 20° in the soutwest-northeast direction and with three main creeks: Santa Rita, Santo Domingo and Carbonera (Figure 3)

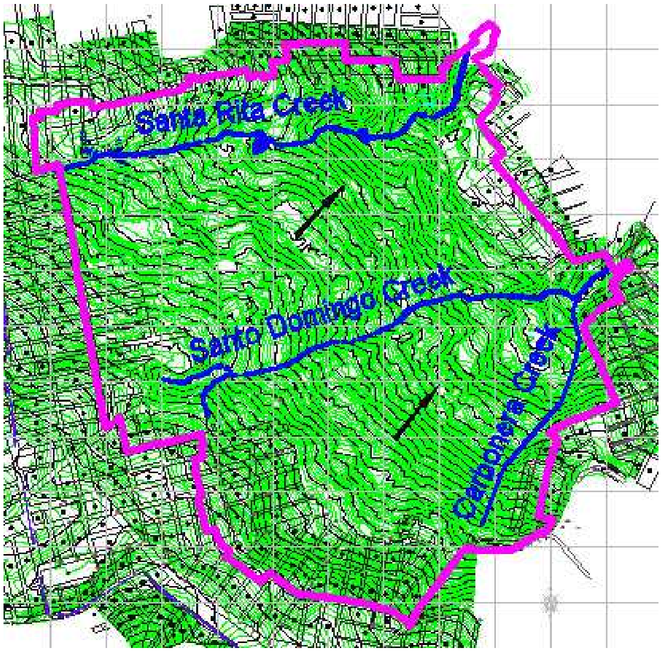


Figure 3. Topography of Altos de la Estancia

2 ALTOS DE LA ESTANCIA - GEOLOGY

Altos de la Estancia is located on the Guaduas Formation (TKg), a coal-bearing formation of Tertiary-Cretaceous age. (Figure 4)

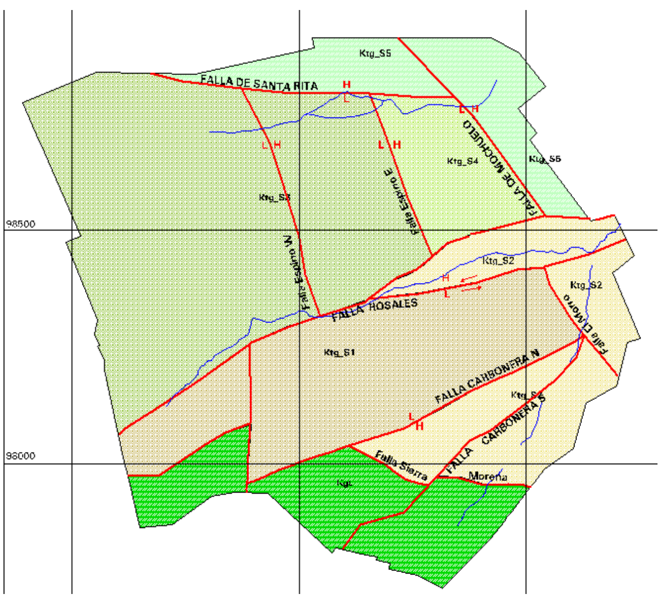
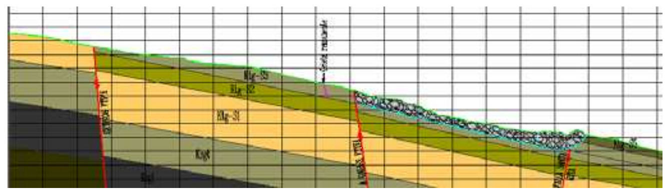


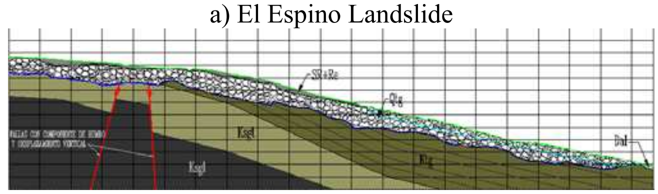
Figure 4. Geology of Altos de la Estancia (IGR ,2004)

The Guaduas Formation has three levels, the coal-bearing level is the inferior one (Tkgi in yellow and brown in Figure 4) and is composed mainly of claystones, interbedded with coal layers and some siltstones and sandstones. The intermediate level (Tkgm in military light green in Figure 4) is composed mainly of sandstones with interbedded medium to thin layers of claystones. The Espino Landslide is located in the intermediate level, whereas the La Carbonera Landslide is sited in a 10m to 20m thick quaternary deposit on top of the Guaduas Inferior Level, remembering that the word “Carbonera” in spanish means coal-bearing. There are also some outcrops of the underying Cretaceous Guadalupe Formation (Kg- in green in Figure 4)

The area is structurally complex with various faults, the more important being those in the general West-East direction and the principal one the so called Falla Rosales (Rosales Fault) which is parallel to the Santo Domingo Creek. Typical geological cross sections of the two landslides are presented in Figure 5



a) El Espino Landslide



b) La Carbonera Landslide

Figure 5. Typical geological West-East cross sections of Altos de la Estancia Landslides (IGR, 2004)

3 ALTOS DE LA ESTANCIA - HIDROGEOLOGY

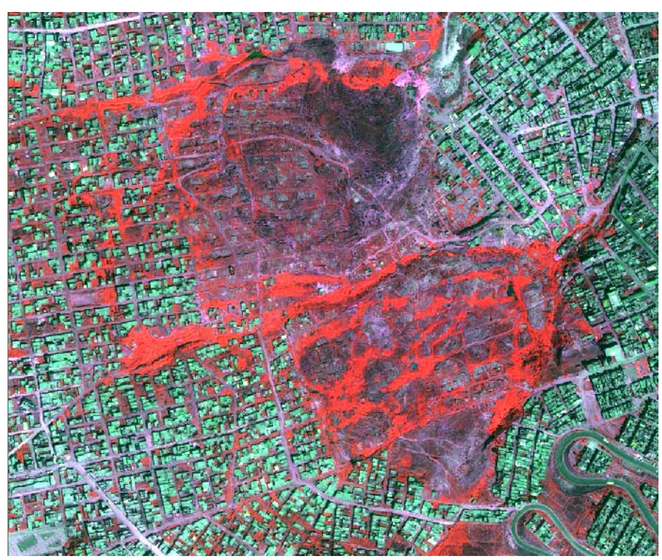


Figure 6. Humidity in Altos de la Estancia (IGR, 2004)

In Figure 6, taken from a satellite image, the levels of humidity of Altos de la Estancia zone are presented, the red ones being the saturated areas. The El Espino northern area shows less red areas, and can be inferred as more permeable than the La Carbonera southern area.

4 ALTOS DE LA ESTANCIA -CLIMATE

The average annual rainfall in Altos de la Estancia is about 650mm (red square area in Figure 7), a low value as compared with the average for the city of about 1,000 mm/year and similar to the annual rainfall in one of the desertic areas of Colombia in La Guajira province.

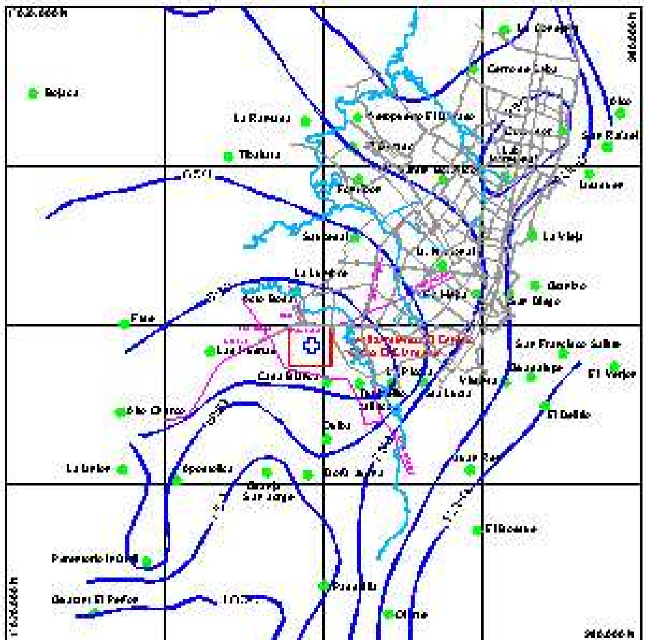


Figure 7. Isohieths in Bogota (IGR, 2004)

There are two annual rainy periods: march to may and september to november (Figure 8)

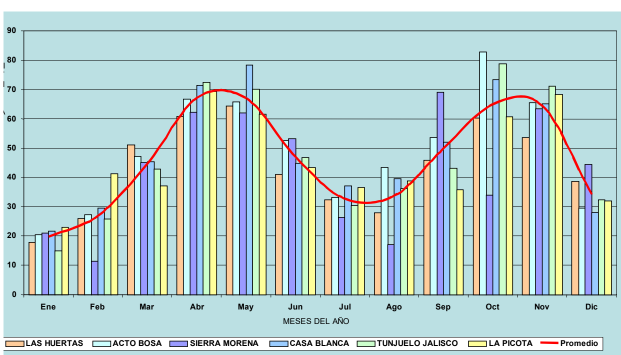


Figure 8. Monthly rainfall in Ciudad Bolívar (IGR, 2004)

5 ALTOS DE LA ESTANCIA- SEISMIC HAZARD

Altos de la Estancia is located in a Seismic Zone denominated Cerros (Figure 9)

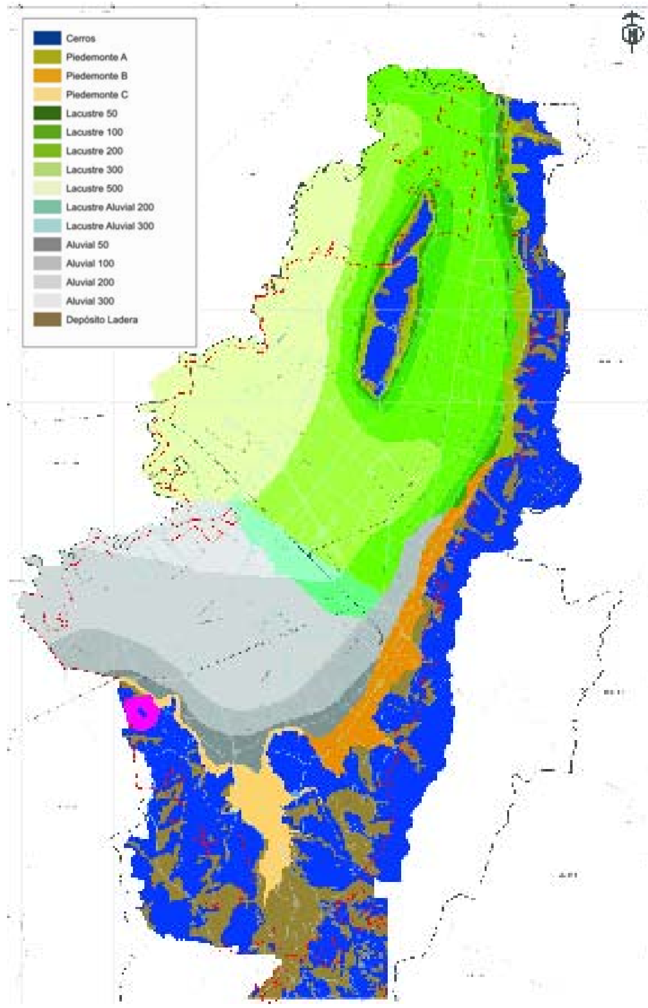


Figure 9. Bogota Seismic Microzoning (FOPAE, 2010)

For Bogota the present design seismic acceleration for buildings is Aa=0.15g in rock for 5% of dampìng and a return period Tr = 475yr. The Cerros Zone has a surface aceleration Ao= 0.18g for the same return period and damping.

6 ALTOS DE LA ESTANCIA - LANDSLIDE HAZARD

Altos de la Estancia is located in an area with Landslide Hazard from Medium to Very High, according to the 1998 Bogota Landslide Hazard map (Figures 10 and 11- INGEOCIM, 1998)

However, there has been many local landslide hazard maps, which have been evolving according to the technical reports done and to the remedial measures taken and they are presented in Figures 10 to 14

Also in Figure 15 the initial zoning to evacuate people is presented (IGR, 2004)

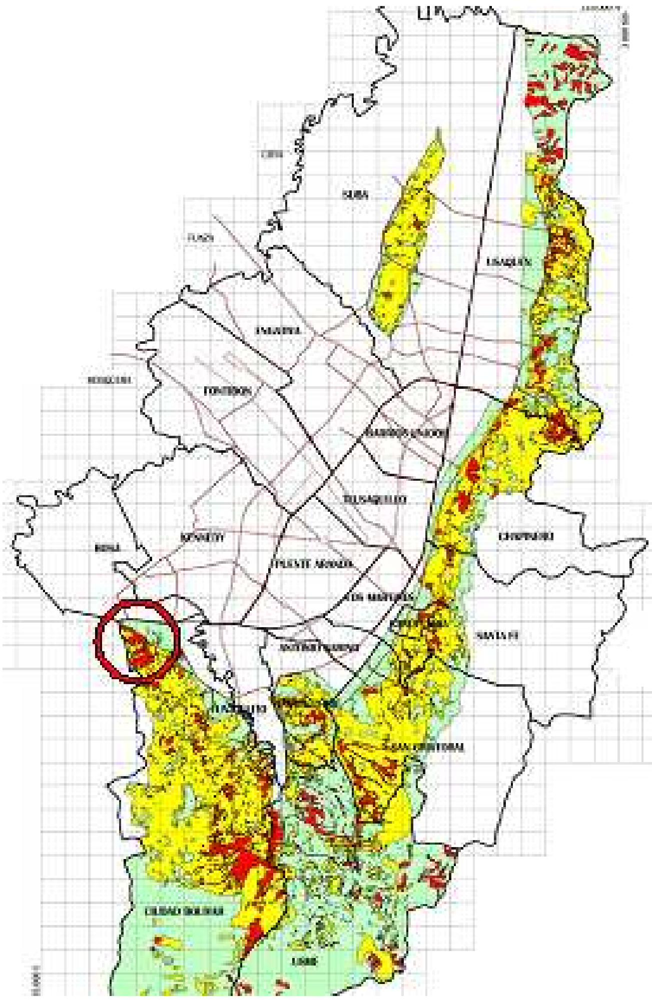


Figure 10. Bogota Landslide Hazard (FOPAE, 2000)

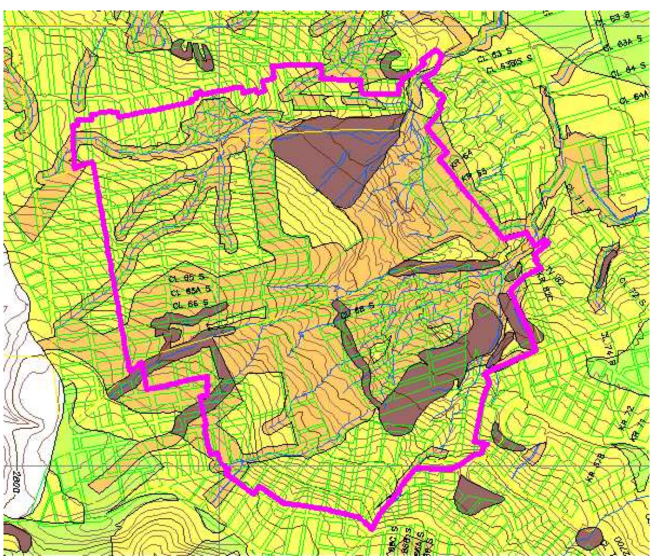


Figure 11. Altos de la Estancia Landslide Hazard Map (INGEOCIM, 1998)

In Figures 10, 12, 13 and 14, the common traffic signal convention is used (red = high hazard; yellow = medium hazard; green = low hazard) whereas in Figure 11 a five level scale is used (brown = very high hazard, red = high hazard, yellow = medium hazard, ligth green = low hazard, dark green = very low hazard)

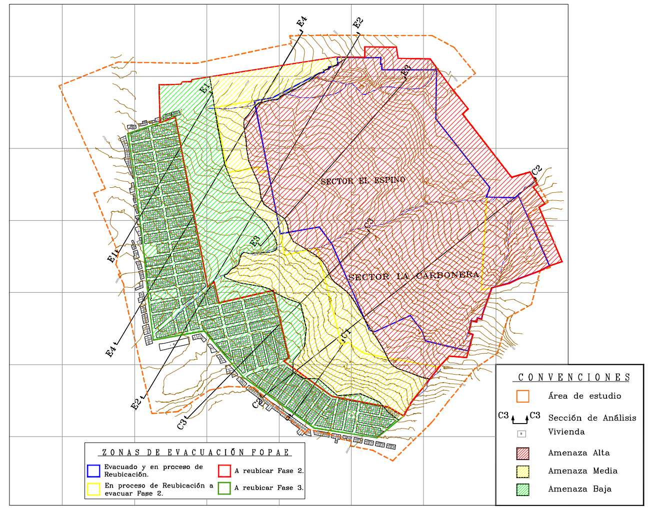


Figure 12. Altos de la Estancia Landslide Hazard Map (IGR, 2004)

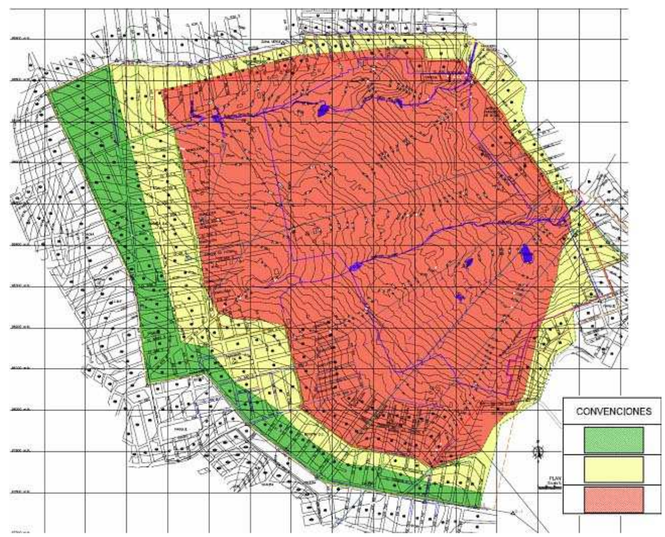


Figure 13. Altos de la Estancia Landslide Hazard Map (CONSORCIO ALTOS, 2008)

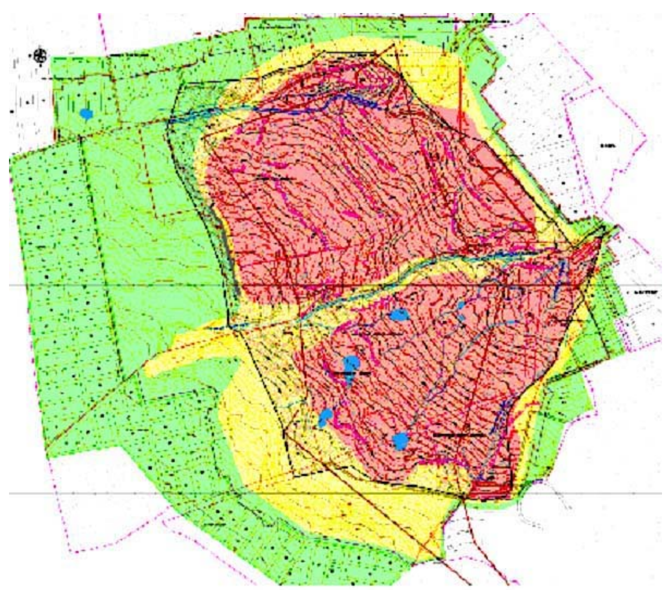


Figure 14. Altos de la Estancia Landslide Hazard Map (CI AMBIENTAL, 2013)

The landslide hazard maps by INGEOCIM (1998) and IGR (2004) were done with scales of probabilities of failure (the Author acted as Director of these two studies) and the CONSORCIO and CI AMBIENTAL maps were obtained with scales of factors of safety, all of them with earthquake and rainfall included. Therefore the effect of the remedial measures can be deduced by comparing these last two maps

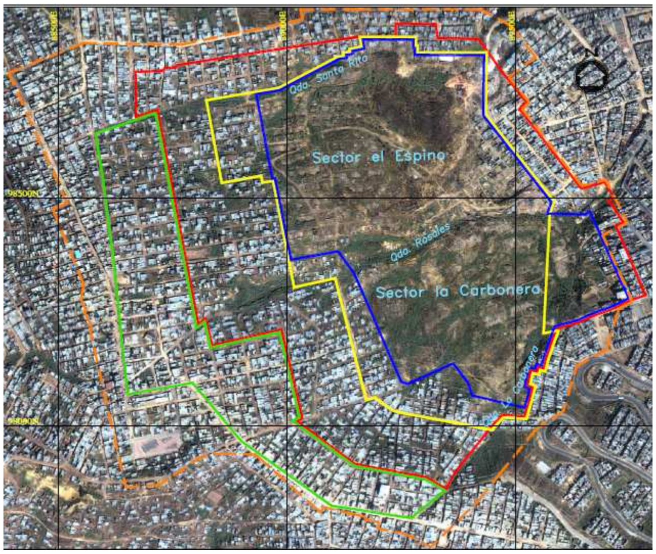


Figure 15. Altos de la Estancia –Evacuation Zoning Map (CONSORCIO ALTOS, 2008)

In this Figure 15, from 2007, the blue zone indicates the already evacuated area in that date, the yellow area the Priority 1 Evacuation Area and the red area the Priority 2 Evacuation Area, which now (2020) is almost completely evacuated. In total about 16,000 persons have been moved out of Altos de la Estancia

7 ALTOS DE LA ESTANCIA – DEVELOPMENT OF INSTABILITIES

7.1 La Carbonera Landslide

La Carbonera area was used as a coal underground mining area perhaps since 1950, when it belonged to the large farm with the same name. The mining operation was rudimentary and the mining waste was disposed near the mines in a non-technical way. Mining personnel was allowed to dwell near the mines, and the landlord also allowed these people to build their houses in those terrains, and then, small and poor communities developed around and nearby the mines

After some time, mining was not allowed by City enforcement, but the communities remained and a poor house settlement developed, which was enlarged by inmigrants coming from different parts of the country, displaced because of the long term conflict with guerrillas since the 50´s and also drug trafficking that had affected Colombia for many years.

Since the urban settlement was irregular according to the urbanistic legislation of Bogota, no public services were officially given to these communities which developed rudimentary water supply systems with plastic hoses connected to a nearby water supply tank and no sewage collection system was built. Therefore disposed water was simply thrown away to water courses or just to ditches in the sloping ground.

Because this erratic use of domestic water and the presence of old coal tailings, some instabilities started in 1997 and in 1999 a first geotechnical study was undertaken (IGL, 1999). After that, several local landslides ocurred in 2000, that implied evacuation of some houses, but it was in 2001, after the El Espino large landslide, that the area was delimited as “Soil Protection for High Non-Mitigable Landslide Risk Area” and declared as such by a City decree in November 2002. (FOPAE, 2014)

7.2 El Espino Landslide

In the Espino area also some mining to extract kaolinitic clays was done in the upper part and at the lower part of the hillslope some open-pit mining for construction materials was active, which caused some small instabilites and also in 1999 a geotechnical study was done (CIVILES-HIDROCONSULTA,1999). Because of surface water coming from uncontrolled disposed water, a sewage network was recommended by this last study for the upper part of the hillslope, already inhabited, and its construction started in the first semester of 2001. Because the S-N streets for the main pipes were located in sandstones, the contractor choose explosives to make the excavations for the pipes, explosives that in August 2001 triggered a huge planar landslide in El Espino along the bedding and a new small hill appeared, near the N-S El Espino East Fault (the intermediate fault in Figure 4).

The topographic levels are presented in Figure 16, where the vertical displacement of 13.1m caused by the slide is presented

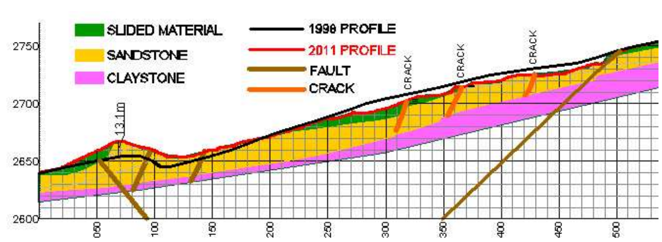
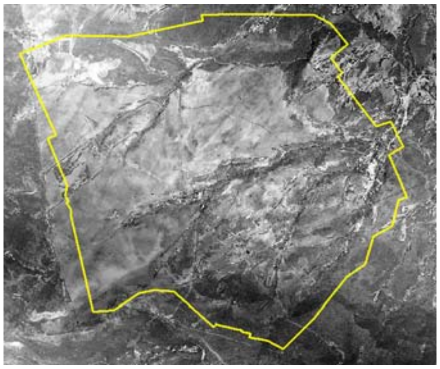


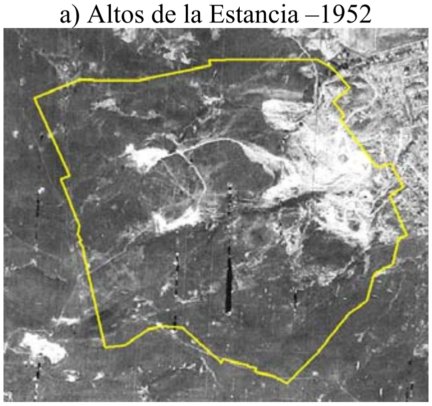
Figure 16. El Espino Landslide- Elevation of the floor

7.3 Historical Aerial Views

In Figure 16 several aerial views of Altos de la Estancia taken from CONSORCIO ALTOS (2008) are presented.



a) Altos de la Estancia –1952



b) Altos de la Estancia –1987

c) Altos de la Estancia –2000

d) Altos de la Estancia –2007

Figure 16. Altos de la Estancia- Historical Aerial Views

In this sequence of photographs, the evolution of the area is seen, with almost no dwellings in 1952, mining scars in 1987, almost full occupation in 2000 and abandoned areas in 2007

8 FAILURE MECHANISMS

8.1 La Carbonera Slide

The inferred failure mechanism is with concave curvilinear surfaces (Figure 17)

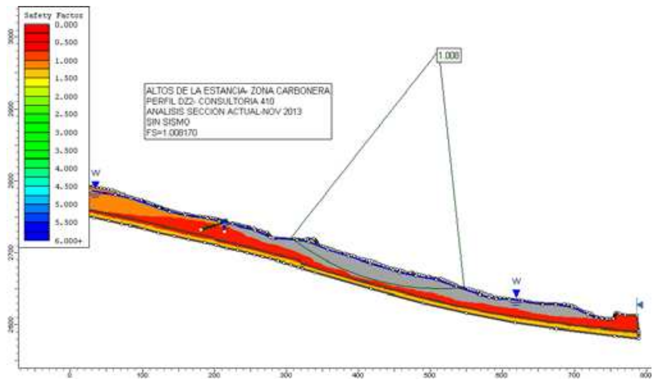


Figure 17. La Carbonera Slide-Stability-Nov 2013- FS=1.01

8.2 El Espino Slide

In El Espino Slide the failure mechanism deducted is a planar rock slide along thin claystone layers interbedded within the main sandstone layers (Figure 18)

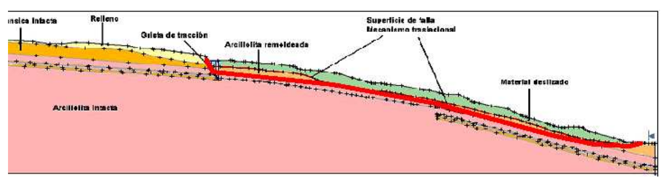


Figure 18. El Espino Slide-CONSORCIO ALTOS (2008)

9 REMEDIAL MEASURES

9.1 Surface Drainage Measures

Figure 19- Altos de la Estancia- Surface Water Control

Since water, both surface and underground, was considered as the main trigger of La Carbonera landslide, and a contributing factor in El Espino landslide, works to control surface water were first considered and constructed (Figure 19)

The three main creeks (Santo Domingo, Carbonera and Santa Rita) were treated with rectified alignments and gabion linings, with typical cross sections as shown in Figure 20

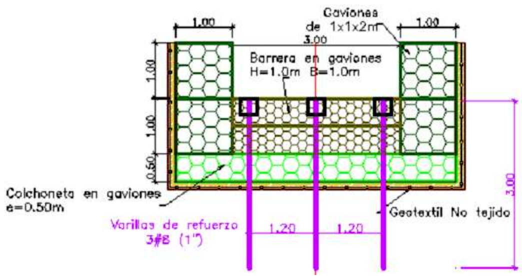


Figure 20- Altos de la Estancia- Typical Gabion Lining

To reduce velocity in the gabion channels, and depending on the slope gradient, gabion barriers were conveniently placed alogn the channels and also to prevent sliding, some times steel bars were used as anchors for the linings

To control the surface water that was coming from the upper inhabited part of the slide area, three small concrete rectangular channels were constructed; Channel 1 discharges in Santa Rita gabion channel., Channel 2 drains into Santo Domingo gabion channel. and Channel 3 goes to Carbonera gabion channel (Figure 19).

9.2 Subsurface Drainage Measures

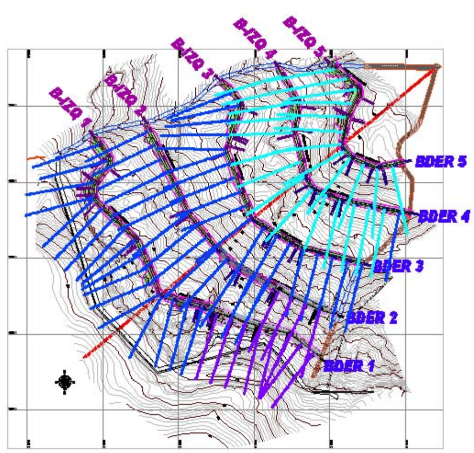


Figure 21- La Carbonera Slide- Horizontal Drains System

Since la Carbonera Area has lower permeability and almost always shows a high water table, subhorizontal drains, inclined 5°, were placed in this area. Some short ones (30m) were placed upstream of channels 2 and 3 (orange in Figure 19), but the main susbsurface system was built in the whole area of La Carbonera slide with 5 berms and 79 horizontal drains from 60 to 90m long (Figura 20) and in stability analyses they proved to be effective by increasing the factor of safety both with high rain and the design earhquake. Underground drainage was not deemed useful in El Espino area because in that place the water table is deep.

9.3 Retaining Measures

These measures were considered preventive rather the corrective and the main purpose was to prevent a remontant behavior of El Espino and La Carbonera slides

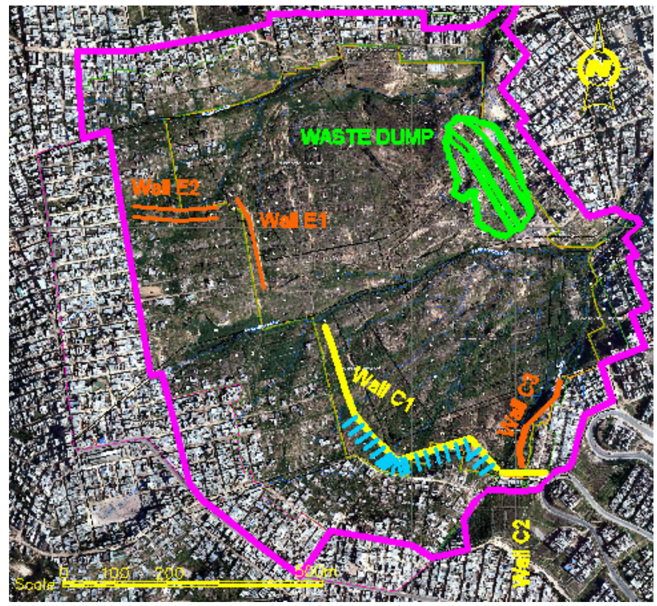


Figure 22- Altos de la Estancia- Retaining Structures

9.3.1 La Carbonera Slide

In La Carbonera there are three retaining walls C1, C2 and C3.

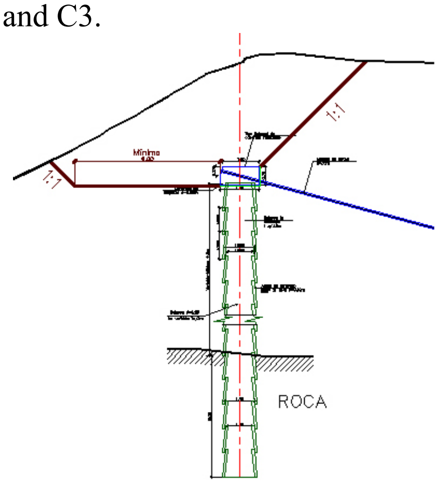


Figure 23- La Carbonera- Retaining Wall with Caissons

C1 an C2 are practically the same type of structure with 12m long, 1.2m diameter reinforced concrete caissons spaced each 4m in a total length of 525m for C1 and 80m for C2. In C1, from each caisson a 50 ton steel anchor is placed to secure the wall (Figure 23). The C3 wall is a 188m long structure with inclined micropiles and a concrete cap, but not anchors (Figure 24)

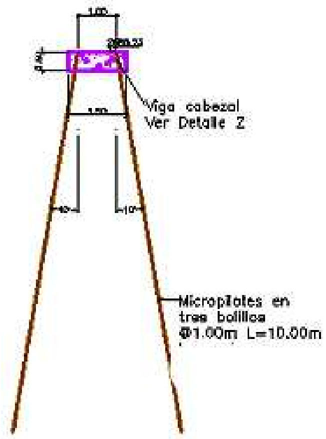


Figure 24- La Carbonera- Retaining Wall with Micropiles

9.3.2 El Espino Slide

In El Espino slide there are two similar walls on micropiles: E1 (180m) and E2 (162m).These walls are on micropiles and each one has two rows of 40m long steel anchors (Figure 25)

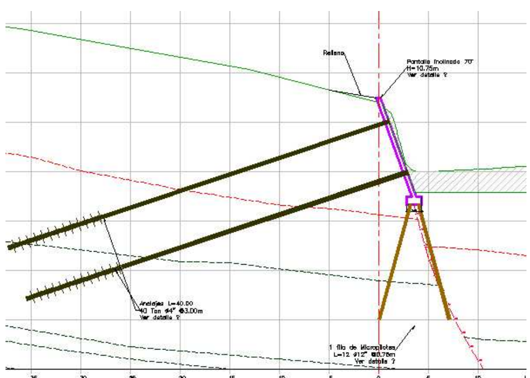


Figure 25- El Espino- Retaining Walls with Micropiles

Figure 26- El Espino- Front View of Retaining Wall E1

In El Espino a Waste Dump Fill was designed, but not built (Figure 22), that is supposed to act as a counterfort at the toe of El Espino Landslide

9.4 Monitoring

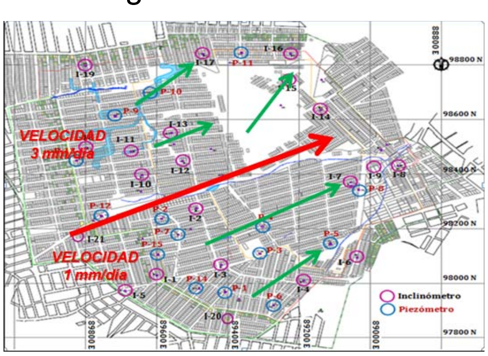


Figure 27- Altos de la Estancia- Surface Velocities in 2007

Although it not strictly a remedial measure, several monitoring campaigns have been done with surface points, inclinometers and piezometers. In Figure 27 an example of surface movement vectors in 2007 is presented.

10. ACKNOWLEDGEMENTS-DECLARATION

The Author thanks IDIGER, the Bogota Risk Management Institute, for permission to use its information for this paper, as the Author has been acting as its Geotechnical Advisor since 2000

The Author(s) declares that he does not have Conflict of Interest with the contents and authorize the Editorial Committee of XIII ISL to publish the paper during the next two years, according of Authors Instructions.

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