Microzonation for the management of landslide risks in natural disasters - Case Study in the Peruvian southern highlands

Christ Jesus Barriga Paria*[a], Jorge Pantaleón Barriga Gamarra[b], Eleonardo Lucas Pereira[c]
[a]*National University of Moquegua, Peru*
[b]*National University Jorge Basadre Grohmann, Peru*
[c]*Federal University of Ouro Preto, Brazil*

*cbarrigap@unam.edu.pe

Abstract

The vulnerability of man and his heritage to natural phenomena in the southern highlands of Peru has increased considerably, especially in the study area. The confirmation of this assertion, which for a large part of the population turns out to be still a hypothesis, forces us to reflect on the schemes foreshadowed by the government agencies related to the subject, in terms of seriously considering why these disasters are less and less natural and what would be the most appropriate management for the risk of landslide. The present case study reaffirms that the interrelation of the physical and social media over time is something that is no longer questioned. This paper analyzes the regionalization of natural phenomena, essential for landslide risk assessment and management. A geotechnical zoning of the case study was carried out based on the geomorphological and soil mechanics study. Likewise, the compilation of the investigations carried out previously in the area, from the field explorations and the results of laboratory tests. Five microzones were identified and the geotechnical hazard zoning concluded with three well-framed danger zones.

1 INTRODUCTION

An analysis of the phenomena that unleash natural hazards must be carried out not only in direct influence, but also in the case study environment to fully cover the full range of external stimuli. According to Dai et al. (2002), these factors (common earthquakes, heavy rains, changes in water level, extreme temperatures or rapid erosions) could be cited as causing a rapid increase in shear stress or a decrease in shear strength of slope formation materials. Landslides representing huge social and property damage each year are one of the main natural hazards (Dowling and Santi, 2013; Li et al., 2016; Grahn and Jaldell, 2017; Froude and Petley, 2018).

According to Li and Wang (1992) is valuable to know the geological structure and topography of the study area, which associated with high intensity rainfall and common earthquakes contribute to significant landslides in mountainous areas, caused a large number of victims and huge economic losses. The uncontrolled interrelation of the physical and social media is a growing trend due basically to urbanization and development in areas prone to landslides, continuous deforestation of areas prone to landslides and increased regional rainfall caused by the change climatic (Schuster, 1996).

This paper identifies natural risks, determines the degree of vulnerability of existing infrastructures to calculate their risk in the area of the case study, through direct and indirect research methods, which allow zoning of high-risk or safe areas (Fell and Harford, 1997; Kirschbaum Bach et al., 2009; Glade et al., 2004). In the safe areas, influence direct and indirect investigations, mainly to know the physical, mechanical and chemical characteristics of the foundation floors, on which a type of foundation for future buildings will have to be applied. Based on the results of these field and cabinet evaluations, the technical capacity will be indicated to indicate the appropriate areas where it should be urbanized. For the present case study, the investigation was divided into three stages: the first stage carried out in a cabinet where all the existing information on the area under study was compiled, such as topography, cadastral base and previous studies; the second stage was in the field, where the necessary data was taken for the analysis, geological mappings, sampling of rock soils, in situ tests, detailed topography and cadastral staking; The third phase was interpretation, which shows the analysis of hydrological data, hazard analysis, risk analysis, microzoning and interpretation of results.

2 METHODOLOGY

2.1 Geological Aspects

With different geological formations, the study area (Figure 1), mostly includes volcanic rocks, intrusive rocks on which quaternary deposits are found (Figure 2). With the presence of the Matalaque Formation that includes lithocrystalline and crystallolytic tuffs, which correspond to the lower Cretaceous, this unit is distributed along the entire right bank of the Curibaya River and the study area, being well welded and in some gap-type sections . The Paralaque Formation has lithic welded tuffs, which are assigned a higher Cretaceous age. This unit is distributed along almost the entire left bank of the Curibaya River and the study area. The Quellaveco Formation has two units, of which only the Samanape Andesite is within the study area, and consists of microporphyric andesites and vitrolytic tuffs, they are assigned a Cretaceous age greater than the Eocene, they are located in both margins, on the Matalaque formation and in the case of the left bank on the Fm. For which. The Tarata Superior Formation consists of pyroclastic rocks, limonites, dark limestones, it is assigned an age of the Upper Paleogene (Oligocene), they are found in the upper parts of both sides of the valley. Alluvial Colluvial Deposits are recent unconsolidated deposits, which are of colluvium and alluvial and colluviums are those found on the slopes, detritus cones on detritic skirts. They are formed by the action of the surface flow of unchanged water, when it flows into the main valley (Curibaya). The texture of the deposits ranges from silt, sand, gravel and buttonhole, subangulous. It is at the base of the debris cones that homes are often located. In the study area they are mainly at the foot of the hills (Wilson and García, 1962).

Figure 1. Satellite view of the study (Google Maps, 2020)

The study area is located in the SW part (2 km.) of a large regional fault, Incapuquio Fault, of NW direction, sinister; This fault is aligned with others of greater length that extend to the north in Chuquibamba (Arequipa) and to the south. Another of medium length, south of the so-called Platform, with the same heading (NW). There are other minor faults, two of them located in the micro-basin of the cone of the Platform, heading further to the NNW, two on the left bank, one in the vicinity of Shintari (NNW), those formations are shown in the Figure 2. The study area, at the regional level, is within the morphological unit called the West Flank of the Andes and within which is the subunit called the Dissected Zone (Jaén, 1965).

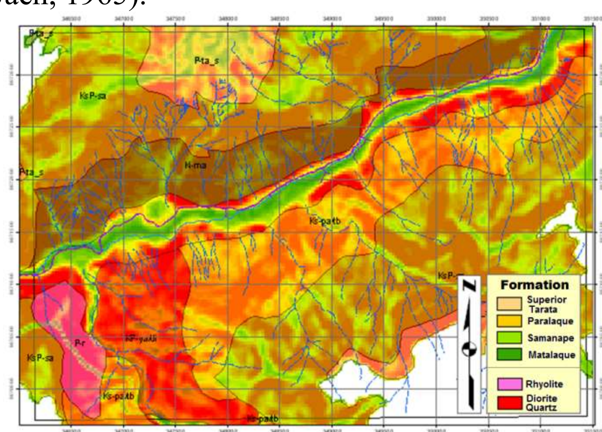

Figure 2. Lithostratigraphic Units of the study area

2.2 Geotechnics of the study area

2.2.1 Soil exploration and sampling

For the soil exploration and prospecting program, they have been developed on the basis of 05 soil research points by opening trial pit that are strategically located taking into account the local geological information of the study area in those areas where it is possible to extrapolate information and extend it to the entire area of interest and in those areas of probable urban expansion, for sampling the strata that make up the subsoil.

2.2.2 Soil mechanics tests

Performed the representative sampling in each one of the trial pit and properly identified, these were transferred to the Laboratory to be tested and to obtain the physical, mechanical, resistance and deformability parameters of the foundation floor. From the point of view of the properties of the soils there is a division according to the tests in the present study that were carried out with international and national standards.

Field test

In this sense, field tests, when possible, stand out as a viable alternative in evaluating the geotechnical behavior of these materials by obtaining the Natural Wet and Dry Density of soil (ASTM D1556 and NTP 339.143) and Light Dynamic Penetration Test. (DIN 4094-2 and NTP 339.159)

Laboratory tests

The physical characteristics cannot do without a detailed analysis of natural humidity (ASTM D2216 and NTP 339.127), granulometric analysis (ASTM D422 and NTP 339.128) of the study area, to evaluate the distribution of particles in their different size ranges. The particle size directly influences the properties of, during the technical development process of the tests. The specific gravity of the grains. The plasticity limit and the liquidity limit were obtained based on the procedures of the Atterberg Limits obtaining procedure (ASTM D4318). The Minimum density (ASTM D4254 and NTP 339.138) and Maximum density (ASTM D4253 and NTP 339.137) were calculated by the regulations are also a physical characteristic of great importance in physical characterization for stability analysis. The Proctor Maximum Density was also developed using ASTM D698 and NTP 339.141. The contents of total soluble salts to know the content of salts and sulfates with regulations NTP 339.152. From these tests, it can be determined whether it is a cohesive or granular soil and also obtain values related to its state of compactness, consistency and compressibility such as: Relative consistency, liquidity index, coefficient of uniformity, curvature coefficient, index of collapse, angle of friction, cohesion.

2.3 Seismicity

The second seismogenic group, produced by cortical deformations, and is associated with the active tectonic faults existing in Peru; this seismic activity is of a lower frequency and of moderate magnitudes. The risk involved is when a project is immersed in the environment of its influence, as is the case of the Incapuquio Fault reactivated during the earthquake of June 23, 2001 (seismicity in the southern region of Peru).

The characteristics of the seismicity of Peru have been described by various authors (Stauder, 1975; Silgado, 1978; Barazangi & Isacks, 1976, 1979; Hasegawa & Isacks, 1981; Cachil & Isacks, 1992) and among the main ones is related with the distribution of the foci in surface and in depth, the same one that has been classified in earthquakes with superficial focus (h<70 km), intermediate (70 <h <300 km) and deep (h> 600 km).

Figure 3 considers the regional seismicity and from it the effects of ground vibration are described, on a standard rigid ground, ideally constituted of outcropping rocky substrate; represents the danger of Base (or Reference), which takes into account the acceleration of peak on the ground and with a probability of exceeding 10% in 50 years.

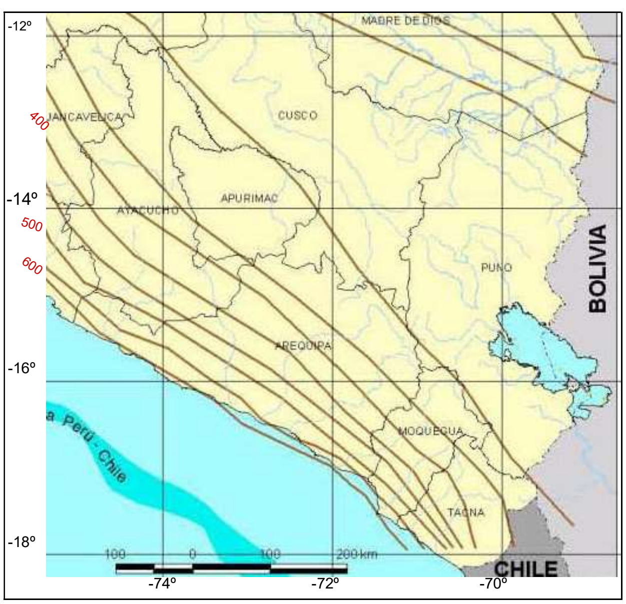

Figure 3. Isoaccelerations map for 50 years

2.4 Expansion Areas

The expansion area I (platform) located at the entrance of the town that comprises an area of approximately 5036 m^2, is based on a well-graded gravel material with non-expansive clay content, of GW-GC classification, of alluvial origin with light brown color, the power of this layer reaches approximately 5.0 m deep, presents clasts of subangular shapes and with diameter of up to 15cm, this material comes from the ravines and drains that are observed in the area.

The expansion zone II (rural property) located at the front of the town, which covers an area of approximately 7992 m^2, is based on a poorly engraved burdensome material with silt contents, of GP-GC classification, of alluvial origin with light brown color, the power of this layer reaches approximately 4.0 m deep, presents clasts of sub-rounded shapes and with diameter of up to 15cm, this material comes from alluvial deposits that correspond to deposits of the main river course formed by a terrace.

2.5 Landslides

The occurrence of landslides is a phenomenon subject to many degrees of uncertainty because the landslides include different types of movements, speeds, failure modes, materials, geological restrictions, etc. Morgenstem (1997) expressed that the role of a safety factor is complex because it does not take into account the uncertainty of ignorance regarding the reliability of the data for analysis, uncertainties in mathematical models and human uncertainties.

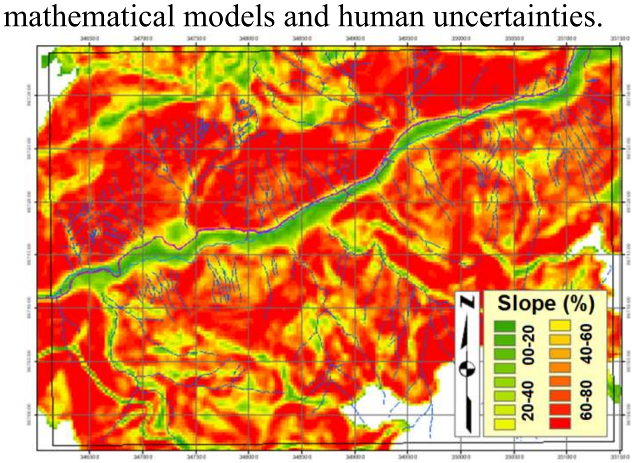

Figure 4. Slope of the study area

Figure 4 represents the degree of inclination of the natural slopes found in the study area. When there is uncertainty about the possibility or not of the occurrence of a phenomenon, generally, wrong design decisions are made. The cost of a project can be very high or risks of undetermined characteristics and magnitudes have to be assumed. A stability analysis of the platform slope of the expansion Zone I was performed as shown in Figure 5.

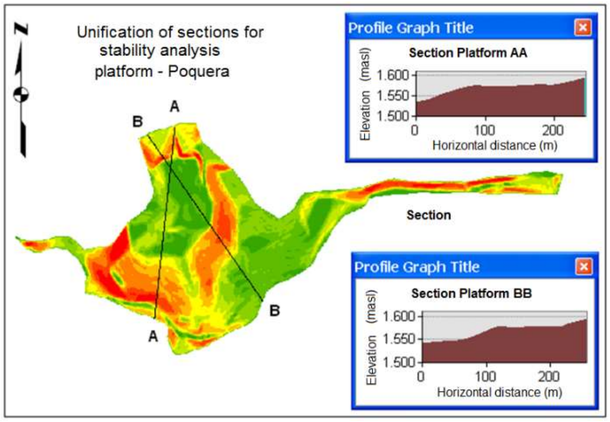

Figure 5. Location of Sections AA and BB, on the Platform, for Slope Stability analysis.

3 RESULTS AND DISCUSSION

3.1 Field and laboratory data

Three horizons have been identified in the study area, the first horizon is made up of river deposits, the second horizon is made up of floodplain-produced soils and the third horizon is made up of canal river deposits, which form the Curibaya riverbed. along the valley, the Curibaya river, in its flood plain has deposited sediments and cut others, due to the hillside processes (detritus cones, detritic skirts, etc.), thus forming terraces, which in general we could indicate a level of terraces. The texture of these terraces includes limos, sands, gravels and boulder. Distinguishing the clasts by their origin: gravitational (subangular), of the laboratory tests carried out in each of the samples of trial pit explored, Table 1, Table 2 and Table 3 are presented.

Table 1: Description of the soil classification

Trial Pit	Depth (m)	Classification		Consistency		
		SUCS	AASTHO	LL	PL	PI
CAP-01	01	GW-GC	A-1-a	22.0	15.8	6.2
CAP-02	01	GW-GC	A-1-a	22.1	16.1	6.0
CAP-03	01	GP-GM	A-2-7(0)	44.9	33.9	11.0
CAP-04	01	GP	A-1-a	20.6	19.4	1.2
CAP-05	01	GW	A-1-a	NP	NP	NP

For the SUCS system, the samples belonging to the GW group are represented by well graded gravel, fine to coarse gravel, those from the GC group by clayey gravel, the GP by poorly graded gravel and finally the GM by silty gravel. The samples with the exception of CAP-03 in their AASTHO classification present the same group A-1-a, where the characteristics of the granulometry test stand out for a No. 10 sieve a 50% maximum passage, for No. 40 sieve a 30% maximum and for sieve No. 200 a 15% intern. A Plasticity Index of 6% maximum. The predominant materials are sand gravel. For sample CAP-03 of group A-2-7 where sieve No. 200 has a 35% maximum throughput, a Plasticity Index of at least 11% and the materials with predominance are sand and sand with silts or clayey.

Table 2: Description of soil in situ Density

Trial Pit	Density in situ		
	Natural (g/cm^3)	Wet %	Dry (g/cm^3)
CAP-01	1.84	1.3	1.82
CAP-02	1.83	1.2	1.81
CAP-03	1.70	1.7	1.67
CAP-04	1.81	1.0	1.79
CAP-05	1.89	0.6	1.88

Table 3: Description of soil Laboratory Density

Trial Pit	Laboratory Density			
	Minimum (g/cm^3)	Maximum (g/cm^3)^{proctor}	Maximum (g/cm^3)	Relative (%)
CAP-01	1.72	2.18	1.860	70.1
CAP-02	1.72	2.17	1.852	68.6
CAP-03	1.45	1.87	1.810	66.7
CAP-04	1.73	2.10	1.820	70.2
CAP-05	1.80	2.17	1.910	72.1

3.2 Hazard assessment

The hazard assessment will be based on the analysis of the coverage formations, which are best, represented and analyzed from a geomorphological and geotechnical point of view; for which the survey on the ground of the Substrate and the Forms has been programmed (Figure 6).

Figure 6. Geological fault, lithological contacts

3.2.1 Field Survey of the Substrate

This characterization corresponds to the collection of geological and geotechnical information.

The geological characterization of the substrate includes a) field work (compass, hydrochloric acid, magnifying glass, symbology) and b) laboratory work (macroscopic and microscopic determination of its components)

The geotechnical characterization of the substrate includes field and cabinet work on soil mechanics and rock mechanics, based on their respective standards: ASTM, SUCS, ISRM, RMR, Q, GSI.

3.2.2 Field Survey of Forms

For the field survey and later elaboration of the geomorphological map, the one that represents the geomorphological units in terms of Landform Patterns Model, or also called process mapping has been considered.

The different processes will be differentiated according to their dynamics (erosion or accumulation) and by the relative activity (active, inactive), according to a color scale (genesis), where each color and stroke has a geomorphological meaning.

3.2.3 Structural shapes

The structural forms refer to the lithological and structural aspects proper, within which there are the following morphological elements: escarpments, ridges, rock.

3.2.4 Forms and gravitational deposits

Within which there are landslides, landslides, laundry, hillside detritus, detritus cone, detritus skirt. These geomorphological features are those of greatest interest in the hazard assessment. Detritus cone located at the foot of a detrital wash (Figure 7).

3.2.5 Forms due to surface runoff water

Within which we have the gullies, erosion escarpments or terraces, alluvial deposits, alluvial cones, colluvial deposit. Alluvial cone is that accumulation deposit, which by way of a fan, is formed by the deposition of some river (Figure 8).

Figure 7. Detritus cone

Figure 8. Alluvial cone

3.3 Physical stability assessment

The application of geotechnical software based on a limit equilibrium analysis, method than allows the determination of the slope factor of safety using the resistance properties and physical characteristics of the material. Stability analyzes of the slopes of the mountains with the highest risk were carried out, with a total of 2 geotechnical sections, under static and pseudostatic conditions.

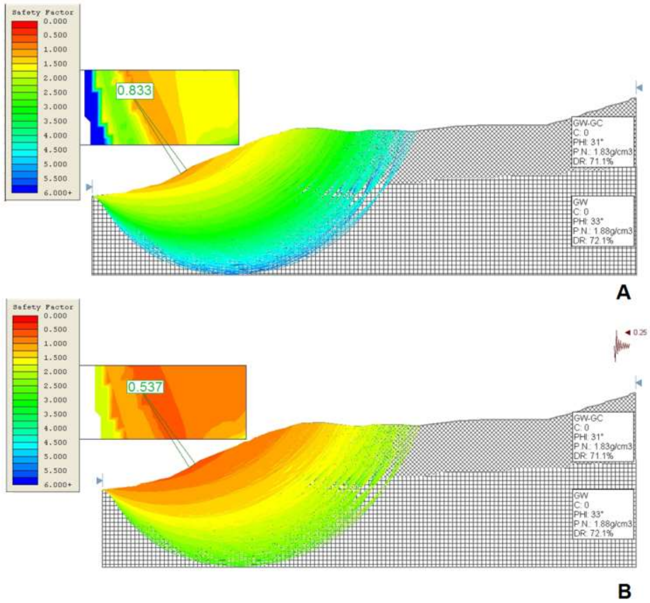

Figure 9. Analysis of the SF in section AA, for all surfaces, in static (A) and pseudostatic conditions (B).

Figure 9A shows that in static conditions the factor of safety has a value of 0.833, a value calculated through a detailed analysis, which expresses that the expected load is moderately greater than the force of the system that prevents slides. Figure 9B shows for seismic conditions (a = 0.25 g), the same slope already presents greater possibilities of instability with a safety factor of 0.537. With reasonable precision, the stability of this slope must be guaranteed, avoiding both external and internal erosion, either with adequate drainage systems or surface waterproofing systems.

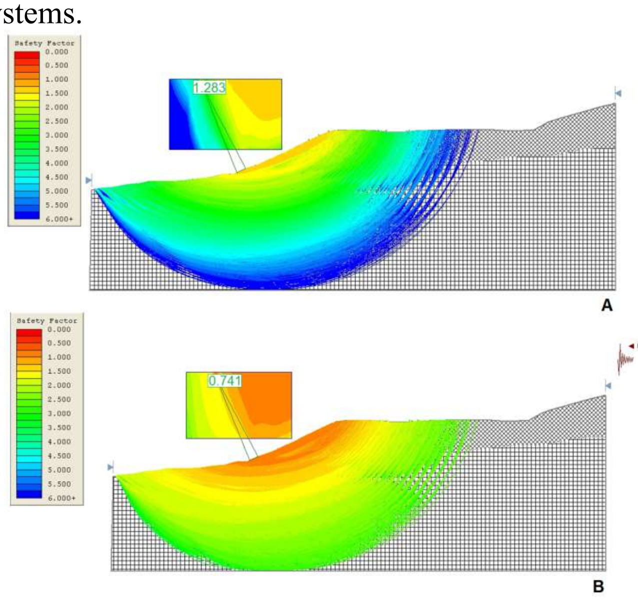

Figure 10. Analysis of the SF in section BB, for all surfaces, in static (A) and pseudostatic conditions (B).

Figure 10A shows the static condition of the slope analysis, by calculating the FS, shows signs of little instability (less than section AA), with a value of 1,283. Figure 10B presents the seismic conditions (a = 0.25g), the same slope already presents possibilities of instability with a FS of 0.741. The capacity of the structure to transport its load must be determined with reasonable precision, recommending an adequate surface waterproofing system or drainage system, to avoid erosion of the structure.

3.4 Microzones

Figure 11 shows five microzones identified by the interpretation of the information obtained in the field data and values obtained during the different tests carried out. Zone I represents the greatest risk and gradually decreases to Zone V.

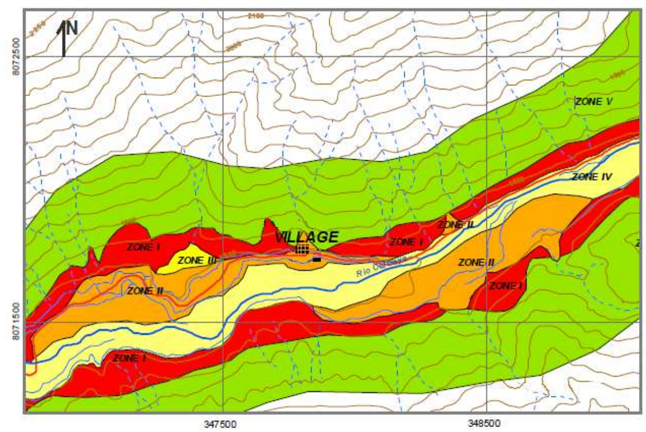

Figure 11. Geotechnical zoning

ZONE I, characterized by being accumulated loose soils, product of landslides, detachment, and flows. Its load capacity values are less than 1.00 kg/cm^2 with amplifications of seismic wave highs. Zone I appears in the slope of the slopes on both flanks of the valley.

ZONE II, is characterized by being gravelly soils with a fine content of alluvial runoff, and diluvial in the area where it is present volcanic clasts, with values of load capacities that are less than 2.50 kg/cm^2 and with amplifications low seismic waves, is occupying the part of the slopes of the hill along the valley. Zone II is covering the existing infrastructure such as the town of and various sections of the main access. It is also presented as part of the expansion Zones I and the entire expansion Zone II.

ZONE III, characterized by burdensome soils of good and poor gradation, of alluvial and diluvial origin, with low amplification of seismic waves. Its loading capacities vary from 2.5 kg/cm^2 to 3.00

kg/cm^2. In the area under study, two sectors have been identified in a timely manner, one that is presented covering the water reservoir sector and the other as part of the expansion Zone II.

ZONE IV, characterized by highly gravelly soils of good gradation and densification due to alluvial and river deposition in the main channel of the valley, has low amplification of seismic waves and soil loading capacities ranging from 3.0 kg/cm^2 to 3.5 kg/cm^2. It is mostly seated on the high voltage line.

ZONE V, these include the geological formations (rocky) of the place, with bearing capacity exceeding 5 kg/cm^2 and low amplifications of seismic waves.

In general, Zones II, III, IV are characterized because they are dense soils, that is, they have relative densities greater than 65%, and according to the analysis performed, the soils are not expandable and present a risk of collapse. From the chemical analysis, it was concluded that the soils of the area of the expansion Zone I and Zone II have a sulfate content that goes from high to very high, so the attack is detrimental to the concrete, which is why it will be essential to use Portland Cement Type V + pozzolan for the preparation of concrete foundation structures.

4 CONCLUSIONS

The zoning of geotechnical hazards concludes with three well framed danger zones.

Low Hazard Zone: Formed by lithostratigraphic units, of rock masses of volcanic origin, and geotechnically referred to as ZONE V.

Medium Hazard Zone: Conformed by dense soils of alluvial and riverine origin, geotechnically referred to as ZONES II, III and IV, they do not present problems of amplification or collapse, they are found in most cases completely covering the populated center, the water reservoir, high voltage line and main access and in expansion zones I and II.

High danger zone: They are deposits of loose material and low consistency such as sands and debris of diluvial, and colluvial origin, geotechnically called ZONE I. Due to the geotechnical conditions this area in particular is expected amplifications of high seismic waves.

The soils in Expansion Zones I and II have sulfate contents ranging from high to very high, which will cause the attack to be harmful to the concrete, that is why it will be essential to use Type V + pozzolan Portland Cement for the preparation of the concrete of the foundation structures; and that there is also no loss of mechanical resistance in the soil due to leaching since the total salt content measured is not greater than 15,000 ppm.

From the expansion zones I and II, basically to the areas where buildings will be built, they must be of noble material (reinforced concrete structures), the town hall having to take into account the conclusions and recommendations of the geotechnical study where the resistance of the bearing of the land, also the study of the dimensioning of the foundation system basically in the expansion zones. On the other hand, there is the alternative of generating specific studies such as the structural analysis of each building from the hazard studies prepared.

ACKNOWLEDGMENT

The authors of this paper would like to thank the City Hall of Ilabaya for the trust and financing of the project for determining risks from natural disasters and mitigation measures. To the National University of Moquegua, Peru (UNAM), Jorge Basadre Grohmann National University (UNJBG), Peru and Federal University of Ouro Preto, Brazil (UFOP) for the dissemination as part of the research and for the help in the work with the valuable discussions and theoretical-scientific contributions which allowed us to improve research.

REFERENCES

ASTM D422-63e2 (2007) Standard Test Method for Particle-Size Analysis of Soils (Withdrawn 2016), ASTM International, West Conshohocken, PA, www.astm.org

ASTM D698-12e2 (2012) Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12 400 ft-lbf/ft3 (600 kN-m/m3)), ASTM International, West Conshohocken, PA, www.astm.org

ASTM D1556/D1556M-15e1 (2015) Standard Test Method for Density and Unit Weight of Soil in Place by Sand-Cone Method, ASTM International, West Conshohocken, PA, www.astm.org

ASTM D2216-19 (2019) “Standard Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass”, ASTM International, West Conshohocken, PA, 2019, www.astm.org

ASTM D4254-16of course (2016) Standard Test Methods for Minimum Index Density and Unit Weight of Soils and Calculation of Relative Density, ASTM International, West Conshohocken, PA, www.astm.org

ASTM D4318-17e1 (2017) Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils, ASTM International, West Conshohocken, PA, www.astm.org

ASTM D4253-16e1 (2016) Standard Test Methods for Maximum Index Density and Unit Weight of Soils Using a Vibratory Table, ASTM International, West Conshohocken, PA, www.astm.org

Barazangi, M. and Isacks, B.L., (1976). "Spatial distribution of earthquakes and subduction of the Nazca plate beneath South America, Geology", 4: 686-692

Barazangi, M. and Isacks B.L., (1979). "Subduction of the Nazca plate beneath Peru: evidence from spatial distribution of earthquakes", Geophys. J.R. Astron. Soc., 57: 537-555.

Cahill, T., and Isacks, B. L. (1992). "Seismicity and shape of the subducted Nazca plate". Journal of Geophysical Research, 97 (B12), 17: 503–529.

Dai, F. C; Flee, C.; Ngai, Y.Y; (2002). "Landslide risk assessment and management: an overview"; Engineering Geology, Volume 64, Issue 1: 65-87.

DIN 4094-2 (2003). "Subsoil - Field Testing - Part 2: Borehole Dynamic Probing". German Institute for Standardisation (Deutsches Institut für Normung).

Dowling, C.A. and Santi, P.M.; (2013), "Debris flows and their toll on human life: a global analysis of debris-flow fatalities from 1950 to 2011", Natural Hazards, Volume 71, Issue 1: 203–227.

Fell, R. and Harford, D.; (1997). "Landslide risk management", D.M. Cruden, R. Fell (Eds.), Landslide Risk Assessment, Balkema: 51-109.

Froude, M.J. and Petley, D.N.; (2018). "Global fatal landslide occurrence from 2004 to 2016"; Natural Hazards Earth Syst. Sci., 18: 2161-2181.

Glade, T.; Anderson, M.G.; Crozier, M.J.; (2004). "Landslide Hazard and Risk", John Wiley & Sons: 824.

Grahn, T. and Jaldell H.; (2017). "Assessment of data availability for the development of landslide fatality curves Landslides", 14: 1113-1126.

Hasegawa, A. and Sacks, I.S., (1981). "Subduction of the Nazca plate beneath Peru as determined from seismic observations", J. Geophys. Res., 86: 4971-4980.

Jaén, H.; (1965). "Geología del cuadrángulo de Tarata (hoja 35.v)". INGEMMET. Boletín. Serie A: Carta Geológica Nacional, 11: 91, 1 mapa.

Kirschbaum Bach, D.; Adler, R.F.; Hong, Y.; Hill, S.; Lerner-Lam; A.; (2009). "A global landslide catalog for hazard applications: method, results, and limitations", Natural Hazards, 52: 561-575.

Li, T. and Wang, S.; (1992). "Landslide Hazards and their Mitigation in China", Science Press, Beijing: 84.

Li, W.; Liu, C.; Hong, Y.; Zhang, X.; Wan, Z.; Saharia, M.; Sun, W.; Yao, D.; Chen, W.; Chen, S.; Yang, X.; Yue; Y.; (2016). "A public Cloud-based China's Landslide Inventory Database (CsLID): development, zone, and spatiotemporal analysis for significant historical events, 1949–2011", J. Mt. Sci., 13: 1275-1285.

Morgenstern, N.R. (1997). "Toward landslide risk assessment in practice. In Cruden, D.M. and Fell"; R; (eds), Proc. Of the International Workshop on Landslide Risk Assessment: 15-24.

NTP 339.127 (1998). "SUELOS. método de ensayo para determinar el contenido de humedad de un suelo". Norma Técnica Peruana, Lima- Perú, 10 p.

NTP 339.128 (1999). "SUELOS. Método de ensayo para el análisis granulométrico". Norma Técnica Peruana, Lima- Perú, 23 p.

NTP 339.129 (1999). "SUELOS. Método de ensayo para determinar el límite líquido, limite plástico, e índice de plasticidad de suelos". Norma Técnica Peruana, Lima-Perú, 27 p.

NTP 339.137 (1999). "SUELOS. Métodos de ensayo estándar para la determinación del índice de densidad y peso unitario". Norma Técnica Peruana, Lima-Perú.

NTP 339.138 (1999). "SUELOS. Método de ensayo estándar para la determinación del índice de densidad y peso unitario mínimos de suelos y cálculo de densidad relativa". Norma Técnica Peruana, Lima-Perú.

NTP 339.141 (1999). "SUELOS. Método de para la compactación del Suelo en Laboratorio". Norma Técnica Peruana, Lima-Perú, 35 p.

NTP 339.143, (1999). "SUELOS. Método de ensayo estándar para la densidad y peso unitario del suelo in-situ mediante el método del Cono de Arena", Norma Técnica Peruana, Lima-Perú. 26 p.

NTP 339.152 (2002). "SUELOS. Método de ensayo normalizado para la determinación del contenido de sales solubles en suelos y agua subterránea". Norma Técnica Peruana, Lima-Perú.

NTP 339.159 (2001). "SUELOS. Método de ensayo normalizado para auscultación con penetrómetro dinámico ligero de punta con cónica", Norma Técnica Peruana, Lima-Perú. 16 p.

Schuster, R.L; (1996). "Socioeconomic significance of landslides"; A.K Turner, R.L Schuster (Eds.), Landslides: Investigation and Mitigation, Special Report 247, Transportation Research Board, National Research Council, National Academy Press, Washington: 12-35.

Silgado, E. (1978). "Historia de los sismos más notables ocurridos en el Perú (1513 -1974)". Instituto de Geología y Minería. Boletín, Serie C: Geodinámica e Ingeniería Geológica, 3: 130.

Stauder, W. (1975). "Subduction of the Nazca plate under Peru as evidenced by focal mechanism and by seismicity". J. Geophys. Res., 80: 1053– 1064.

Wilson, J. J. and García, W.; (1962). "Geología de los cuadrángulos de Pachía y Palca 36-v y 36-x - [Boletín A 4]", INGEMMET. Boletín, Serie A: Carta Geológica Nacional, N° 4: 82.