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SEISMIC VULNERABILITY OF THE HUANCARO-SANTIAGO ECOSYSTEM - CUSCO

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ABSTRACT: The research, the objective is to analyze the geological and geotechnical characteristics of the foundation terrain, as well as the probability of earthquakes and the fragility of the buildings, to finally determine the degree of vulnerability, In the Huancaro micro-basin, as part of the urban expansion of the city of Cusco, base maps were drawn up to identify seismic vulnerability, concluding that there is a high probability of earthquakes occurring between 6 and 7 degrees on the Richter scale and because of the nature of the soils, which are of lacustrine origin (70%) and alluvial fluvial (30%); The fragility of the constructions must also be considered, which especially in the peripheral zones are precarious constructions of adobe without any planning (70%).

KEYWORDS: Seismic vulnerability, ecosystem, geological characteristics, geotechnical characteristics

I. INTRODUCTION

Peru is within the Pacific circle of fire, which means that it is part of the most intense geodynamic system on earth, which includes countries such as Japan, North America, Peru, Chile, and other countries that border the Pacific Ocean. Due to the above mentioned, a great quantity of earthquakes occur in these indicated continental areas; in the case of Peru equally the earthquakes are intense and many times severe; nevertheless it is possible to differentiate two types of earthquakes in Peru, the same ones that are: Inter-plate earthquakes that occur in the coast and adjacent zones to the coast, related directly to the movement of tectonic plates and on the other hand the intra-plate earthquakes, that occur in the interior zones to the coast, rs to say in the heat of mountain range and eyebrow of the forest of Peru; the earthquakes that occur in Cusco correspond to this second group of earthquakes intra-plate, related to the reactivation of quaternary faults with present movement. [1]

The investigations have demonstrated that the quaternary faults (like those found in Cusco) produce superficial earthquakes, less than 70 km. They are deep and, because they are not very damped, are of significant magnitude (up to 7° on the Richter scale).

The city of Cusco is located near a geological megastructure known as the Abancay Deflection. Due to this fact, its structures are oriented on one side of NW-SE and E-W; also, due to recent tectonic activity, many of these fault structures are active (Tambomachay, Qoricocha, Pachatusan, Paruro, Urcos, Zurite, Abancay, etc.).), which means that active faults surround Cusco and that the closest to the city is the Tambomachay fault (only 12 km from the city). [2]

The constructions in the city of Cusco are exposed to the danger of earthquakes, for two main reasons: High probability of occurrence of earthquakes between 6 and 7 degrees on the Richter scale and by the nature of the soils that are of lacustrine origin (70%) and alluvial fluvial (30%); also it is necessary to consider the fragility of the constructions, that especially in the peripheral zones are precarious constructions of adobe without any planning (70%). It should also be noted that they are built on slopes with saturated soils, especially in the peripheral areas, as is the case of the Huancaro micro-basin.

With a design earthquake of 7 degrees of magnitude, in highly dynamic soils (even with some liquefaction zones), vulnerability to earthquakes in the Huancaro micro-basin is quite high (75%).[1] [3]

II. METHODOLOGY

The research we had the specialized or thematic mapping, geomorphological, geological, land use, urbanization areas, monitoring of satellite images, historical data of the origin, growth of urbanization in the last 30 years, statistical data of population and areas of urban expansion, socio-cultural aspects, etc. Hydrometeorological data (SENANMHI) was used, and finally, the physical vulnerability of the buildings was surveyed. [4]

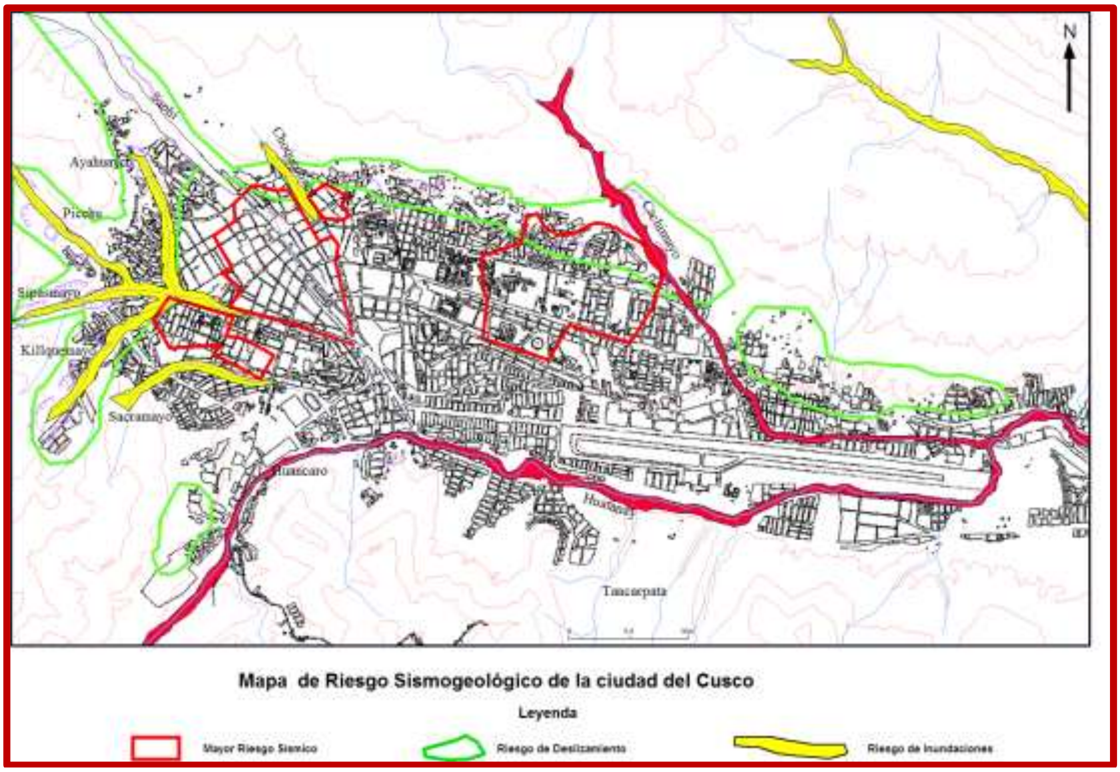


Figure 1: Symological risk map of the city of Cusco, Source: INGEMMET

Figure 1, according to Ingemment, shows the delimitation of the vulnerable zones according to their level of risk.

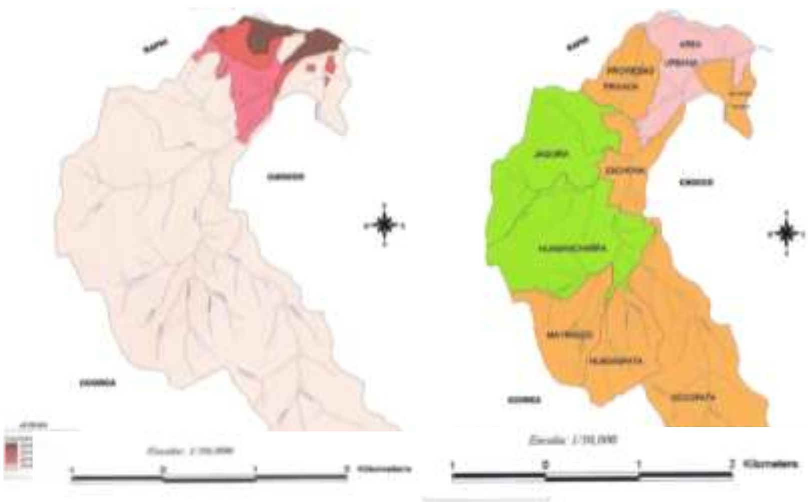
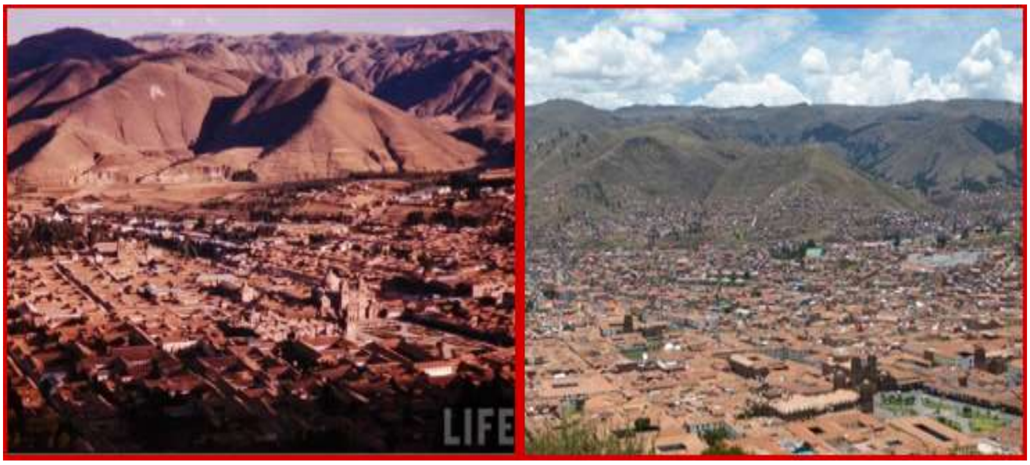


Figure 2: map of the Huancaro micro-basin population density and level of seismic vulnerability.



(a) (b)

Figure 3. The city of Cusco (1960) (a), and the (b) current town of Cusco and the city of Cusco (2019), Source: Life

Figure 3shows the population explosion in recent years has increased alarmingly, in the study area, did not have a flat land surface, was rugged terrain, had diverse geomorphology, had elevations, slopes, orientations, stratifications, rock formation, soil types, etc., which is why the research took an additional time as in figure 2.

III. RESULTS

95% of the houses are made of adobe and are self-constructed, the materials are inadequate in a rugged topography of intense rainfall and high seismicity, there are no defined roads, the accesses are eroded by the Huancaro river (in the rainy season), this makes any emergency attention difficult, and with 80% of the constructions made of adobe, without urban planning, they are very vulnerable to natural geodynamic hazards. There is incessant dumping of waste and solid waste in ravines.

(a) (b)

Figure 4: Self-build adobe homes up to three stories (a) and the (b)houses in the nearby part of the Huancaro river, Own source

Figure 4 shows buildings of up to three floors in a highly seismic zone that constitute very vulnerable housing and on the right side the Huancaro River, where there are houses in the riverbed in which its flow increases by 50 times in the rainy season.

Table 1: Hazard analysis in the Huancaro microbasin

Potential natural hazards			Anthropic hazards
Internal geodynamic processes	External geodynamic processes	**Meteorological processes**	**Human processes**
Earthquakes.	Slides. Landslides. Rockfalls. Floods. Settlements. Downsizing. Erosion. Soil expansion and collapsibility.	Torrential rains. Flooding and flooding. Rashes.	Forest fires. Deforestation. Irrational use of natural resources. Alteration of the environment. Environmental pollution. Inadequate use of the soil.

In table 1, the possible natural hazards have been analyzed.

Table 2: Vulnerability Assessment of Housing in the Arauay Sector (January 1 - Ccachona)

VULNERABILITY	CODE	%	RATING
Non-vulnerable buildings	NV	0	0
Low-vulnerability buildings	PV	0 - 25	0 - 0.25
Medium-vulnerable buildings	MV	25 - 50	0.25 - 0.50
Highly vulnerable buildings	AV	50 - 75	0.50 - 0.75
Vulnerable buildings	TV	75 - 100	0.75 - 1.00

Table 3: Base Matrix for Vulnerability Analysis

Very High Danger	High Risk	High Risk	Very High Risk	Very High Risk
High Danger	Medium Risk	Medium Risk	High Risk	Very High Risk
Medium Danger	Low Risk	Medium Risk	Medium Risk	High Risk
Low Danger	Low Risk	Low Risk	Medium Risk	High Risk
	Vulnerability Low	**Medium Vulnerability**	**High Vulnerability**	**Very High Vulnerability**
LEGEND				
Low Risk	< of 25 %			
Medium Risk	26 % to 50 %			
High Risk	51 % to 75 %			
Very High Risk	76 % to 100 %			

In table 3, through a matrix, the basis of the level of seismic vulnerability has been determined, according to the study zone. This creates a permanent psychosocial problem in people with fewer economic resources, due to the direct relationship between the quality of their homes from their location and the quality of the construction itself (precariousness of the buildings). To the fact of being classified as seismic zone, it is necessary to add the quality of grounds (for construction) that in the zones of urban expansion are constituted by lacustrine grounds and marshes of low bearing capacity (< 2 kg/cm2), a great part of these grounds is the saturated reason why its resistance low still more, in front of the earthquakes they have a seismic amplification until of 0.5 (K = 0.5); with a factor of the zone of 0.30 (Z = 0.30). [5]

The date of occurrence of earthquakes is unpredictable; however, being aware of the seismic zone, it is necessary to carry out prevention and damage mitigation tasks by the fact that having geotechnically poor soils in an area of high seismicity creates a great risk and expands vulnerable areas. In the Huancaro micro-basin, many precarious constructions have been observed (35 % of the total number of constructions), without any technical support in inadequate materials that constitute areas vulnerable to earthquakes and other natural geodynamic events such as hydrometeorological ones. [5] [6]

Every year we can observe the concern of the people, especially in the rainy season, about the "attack" of the intense rains that increase the erosive power of the soils (4 to 5 times), which easily erode the foundations of the adobe houses built on slopes. Also, the inhabitants are almost "accustomed" to the filtrations of the rainwater through the roofs, and the children already live with this culture that within their existence, they must worry about the "leaks" and other catastrophic eventualities. [7]

Table 4: Degrees of Danger

DANGER LEVELS				
DEGREE OF DANGER	FEATURES	EXAMPLES	RESTRICTIONS AND RECOMMENDED APPLICATIONS	VALUE %
1 VERY HIGH DANGER (PMA) (Red Color)	Natural forces or their effects are so great that existing buildings cannot withstand them.	Sectors threatened by landslides or high-speed flooding (Huamancharpa sector)	Its use for urban purposes is prohibited.	4 76 a 100 (12 % of the area)
2 HIGH DANGER (PA) (Orange color)	The natural hazard is high, but effective damage reduction measures can be taken at acceptable costs using appropriate techniques and materials.	Sectors where high seismic accelerations are expected (in the lower parts of saturated soils). Due to their geotechnical characteristics, sectors that are flooded at low speed and remain underwater (low parts of January 1, Arahuay, Etc)	It is recommended to use them as intangible ecological reserves,	3 51 a 75 (20 % of the area)
MEDIUM DANGER (PM)(Yellow Color)	Moderate natural hazards.	The soil of intermediate quality, with moderate seismic accelerations. Very sporadic flooding, with low tension and speed (Intermediate flat areas with semi-consolidated soils)	Urban use is allowed after detailed studies by experienced specialists, to qualify the degree of danger and set the limits with the highly vulnerable sector and recommended for low-density urban use.	2 26 a 50 (35 % of the area)
4 LOW DANGER (PB) (Green color)	Where the probability of intense natural phenomena or gradual soil failure is very remote.	Flat or slightly sloping terrain, compact and dry rock and soil, with high bearing capacity. High lands that cannot be flooded, away from ravines or crumbly hills. Not threatened by hazards. (Settlements in compact and semi-compact rocks and soils of the low slope)	Suitable for urban uses, ratified by geotechnical investigations	1 < 25 (33% of the area)

In table 4, the basis of the level of seismic vulnerability has been determined, in which the average hazard covers the largest sector of the urban zone in Huancaro with 30%, which refers to the central flat areas with semi-consolidated quaternary soils and groundwater. The low hazard constitutes 31% of the urban sector of

Huancaro; these are buildings in high sectors founded on stable rocks with moderate slopes; also, residential sectors of Huancaro with soils of good bearing capacity. [4] [8]

Vulnerability is qualitatively considered in the following ranges: VMA = 1-0.8; VA = 0.8-0.6; VM = 0.6-0.4; VB = 0.4-0.2; VMB = 0.2-0 which in turn corresponds to Very High Vulnerability (VMA); High Vulnerability (VA); Medium Vulnerability (VM); Low Vulnerability (VB) and Very Low Vulnerability (VMB.

Table 5: Vulnerability Assessment in Buildings

VARIABLE	DESCRIPCION		VALOR 0 a 1
DEGREE OF EXPOSURE	**Relative location of the building**	If the building is outside the geodynamic hazard and its area of influence.	0 - 0.3
		If the building is in the area of influence of the Geodynamic hazard.	0.4 - 0.7
		IF the building is within the body of the Geodynamic hazard.	0.8 - 1
	Phenomenon activity	No activity	0 - 0.2
		Little or no activity	0.3 - 0.5
		Medium activity	0.6 - 0.7
		High activity	0.8 - 1
BUILDING VARIABLE	**Main building material**	Concreto armado con muros de albañilería de ladrillo o bloqueta Albañilería de ladrillo o bloquetas con columnas de C°A° de arriostre	0 - 0.2
		Adobe	0.3 - 0.5
		Concreto armado con muros de albañilería de ladrillo o bloqueta	0.6 - 0.8
		Albañilería de ladrillo o bloquetas con columnas de C°A° de arriostre	0.9 - 1
	Structure	Good	0 - 0.3
		Regular	0.4 - 0.7
		Mala	0.8 - 1
	Construction process	Well	0 - 0.3
		Regular	0.4 - 0.7
		Bad	0.8 - 1
	Space distribution	Well	0 - 0.3
		Regular	0.4 - 0.7
		Bad	0.8 - 1
	State of conservation	Well preserved	0 - 0.1
		Regularly preserved	0.2 - 0.3
		Poorly preserved	0.4 - 0.5
		Very badly preserved	0.6 - 0.7
		Collapsed	0.8 - 1
SOIL VARIABLE	**Pending**	Trowel or soft	0 - 0.3
		Moderately pronounced	0.4 - 0.7
		Very pronounced	0.8 - 1
	Soil condition	Compact	0 - 0.3
		Medium compact	0.4 - 0.7

		Loose or sluggish	0.8 - 1

In table 5, Show the characteristics of the vulnerability variables of the buildings in the area are.

Table 6: Vulnerability Analysis

ASSESSMENT FACTOR	VALUE	HOMES (%)
Relative location	0,7	7
The activity of the natural phenomenon	0,7	6
Building material	0,7	25
Structuring	0,7	5
Construction process	0,6	19
Spatial distribution	0,7	8
State of conservation	0,7	10
Pending	0,6	12
Soil condition	0,6	8
Total	**0,67**	**100**

Table 6 shows it is observed that houses are highly vulnerable on average (0.67); as far as the percentages of houses are concerned, it has been found that the greatest factor of vulnerability (25%), corresponds to the bad construction materials used, followed by the construction process (19%) which means that houses are built by the inhabitants themselves; in third place is the slope factor because houses are built on the slopes of the hills where the cost of the land is low. As we can see in table 5 and table 6, the factors indicated are directly related to the economic condition of the settler. [10]

IV. DISCUSSION

The flat and medium flatlands are already occupied (in the border area between urban and rural), so the urban expansion in these places is limited to the highest slopes (above 30°); the most immediate and direct consequence is the growth of vulnerability in geometric scale, due to the following reasons:

Horizontal oscillation and acceleration of seismic waves increase more in areas with high slopes.

Many of the areas of high slopes are found with pre-consolidated or unconsolidated soils, with a very low fixation to rocks, which constitute unstable terrains with a high instability for constructions and a high vulnerability to any catastrophic event.

The constructions in slopes of high slopes are without any planning (generally invasions or illegal lands handled by traffickers); therefore they do not have the routes or the suitable accessibility for many aspects, between them we have: The very movement of people, access for all types of transport; access for firemen; access for ambulances; access for waste collection carts; access for the transport of construction materials; access for the transport of cuttings, etc. [1] [4]

71% of homes have been built on lake floors; 25% have been built on solid rock (these being the most peripheral parts) and 4% on unstable terrain (known as "landfill").

On the other hand, 31% of the houses have been built on relatively flat areas; 32% have been built on moderate slopes, while 26% have been built on high, very high, and deep ravines; 16% along riverbanks.

It is necessary to clarify that flat and moderately sloped areas involve semi-consolidated lake soils, so by crossing the information (in percentages), it can be indicated that there are 65% of houses with low physical vulnerability to natural disasters (earthquakes and hydrometeorological), while 35% of houses are vulnerable to geodynamics.

V. CONCLUSIONS

The very high danger corresponds to 12% of the urban area of the micro-basin and 27% of the high danger, adding the two areas give as a very high and high danger zone 39% especially located in areas close to the accumulation of debris in the sector of Huamancharpa and some areas of urbanization on the edge of the cliffs as seen in 1 de Enero and Arahuay, as well as the sectors of accumulation of cuttings in the streets and streams.

The average hazard covers the largest sector of the urban area in Huancaro with 30%; it refers to the central flat areas with semi-consolidated quaternary soils and groundwater. The low danger constitutes 31% of the urban sector of Huancaro; these are buildings in high sectors founded on stable rocks with moderate slopes; also, residential sectors of Huancaro with soils of good bearing capacity. [1] [2]

The peripheral zones of the cities, as it is the case of the Cusco, by the disorder, the urban precariousness, the forgetfulness and the bad quality of life of their inhabitants are true "incubators" of the in culture, delinquency, gangsterism, alcoholism, drug addiction, prostitution, etc. In other words, the whole set of harmful and counterproductive elements for the sustained development of the peoples; but the most regrettable thing is that the rulers, despite knowing this reality, do not propose serious development policies to attack these evils from the periphery to the center of the cities, because there the greatest problems are found.

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