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The Seismic Vulnerability of Buildings in the Central Zone of Peru through the Application of the Rapid Visual Detection Method

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Abstract In order to predict the occurrence of major earthquakes, the world scientific community carried out the World Seismicity Map, establishing the most seismic zone known as the Pacific Ring of Fire, where Peru is included, as a result of the earthquakes that have occurred and that have led to structural damage to buildings and loss of human lives throughout the history of disasters in the country. The city of Chupuro is located in the central zone of Peru, categorized as a level III seismic zone, which makes it susceptible to seismic events. That is why the purpose was to determine the seismic vulnerability in 226 buildings in the city of Chupuro that were analyzed using the rapid visual detection method (RVS), with the use of the data collection sheet stipulated by the FEMA P-154 methodology, which is quite conservative and is based mainly on the category, structural system, soil and topography, providing a quick evaluation in any type of building and place. The field investigation identified the buildings according to the number of floors, type of construction, year of construction, irregularities in floor plan and height; they showed that 61% of the buildings are immersed to suffer seismic damage and hazards. In addition, these buildings showed that they are prone to suffer grade 2 (moderate damage) and grade 3 (severe damage) damage, mostly comprised of masonry buildings of medium height. It is concluded that there is a clear probability that the damage state of the buildings is 53.1% Grade 2 and 27.0% Grade 3 leading to moderate and severe damage respectively. Finally, with this we want to initiate actions to follow in order to achieve a country less vulnerable to seismic events with adequate management policies that include the population and authorities.

Keywords Seismic Vulnerability, Rapid Visual Detection, Degree of Structural Damage, Buildings and Safety

1. Introduction

In the 70's, the first achievement was to predict the occurrence of large earthquakes, and the first one was the World Seismicity Map. In this way, the zone known as the Pacific Ring of Fire was established, where earthquakes and volcanic activity occur in the interior due to the release of more than 80% of accumulated energy, having the western edge of South America and therefore Peru within the zone. For this reason, according to the Geophysical Institute of Peru in cooperation with the World Bank, the Republic of Peru is located in the zone with the highest seismic activity in the world [1], as shown in Figure 1 and as summarized in the Seismic Map of Peru shown in Figure 2.

According to evaluations of the intensity of the earthquakes that have occurred during the history of Peru, we know that these have been greater than 4.9, which is considered a cause for the deficiency in the structural behavior of buildings. The coastal area of Peru is where liquefaction processes occur, giving a greater risk of occurrence of earthquakes, and on the slopes of the Andean Mountain range, the occurrence of earthquakes that are associated with geological faults with possible secondary effects such as landslides. In the Andean zone, there are specific earthquakes of great magnitude in Huaytapallana (Junín), Ayacucho, Cusco, Abancay and Arequipa due to the presence of important reverse and normal fault systems. For this reason, there is a local deformation that occurs in the central region of Peru (Huancayo) that originates from the process of subduction by the convergence of the Nazca and South American plates, generating seismic events of various magnitudes [2], and this leads to structural damage to buildings and loss of human lives [3]. Unfortunately, due to the lessons not learned from the last seismic events, there are still several buildings that are unsafe and in poor condition [4], although the seismic codes for masonry buildings were modified twice in recent times as E.070-2006 [5] and E.070-2020 [6] with conservative approaches to the design of buildings in case of an earthquake, however, several destructions have been caused by construction deficiencies in seismic events. Therefore, in order to avoid major disasters and safeguard human life in future earthquakes, it is necessary to determine the seismic vulnerability of buildings due to earthquake loads as a fundamental parameter in the seismic disaster management policy [7]. Finally, to contribute to increasing the knowledge of earthquake resistant engineering, in order to avoid catastrophes caused by a seismic event [8], [9].

There are different methods for the seismic evaluation of buildings with a detailed analysis and a good structural design [10]. Performing a more detailed analysis with these methods takes more time and even more if a large number of buildings are evaluated, this becomes a complex and costly task [11]. In addition, experts suggest using a simple assessment to sample common buildings [12]. Rapid visual screening (RVS) is a qualitative method used to assess seismic vulnerability in a quick and simple way based on building characteristics such as seismic zone, soil type, irregularities in plan and height, type of structure, and pre- or post-code reference details [13], through a visual observation of the building from the exterior and interior, with a database collected by a "sidewalk survey" [14].

On the other hand, the district of Chupuro is located in the central region of Peru, province of Huancayo, department of Junín, categorized as an area exposed to seismic hazards, where self-construction is practiced without any technical engineering safeguards [15]. Also, it is located within zone 3 according to the zoning established by Norm E 030[16], where the distribution of zones is proposed based on the spatial distribution of observed seismicity, the general characteristics of seismic movements and their attenuation with epicentral distance, as well as neotectonic information. Given these parameters, four zones are established, with zone 4 being the high seismic hazard zone and descending to zone 1, as shown in Figure 3.

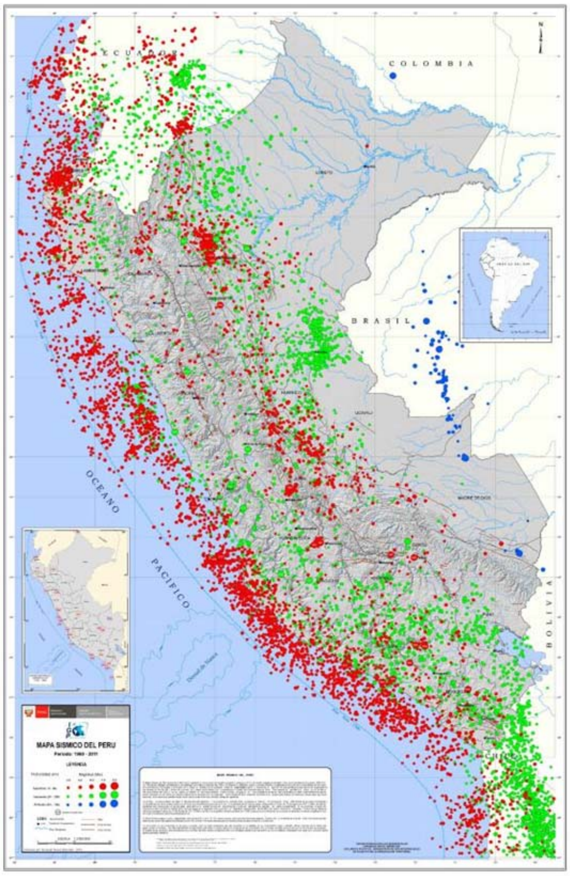
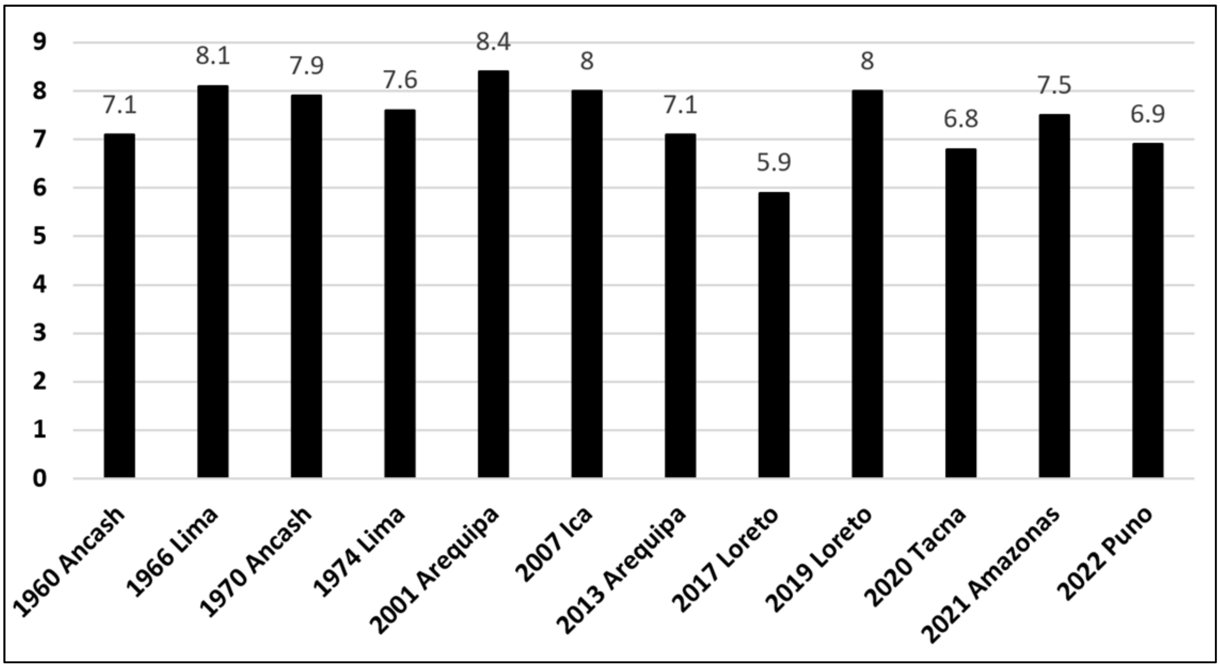


Figure 1. Seismic Map of Peru for the period 1960 and 2011



(Source: Geophysical Institute of Peru)

Figure 2. Magnitude of seismic events in Peru

Figure 3. Seismic zones

It is important to determine the seismic vulnerability in this zone, analyzed by the rapid visual detection method (RVS), all this in order to technically predict the susceptibility of the buildings in this zone or to affirm that a more detailed study is necessarily required by means of an analytical analysis as stipulated by the FEMA P-154 methodology [17]. In addition, it is expected that within the next 75 years, Peru will suffer one of the largest seismic events in the country with a magnitude 8. 8 since according to [18] the presence of a seismic lagoon has been identified in the central region of Peru that has been accumulating seismic energy since the year 1746 (276 years ago), for this reason the main objective is to determine the seismic vulnerability in the central zone of Peru, in order to prevent and inform citizens and safeguard their lives, also with this research will alert the authorities to identify and prioritize areas that need attention and propose solutions in these areas [19], through a map of seismic hazards, with a future planning, therefore making a prediction of the buildings that require a thorough analysis.

2. Literature Review

Over the years, several research works have been carried out to determine the seismic vulnerability in different areas or zones susceptible to damage in their buildings. One of them was Seismic Risk Assessment of Peruvian Public School Buildings Using FEMA P-154 Rapid Visual Screening [20]. This study evaluated the seismic risk in schools located in San Juan de Miraflores under a Rapid Visual Screening methodology, it was found that most of the schools have a high degree of seismic risk and do not meet the requirements of the Peruvian National Building Regulations.

On the other hand, the study of seismic safety for the control of hazards in buildings helps to contribute to urban sustainability [21]. That is why the application of the Rapid Visual Screening method is a vital tool to estimate damage in buildings and the results may vary according to the type of building, soil conditions and seismic zone leading to an overestimation of structural damage [21].

In addition, the evaluation with the RVS method in 201 buildings in Patna showed that 1% of the buildings are grade 5, 23% are grade 4, 75.6% are grade 3 and 0.04% are grade 2 based on the flow chart shown in Figure 4 [22]. Another study conducted for 250 existing buildings in Kota Kinabalu, using Rapid Visual Screening (RVS) method, revealed that 60% of their buildings presented a high risk to moderate earthquake and the most preponderant damage grades are 3 and 4 [23].

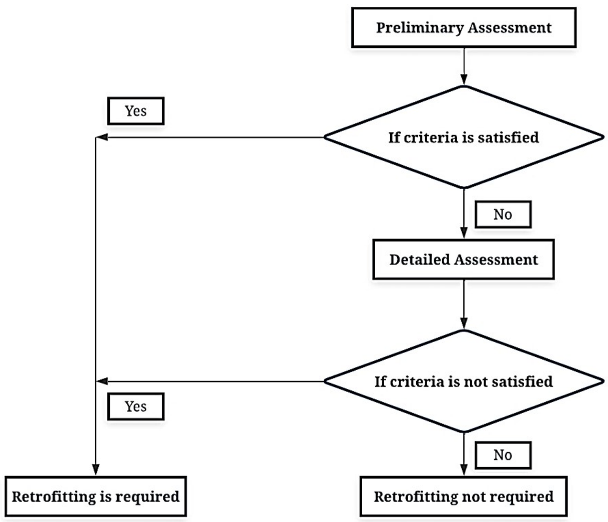


Figure 4. Flowchart of the vulnerability assessment process [19].

New research on seismic vulnerability proposes the elaboration of a more detailed map of seismic hazards in various cities in order to warn the authorities of the potential risk that they are susceptible to in each study area [24]. Next, another study conducted in Kundasang Sabah region (Malaysia) effectively using the Rapid Visual Screening method to assess the seismic vulnerability of each building showed that 66% of the buildings are safe, but 34% of the buildings need a more detailed analysis [25].

The reference [26], indicates that the country of India has poor preparedness to a seismic event, this analyzed under the RVS scheme presents a level of predicted damage quite coincident with the information observed in its existing buildings, which suggested reinforcements and retrofitting in vulnerable areas.

Subsequently, the vulnerability of the buildings is linked to fundamental parameters such as the effect of pounding, soft floor and deficiency in the quality of construction materials [27].

Finally, this qualitative methodology (RVS) had a margin of error of 5% in the evaluation of 100 buildings, also when performing the analytical analysis of seismic vulnerability there was a variation of 14%, which shows that the method generates accurate estimates, to cover numerous existing buildings including reinforced concrete, masonry or reinforced earth [28].

3. Methodology

3.1. Rapid Visual Screening (RVS) Procedure

We know that the FEMA P-154 methodology is quite conservative, so it can yield scores that indicate a higher risk than a building actually has, thus providing us with a rapid seismic evaluation in any type of building and location, based mainly on the category, structural system, soil and topography. For this research work, the Rapid Visual Screening methodology followed a procedure according to Figure 6. For this reason, according to the E.030 Seismic Resistant Design Standard, it must be taken into consideration that the category of the buildings must be a fundamental parameter when choosing the structural system to be used and, in the same way, to know in which operating conditions a building must be found in the face of a severe seismic event. Thus, Standard E.030 alludes that structural systems become a set of elements that provide design and resistance to the loads of itself and external agents, which due to the positioning of each element and its composition helps us to describe the behavior that a building should have throughout its useful life.

In order to carry out this methodology, first of all, we proceed to the selection of the data collection sheet to evaluate the buildings that are mostly made of masonry, which by not using the correct materials in the construction process have as a consequence a greater suspicion in the face of seismic events. It should be noted that the masonry units are one of the materials that present the greatest deficiency in the buildings selected for the study, since units suitable for load-bearing walls should be used, however, the use of "pandereta" bricks was found, which was created to build non load-bearing partition walls. As stipulated in Standard E.070 Masonry, shown in Figure 5, for seismic zone 3 in buildings of 1 to 4 stories or more, the use of hollow or tubular units is not allowed and is also a factor for failure during seismic activity.

TABLE 2			
LIMITATIONS ON THE USE OF THE MASONRY UNIT FOR STRUCTURAL PURPOSES			
TYPE	SEISMIC ZONE 2 AND 3		SEISMIC ZONE 1
	Load-bearing wall in buildings of 4 floors or more.	Bearing wall in 1 to 3-story buildings	Bearing wall in all buildings
ARTISANAL SOLID	NO	YES, up to two stories	YES
INDUSTRIAL SOLID	YES	YES	YES
ALVEOLAR	YES, cells completely filled with grout	YES, cells partially filled with grout	YES, cells partially filled with grout
HUECA	NO	NO	YES
TUBULAR	NO	NO	YES, up to two stories

Figure 5. Masonry units for structural purposes.

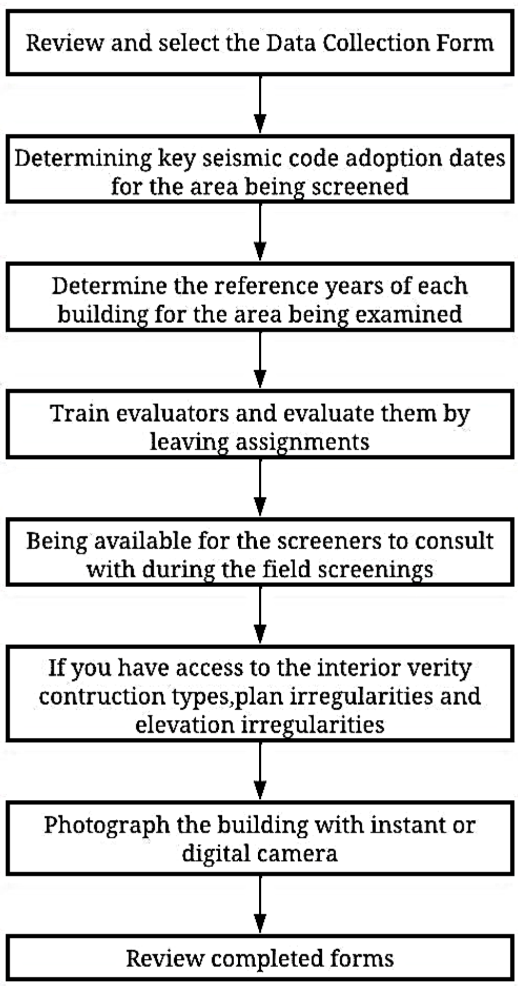


Figure 6. RVS Procedure Flowchart [19]

Then we proceeded to look for the work area, where we inspected and collected complementary data such as the plan, soil types, etc.

Subsequently, groups of junior engineers trained and evaluated in the FEMA P-154 methodology are formed. Then, they are assigned the inspection tasks, based on their technical interpretations, to be sent to the study area, to evaluate the buildings that can be residential, commercial, industrial, educational or governmental centers. [29]. The primary information collected from the survey included photographs of the building, sketches, number of floors, irregularities in plan and height, etc.

Finally, feedback is given to the collected information to check that the record cards have complete data so that then are able to save them in a database.

3.2. General Evaluation of the Study Area

The evaluation was carried out in the district of Chupuro, which belongs to the Junín region and is located in the center of Peru. This district is located in a seismic zone level III (high seismicity) according to Technical Standard E.030 Seismic Resistant Design [16]. The district of Chupuro is adjacent to the west with the city of Lima where there is a history of earthquakes in the years 1650, 1939, 1966 and 1995 causing the loss of human lives and leaving the city in ruins full of debris [2].

The study area was chosen because of the precariousness of its constructions, since the population is constantly growing, and self-construction of masonry-type buildings is commonly practiced, without any advice from specialists or knowledge of construction processes [30]. This reality is due to the lack of the economic factor of the inhabitants in search of new opportunities to access basic needs such as urban sanitation, education, health, among others things [20].

According to the National Institute of Statistics and Informatics, the district of Chupuro has approximately 1315 hectares shown in Figure 7, with a total of 545 buildings, including 105 buildings of noble material (masonry) [31]. It is worth mentioning that the main structural systems used in the area are reinforced concrete, masonry and earthen structures. Therefore, a representative sample of the area was chosen where the buildings were randomly selected, taking into consideration that this choice leads us to buildings that have the necessary conditions and contributions for the study, thus sampling 226 buildings of Steel frame buildings with unreinforced masonry infill walls (S5), Concrete frame buildings with unreinforced masonry infill walls (C3), Reinforced masonry buildings with rigid floor and roof diaphragms (RM2) and Unreinforced masonry bearing wall buildings (URM) shown in Figure 8, which will be analyzed with the Rapid Visual Screening (RVS) method.

Figure 7. Study area - Chupuro.

3.3. Data Collection

The selection of the collection card is characterized on the basis of seismicity. In this case, according to the study area, the high seismicity card was used, based on this, several parameters were analyzed, including occupancy, type of soil, type of building, irregularity in plan and height, before the code and after the reference point, these criteria will be described below.

Occupancy: This parameter is fundamental to evaluate the maximum load that the building can resist according to the surface area and its use as shown in Table 1 [24]

Figure 8. Representative sample chosen for the study, 226 buildings.

Table 1. Permitted Load according to Use

Use of the building	Square feet per person
Assembly	Variable, 10 minimum
Commercial	50-200
Emergency Service	100
Government	100-200
Industrial	200-500
Office	100-200
Residential	100-300
Educational Centers	50-100

Soil Types: Soil type information is extracted from each building owner, in their soil survey or information from governmental entities. Soils type A, B and C are characterized as rocks, type D is rigid soil and type E is classified as soft soil [14] [17].

Type of building: They are classified into 15 types as shown in Table 2 [24].

Table 2. Classification of building types

Type of building	Description
W1	Light wood frame single- or multiple-family dwellings
W2	Wood frame commercial and industrial
S1	Steel moment-resisting frame buildings
S2	Braced steel frame buildings
S3	Light metal buildings
S4	Steel frame buildings with cast-in-place concrete shear walls
S5	Steel frame buildings with unreinforced masonry infill walls
C1	Concrete moment-resisting frame buildings
C2	Concrete shear wall buildings
C3	Concrete frame buildings with unreinforced masonry infill walls
PC1	Tilt-up buildings
PC2	Precast concrete frame buildings
RM1	Reinforced masonry buildings with flexible floor and roof diaphragms
RM2	Reinforced masonry buildings with rigid floor and roof diaphragms
URM	Unreinforced masonry bearing wall buildings

Vertical Irregularity: It is considered when there is a discontinuity in the elevation of its structural elements varying their stiffnesses and when there are inclined divisions and short columns [16].

Plan Irregularity: It is considered when there is a discontinuity in plan of its structural elements varying its stiffnesses and when it does not contemplate a symmetry giving rise to torsion due to its eccentricities [16].

Pre-Code: It is contemplated when the building was constructed before the new seismic codes were proposed in its respective space, having as a base reference the year 1941 [24].

Post-Code: It is contemplated when the building was designed and constructed after the new seismic codes were raised in their respective jurisdiction, this may differ for each type of building [24].

Based on the above, the calculation is made using a formula as shown below:

Final score (S) = Basic score (BS) + Modifiers (SM) (1)

After obtaining the final score, we proceed to associate 5 degrees of damage as shown in Table 3. Grade 1 shows results of minor damage, grade 2 is equivalent to moderate damage with small cracks in the walls and beams, grade 3 means severe damage, causing cracks in the beam-column interaction and the coupling of the wall joints, grade 4 which is very incident causes collapse in the floors by the structural failure of its columns, also grade 5 already has a destructive character, causing the failure from its upper floor to its foundation of the building [17]. In addition, these values must exceed the value of Smin=2 to indicate that it is no longer necessary to perform a deep analysis to determine its vulnerability, otherwise the study will be a more detailed analytical method [33].

Table 3. Degree of damage by SVR score

Rapid Visual Screening Score	Degree of damage
$S < 0.3$	Probability of damage grade 5
$0.3 < S < 0.7$	Probability of damage grade 4
$0.7 < S < 2.0$	Probability of damage grade 3
$2.0 < S < 2.5$	Probability of damage grade 2
$S > 2.5$	Probability of damage grade 1

Some images taken in the study area of the analyzed buildings are shown in Figure 9, Figure 10, Figure 11 and Figure 12.

Figure 9. Reinforcing steel exposed to corrosion

Figure 10. Use of hollow bricks as a structural wall

Figure 11. Absence of confinement elements

Figure 12. Abrupt changes in stiffness of floors

4. Results

With the help of the data collection form, according to the final score obtained from equation 1, different values were obtained to associate with the state of damage. Figure 13 shows the damage states for the buildings under study, with grade 2 being the most incident (moderate damage) and grade 3 (severe damage) of all the samples under study. In addition, for the 226 buildings under study, the minimum accepted values (S=2) were evaluated and all the results were processed for a comprehensive analysis as shown in Figure 14, this indicates that 68.14% of the samples do not require further analysis as they resulted to have a score higher than 2, while 31.86% had values lower than the minimum accepted, which indicates that a deeper analysis should be performed to determine their seismic vulnerability.

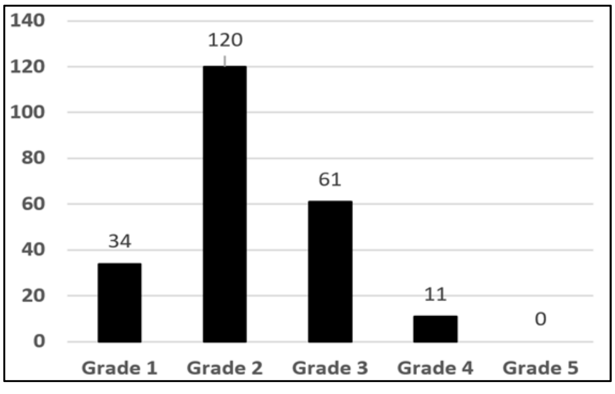


Figure 13. Degree of damage of buildings in the district of Chupuro

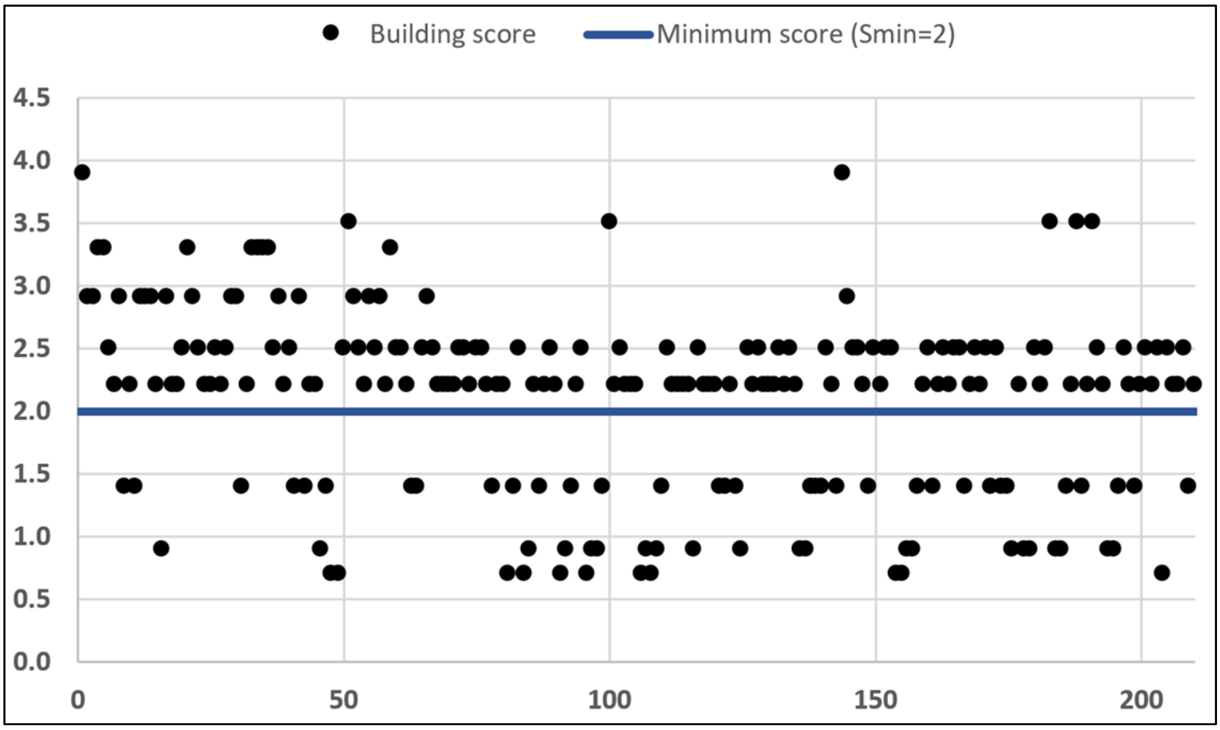


Figure 14. Final score of buildings according to the RVS method

A total of 226 buildings were evaluated; in reference to this, the types of buildings were first classified according to the indications stipulated by FEMA P-154 [17], a bar diagram was made representing the number of buildings according to their type found in the study area as shown in Figure 15. Reinforced masonry buildings with rigid floor and roof diaphragms (RM2) and Concrete frame buildings with unreinforced masonry infill walls (C3) were the most found in the district of Chupuro representing residential and commercial dwellings respectively. While the URM type buildings represent buildings built in the past and the S5 type buildings are characterized as sporting venues.

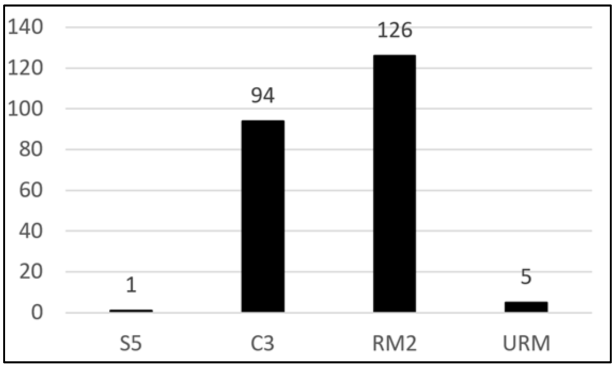


Figure 15. Numbers of buildings according to their types

Next, Table 4 and Figure 16 show the height of all the buildings presented in the research. High-rise buildings are the least perceptible in Chupuro, accounting for 15% of the total, low-rise buildings are regularly visible, accounting for 31%; likewise, the most representative in the area is the medium-rise building (3-4 levels) with a margin of 54%.

Table 4. Type of height according to the number of buildings

Height of the buildings	Number of buildings
Low rise	70
Middle rise	121
High rise	35

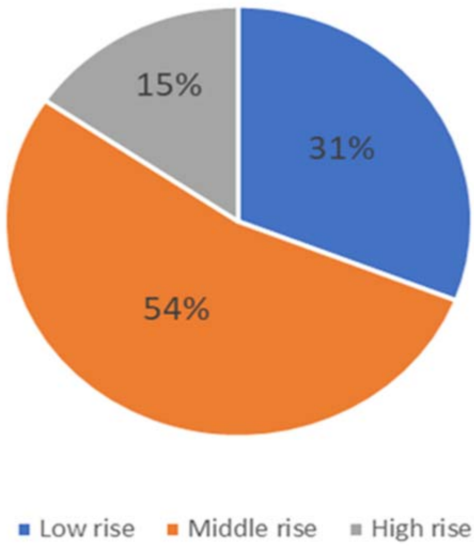


Figure 16. Buildings according to their types of height

Subsequently, according to Figure 17, a balance of scores was made between the minimum accepted and the type of building, the most prevalent in Chupuro area was Reinforced masonry buildings with rigid floor and roof diaphragms, this type of building has 83.3% as accepted values and 16.7% as lower than the minimum. In the same way, the relationship between the minimum value and the most representative building height (Medium) of the zone was performed, achieving more than 51.6% as favorable results, while 48.4% require a deeper analysis as shown in Figure 18.

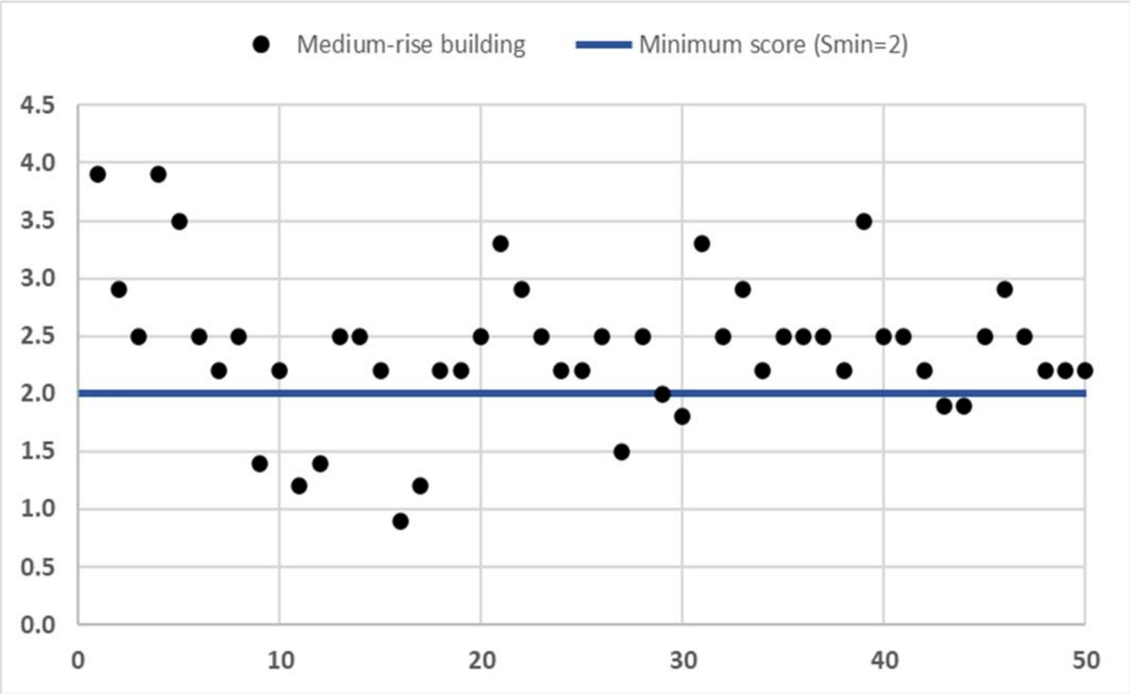


Figure 17. Final score in relation to masonry buildings according to the RVS method

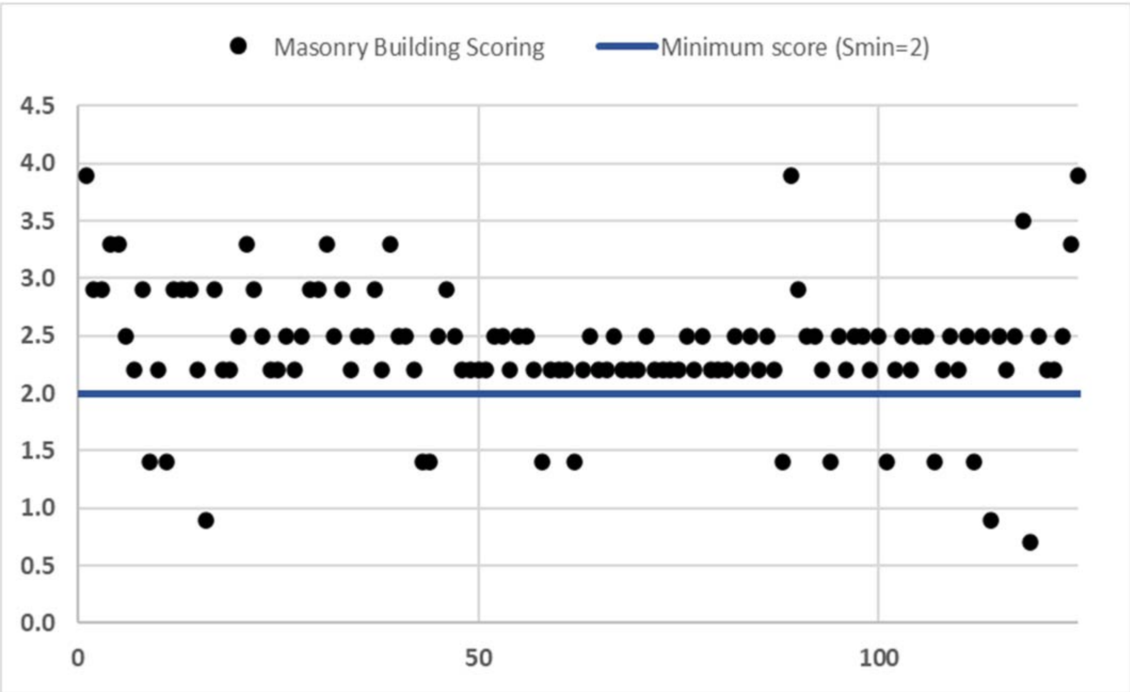


Figure 18. Final score in relation to medium-rise building according to the RVS method

5. Discussion

The seismic vulnerability of the 226 buildings is variable due to their structural aspects, lack of maintenance and the scarce regulatory provisions of the current codes as indicated by [22], since management policies in Peru have been recently implemented and actions have been initiated recently in order to achieve a country that is less vulnerable to seismic events.These factors originate the susceptibility to suffer risk to hazards, this agrees with predecessor research carried out in Peru [34], this mentions that most of the buildings are built without design or engineering supervision, so it is evident a high seismic vulnerability, then when a seismic event occurs, the damages will be very significant, also the irregularities found in the buildings of the research show that it is another cause of a high probability of seismic vulnerability, this agrees with the research carried out in India [35].

Of the 226 buildings studied, according to Figure 9, 120 reached the state of damage grade 2, which means to suffer moderate damage, this is due to irregularities in plan and height [36]; also 61 buildings belong to grade 3 as they have structural deficiencies that do not comply with the Peruvian Seismic Design code, also 34 buildings had a probability grade 1 which represents just 15%, this percentage is close to a study conducted in the district of Chongos Bajo, which is located about 19.6 km from our study area, this is due to the fact that few people hire professionals in construction, which currently according to [37], most of the Peruvian population is not aware of the dangers and effects that can cause an informal building without any structural technical support to ensure its safety. It is of utmost importance to reinforce structurally to increase the percentage of safer buildings in the district of Chupuro, which in the future will also serve as a shelter during a seismic event [38].

This RVS methodology does not have a deep system, but it helped to evaluate the buildings in a quick and simple way. In order to provide information to the responsible authorities, for the updating of seismic hazard protocols [39], through structural reinforcements, based on the new requirements of the seismic codes in order to avoid the inefficient use of resources [40], this will also allow making decisions for further study.

6. Conclusions

We know that in Peru, risk management policies were given recently, and actions have been initiated to follow to achieve a country less vulnerable to natural hazards such as earthquakes, this because the loss of human lives by the event itself is generally few, but most of the victims are presented by the collapse of structures. It remains to know the location of the highest risk areas and a practical way to do it, which should be reviewed through history.

Earthquakes are cyclical, where an earthquake occurred, another one will occur again in the future and will bring with it similar damages and effects. In other words, the scenarios of the past will repeat themselves, but perhaps now this one is more critical due to the increase in population and the disorderly urban development of cities.

Rapid Visual Screening (RVS) is a conservative and efficient tool to evaluate large numbers of buildings in a fast, simple and low-cost way, as it provides scores that indicate a higher risk than a building actually presents. Taking into consideration that the different scores established for each parameter were defined by expert judgment.

According to the results of the RVS survey in the present study, it was observed that 68.1% of the buildings are susceptible to hazards or risks in their structure upon the occurrence of a high seismicity, consisting of 55.8% of buildings of the Reinforced Masonry type. 8% of type Reinforced masonry buildings with rigid floor and roof diaphragms, 41.6% of type Concrete frame buildings with unreinforced masonry infill walls, 2.2% of type Unreinforced masonry bearing wall buildings, 0.4% of type Steel frame buildings with unreinforced masonry infill walls and most of them are of medium floor plan.

Likewise, it was observed that there is a clear probability that the district of Chupuro will suffer moderate to severe damage to its buildings during a seismic event, with values of 53.1% Grade 2 and 27.0% Grade 3 respectively, while 68.14% of the buildings with results less than or equal to grade 2 apparently induce that they are sufficiently stable and safe in any earthquake, which do not require a deeper analysis, otherwise if it is desired to know their seismic vulnerability, a detailed analytical method should be used.

Finally, the results of this research should be used for the incorporation of a seismic hazard map of the district of Chupuro for the complementation of future anti-seismic projects, also to lead to a deeper study with a quantitative analysis for the buildings that require it, also for the knowledge of the authorities of the district of Chupuro for future prevention and lead to form new plans of safety measures for any future catastrophic event. The population and authorities must consider an adequate structural development and a respectable level of prevention and damage mitigation culture.

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