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Seismic Vulnerability Assessment in Non-Engineered Dwellings Using RVS Methods and Its Validation with a Quantitative Approach

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Abstract **-** This research presents an analysis of seismic vulnerability in dwellings built without engineering criteria, aiming to determine their levels of vulnerability. Rapid Visual Screening (RVS) methods, such as those proposed by FEMA P-154 and developed by INDECI, were employed to assess the vulnerability of 20 dwellings. Additionally, a quantitative validation was conducted on two of these dwellings using parameters like lateral drift to complement the qualitative analysis. The results obtained through FEMA P-154 indicate that 50% of the dwellings exhibit a "Very High" level of vulnerability, 45% a "High" level, and 5% a "Low" level. Meanwhile, the INDECI method classifies 45% of the dwellings as having "Very High" vulnerability and 55% as "High." The quantitative evaluation of lateral drift showed that Dwelling 1 and Dwelling 2 experienced excessive drift values of 0.006979 and 0.004624, respectively, classifying both as "vulnerable" to seismic events. When comparing the qualitative methods (FEMA P-154 and INDECI) with the quantitative method (lateral drift), slight discrepancies were identified in the assigned vulnerability levels, although they maintained a close correlation. While the qualitative methods indicated high and very high vulnerability, the quantitative method classified them as "Vulnerable." Despite these differences, the results converge in highlighting the high susceptibility of the analyzed dwellings to seismic events. These findings emphasize the need to prioritize structural reinforcements to reduce seismic risk levels in the evaluated area.

Keywords**:** Seismic vulnerability, FEMA P-154, INDECI, informal dwellings, RVS methods.

1. Introduction

Seismic vulnerability in self-built dwellings without engineering supervision is a critical issue in high-seismicity regions, especially in densely populated urban areas such as Las Gaviotas de Oquendo, Callao, Peru. Informal construction in these areas significantly increases the risk of structural collapse during an earthquake due to the lack of proper design standards and the use of low-quality materials [1,2]. This situation is common in various regions worldwide, and the need for rapid and effective assessments has driven the development of rapid visual screening (RVS) methods, such as those proposed by FEMA P-154 and INDECI, to preliminarily estimate the seismic vulnerability of dwellings [3,4].

The state of the art in seismic vulnerability assessments has shown that RVS methods are effective in identifying at-risk dwellings, although they have limitations in terms of accuracy and subjectivity, especially in informal constructions with complex architectural configurations. Some studies have proposed improvements to traditional RVS methods by incorporating fuzzy logic systems, which help manage uncertainty and reduce the inherent subjectivity in visual inspections [5,6]. Furthermore, recent research in similar environments, such as unreinforced masonry dwellings in Peru and the Himalayan region in India, has implemented complementary analyses, including fragility curves and lateral drift tests, to quantitatively validate RVS results and provide a more robust risk assessment [7,8]. Additionally, digital tools have been developed to integrate qualitative resistance and vulnerability indices, enabling more accurate and accessible assessments of at-risk dwellings. These tools have also proven effective by adapting to local regulations and optimizing the speed of analyses [9,10].

This research addresses the seismic vulnerability assessment of 20 dwellings in Las Gaviotas de Oquendo using the RVS methods of FEMA P-154 and INDECI, and performs a quantitative validation on two of these dwellings through lateral distortion analysis. The lateral drift analysis allows for an accurate quantification of the structural risk of the dwellings, complementing the initial assessment conducted with RVS [11,12]. This integrated approach responds to the need for methods that combine speed and accuracy to identify and quantify the seismic vulnerability level of the analyzed area, offering a methodological tool that facilitates decision-making and the formulation of effective mitigation and structural reinforcement strategies to improve population safety against future seismic events.

2. Methods and tools

For the seismic vulnerability assessment of the dwellings in the Las Gaviotas de Oquendo neighborhood, the study employs a combination of qualitative and quantitative methods, incorporating tools and techniques that enable a comprehensive evaluation. The methodology is organized into three main components: the use of rapid visual screening (RVS) methods through the FEMA P-154 and INDECI approaches, and a quantitative analysis of lateral distortions supported by ETABS software.

2.1. Qualitative RVS Methods

Los métodos RVS son herramientas de inspección visual que permiten clasificar preliminarmente el nivel de vulnerabilidad de las edificaciones [13]. En este estudio, se utilizan dos enfoques: FEMA P-154 e INDECI.

- FEMA P-154: Developed by the Federal Emergency Management Agency (FEMA), this method focuses on a rapid classification of buildings based on the observation of structural and geometric characteristics, such as configuration and construction materials [14, 15]. This method allows for the assessment of a building's seismic vulnerability by identifying factors that influence its structural performance [16].
- INDECI: Adapted to the Peruvian context, this method expands the FEMA P-154 analysis by incorporating local factors such as soil type and compliance with national regulations, making it particularly relevant for assessing non-engineered dwellings [17, 18].

The combination of both methods enables a more accurate preliminary assessment by integrating an international standard with an approach tailored to the local context.

2.2. Quantitative Method: Lateral Distortion Analysis Using ETABS

To complement the qualitative assessment, a structural analysis of lateral distortions is conducted using ETABS, a software specialized in simulating the seismic behavior of buildings.

- Structural Modeling in ETABS: Detailed models are created, incorporating geometry, materials, and architectural configuration to accurately replicate the structural response to loads, facilitating the identification of potential critical vulnerability points.
- Lateral Distortions: The lateral distortion analysis in ETABS measures the relative displacement between floors, a key indicator of seismic vulnerability. This method evaluates the structural resistance to deformations and susceptibility to damage, quantitatively complementing the qualitative assessment of RVS methods.

3. Methodology

To conduct this study, 20 dwellings in the Las Gaviotas de Oquendo urbanization were assessed using rapid seismic vulnerability evaluation methods, specifically those proposed by FEMA P-154 and INDECI. Through this qualitative assessment, a preliminary classification of seismic vulnerability levels was obtained for each dwelling, allowing for the identification of those with the highest structural risk.

Subsequently, in two of these dwellings selected based on their vulnerability level a lateral distortion analysis was performed using ETABS software. This quantitative analysis focused on calculating the detailed structural response under seismic loads, providing an accurate measure of the structures' susceptibility to an earthquake.

3.1. Application of FEMA P-154

Visits were conducted to the dwellings to identify their structural and architectural characteristics, recording the information in inspection forms. The structural configuration was assessed based on its construction system and geometric layout, identifying potential weaknesses. Vulnerability scores were then assigned considering factors such as height, age, and state of preservation, classifying the dwellings into risk levels according to an established scale.

Table 1: Vulnerability classification according to FEMA P-154.

VULNERABILITY INDEX	
Very high	0 - 1
High	1 - 2
Medium	2 - 3
Low	3 - 4

3.2. Application of the INDECI Method

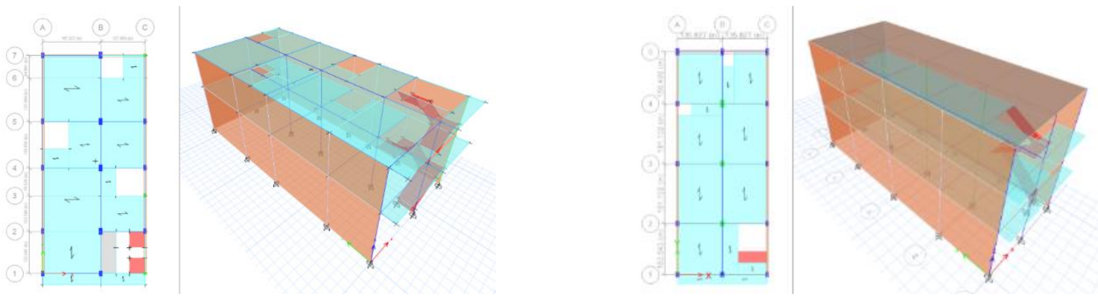
Detailed inspections were conducted, incorporating additional variables such as soil geology and the local environment. Peruvian regulatory criteria, which consider structural and design factors, were applied to provide a more contextualized assessment. Finally, the dwellings were classified into vulnerability levels, establishing categories such as "Very High," "High," "Moderate," and "Low."

Table 2: Vulnerability classification according to INDECI.

LEVEL OF VULNERABILITY	
Very high	Greater than 24
High	18 - 24
Moderate	15 - 17
Low	Up to 14

3.3. Application of Quantitative Analysis of Lateral Distortions in ETABS

To quantitatively validate the qualitative results and assess seismic vulnerability, two representative dwellings from the study area were modeled in ETABS. Their structural and architectural characteristics, including beam, column, and slab dimensions, material properties, and geometric layout, were incorporated to accurately replicate their structural behavior.



(a) (b)

Fig. 1: Floor plan and 3D view of the modelling: (a) dwelling 1; (b) dwelling 2.

Seismic loads were applied to the models following Peruvian regulations, considering the probable seismic intensity in Callao and evaluating the response in different directions. Lateral distortion at each level was analyzed to determine the relative displacement between floors, identifying structural vulnerabilities based on regulatory limits. Finally, drawing on previous studies on masonry buildings subjected to lateral loads [19], the results were interpreted, and the vulnerability of the structures was classified quantitatively.

Additionally, Huaco's distortion classification table was adapted to classify the vulnerability of a dwelling based on the ETABS distortion results.

Table 3: Classification of vulnerability based on distortions.

Distortion	Classification
1/3200 ≤ distortion < 1/400	Not vulnerable
1/400 ≤ distortion < 1/100	Vulnerable
1/100 ≤ distortion	High vulnerable

Based on this table, the seismic vulnerability was quantitatively assessed by considering distortions. When establishing a range between 1/3200 and 1/800, the structure was classified as non-vulnerable, as the damage is minimal. In the range of 1/400 to 1/200, the building was considered vulnerable since structural elements begin to lose their load-bearing capacity. Finally, values of 1/100 or higher indicate high vulnerability, as the damage is severe and there is a risk of collapse [20].

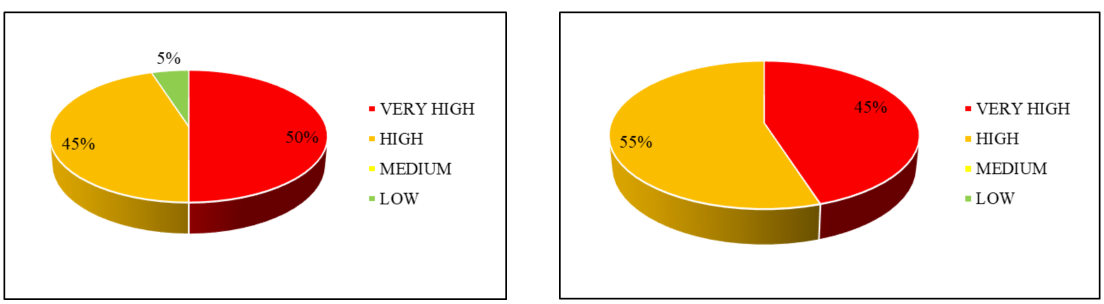
4. Results and analysis

4.1. FEMA P-154 Method

The analysis conducted using the FEMA P-154 method yielded the seismic vulnerability scores of the evaluated dwellings, as shown in Figure 2. Fifty percent of the dwellings exhibit very high vulnerability, 45% show high vulnerability, and only one dwelling, representing 5% of those evaluated, has low vulnerability.

4.2. INDECI Method

The analysis revealed the seismic vulnerability results of the evaluated dwellings, as shown in Figure 2. Forty-five percent of the dwellings exhibit very high seismic vulnerability, while the remaining 55% have high vulnerability. These dwellings also require structural interventions to improve their seismic performance.



(a) (b)

Fig. 2: Percentage distribution of seismic vulnerability: (a) FEMA P-154; (b) INDECI.

4.3. Comparison Between RVS Methods

Both methods exhibit similar levels of vulnerability in most of the analyzed dwellings. The main difference is observed in the wooden building, dwelling number 15. While the INDECI method considers a broader range of factors specific to the area, the FEMA P-154 method only takes into account the basic score for the dwelling, as it does not present height or plan irregularities that could affect its vulnerability level.

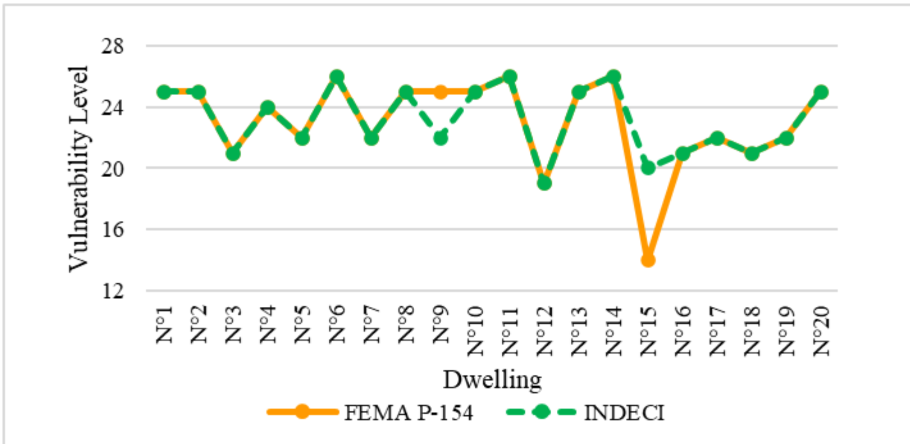
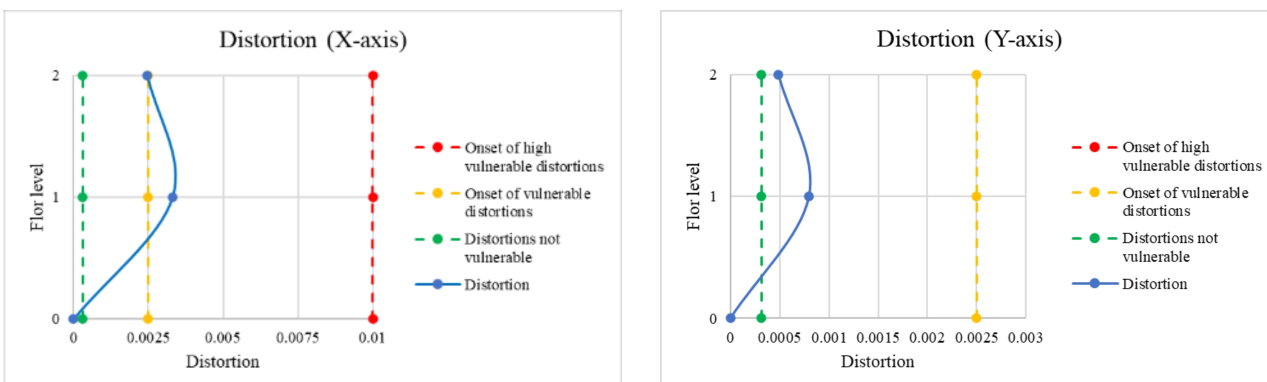


Fig. 3: Distribution of dwelling vulnerability using RVS methods.

4.3. Lateral Distortions

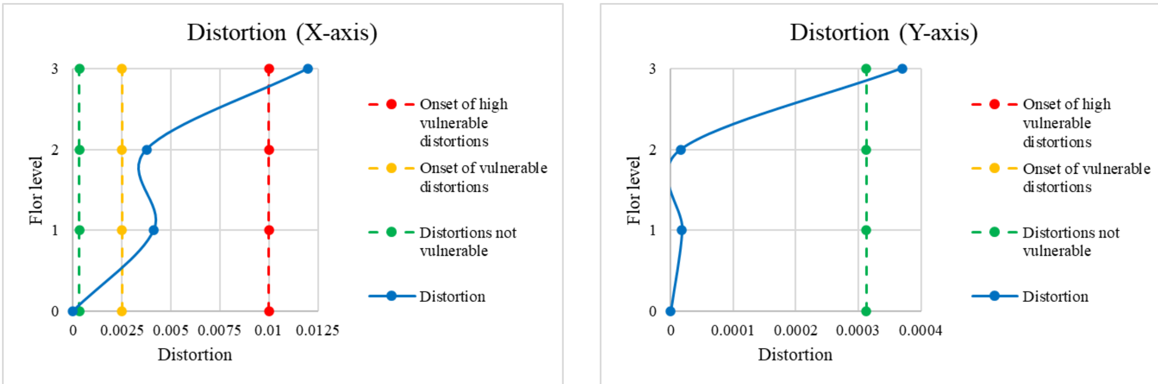
The following section presents the drift results for each analyzed dwelling using ETABS software.



(a) (b)

Fig. 4: Lateral distortions of dwelling 1: (a) X-axis; (b) Y-axis

The dwelling 1 was classified as "Vulnerable" in the Y direction, especially on level 3, due to the lack of structural stiffness caused by the presence of a single confined masonry wall at the back of the X direction. In the X direction, levels 1 and 2 were also classified as "Vulnerable." These structural deficiencies suggest cracking in the columns and the formation of diagonal openings in the walls. Overall, the analysis concludes that dwelling 1 has a maximum vulnerability level classified as "Vulnerable."



(a) (b)

Fig. 5: Lateral distortions of dwelling 2: (a) X-axis; (b) Y-axis

The dwelling 2 was classified as "Vulnerable" in the X direction at levels 1 and 2, indicating the onset of cracks in the columns and diagonal walls. At level 3, the classification was "High vulnerable," reflecting an imminent risk of collapse, loss of verticality, and failure of structural elements such as doors and partitions. In summary, the analysis concludes that dwelling 2 has a maximum vulnerability level classified as "High vulnerable”.

4.4. Comparison between RVS and Quantitative Methods

For the comparison, the vulnerability level results obtained from both qualitative methods and the classification from the quantitative analysis method will be considered. The following results are presented

:

Table 4: Comparison between RVS methods and quantitative methods in dwelling 1.

RVS Methods		**Quantitative Met.**
FEMA P-154	**INDECI**	**Lateral distortions**
Very high vulnerability	Very high vulnerability	Vulnerable

In Dwelling 1, the qualitative methods classify it as having "very high" vulnerability, while the quantitative analysis categorizes it as merely "vulnerable." This indicates that, although the quantitative analysis does not consider it as highly critical, it does recognize significant structural vulnerability.

Table 5: Comparison between RVS methods and quantitative methods in dwelling 2.

RVS Methods		**Quantitative Met.**
FEMA P-154	**INDECI**	**Lateral distortions**
Very high vulnerability	Very high vulnerability	High Vulnerable

The agreement between qualitative and quantitative approaches in Dwelling 2 highlights the importance of obtaining consistent results, which increases confidence in the evaluation. This similarity suggests that visual and structural design assessments, as well as deformation measurements, identify a critical vulnerability in the dwelling.

5. Conclusion

The analysis conducted using the FEMA P-154 method showed that 50% of the dwellings have very high vulnerability, 45% have high vulnerability, and only 5% have low vulnerability. Additionally, the pounding identified in 90% of the dwellings, along with plan irregularities (90%) and height irregularities (40%), highlights critical deficiencies in structural design. This underscores the urgency of implementing improvements that comply with Standard E.030 to ensure greater seismic resistance.

According to the results obtained with the INDECI method, 45% of the analyzed dwellings exhibit very high vulnerability, while 55% have high vulnerability. This reflects severe structural deficiencies and the need to apply reinforcement and adaptation measures to align these buildings with construction regulations and reduce the risk of collapse.

The lateral distortion analysis indicated that both dwellings have significant vulnerability. Dwelling 1, with a maximum drift of 0.003309, was classified as "vulnerable" and could sustain moderate structural damage even in minor earthquakes. Dwelling 2, with a maximum drift of 0.01199, was classified as "highly vulnerable" and presents a greater risk of severe damage, reinforcing the necessity for structural reinforcements in both constructions.

The comparison between qualitative and quantitative methods revealed both similarities and differences in the results. In Dwelling 1, the qualitative methods determined a very high vulnerability, while the quantitative method classified it as "vulnerable." In Dwelling 2, both methods agreed on a very high vulnerability classification. Despite these minor discrepancies, the analyses confirmed that both dwellings are highly susceptible to seismic damage.

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References

[1] N. Tarque y E. Pancca-Calsin, “Building constructions characteristics and mechanical properties of confined masonry walls in San Miguel (Puno-Peru)”, Journal Of Building Engineering, vol. 45, p. 103540, nov. 2021, doi: 10.1016/j.jobe.2021.103540.

[2] A. San Bartolomé, “Comentarios a la norma técnica de edificación E.070 Albañilería”, Lima: Pontificia Universidad Católica del Perú, 1994. [En línea]. Disponible: http://blog.pucp.edu.pe/blog/wp-content/uploads/sites/82/2008/01/C00-Introduccion.pd

[3] M. Yekrangnia, “Seismic Vulnerability Assessment of Masonry Residential Buildings in the Older Parts of Tehran through Fragility Curves and Basic RVS Scores”, Buildings, vol. 13, n.o 2, p. 302, ene. 2023, doi: 10.3390/buildings13020302.

[4] N. Bektaş y O. Kegyes-Brassai, “Development in Fuzzy Logic-Based Rapid Visual Screening Method for Seismic Vulnerability Assessment of Buildings”, Geosciences, vol. 13, n.o 1, p. 6, dic. 2022, doi: 10.3390/geosciences13010006.

[5] Aggarwal, Y., & Saha, S. K. “An improved rapid visual screening method for seismic vulnerability assessment of reinforced concrete buildings in Indian Himalayan region”. Bulletin of Earthquake Engineering, 21(1), 319–347. 2023,doi.org/10.1007/s10518 022-01537-2

[6] N. Bektaş, F. Lilik, y O. Kegyes-Brassai, “Development of a Fuzzy Inference System Based Rapid Visual Screening Method for Seismic Assessment of Buildings Presented on a Case Study of URM Buildings”, Sustainability, vol. 14, n.o 23, p. 16318, dic. 2022, doi: 10.3390/su142316318.

[7] N. Tarque, A. Manchego, H. Lovón, M. Blondet, y H. Varum, “Experimental in-plane behaviour and drift-based fragility assessment of typical Peruvian confined masonry walls”, Construction And Building Materials, vol. 341, p. 127893, may 2022, doi: 10.1016/j.conbuildmat.2022.127893.

[8] S. Ahmed, A. Abarca, D. Perrone, y R. Monteiro, “Large-scale seismic assessment of RC buildings through rapid visual screening”, International Journal Of Disaster Risk Reduction, vol. 80, p. 103219, ago. 2022, doi: 10.1016/j.ijdrr.2022.103219.

[9] M. R. Valluzzi, V. Follador, y L. Sbrogiò, “Vulnus Web: A Web-Based Procedure for the Seismic Vulnerability Assessment of Masonry Buildings”, Sustainability, vol. 15, n.o 8, p. 6787, abr. 2023, doi: 10.3390/su15086787.

[10] R. P. Nanda, R. Damarla, y K. A. Nayak, “Android application of rapid visual screening for buildings in Indian context”, Structures, vol. 46, pp. 1823-1836, nov. 2022, doi: 10.1016/j.istruc.2022.10.140.

[11] L. Izquierdo-Horna, J. Zevallos, y Y. Yepez, “An integrated approach to seismic risk assessment using random forest and hierarchical analysis: Pisco, Peru”, Heliyon, vol. 8, n.o 10, p. e10926, oct. 2022, doi: 10.1016/j.heliyon.2022.e10926.

[12] P. B. Murray, D. Feliciano, B. H. Goldwyn, A. B. Liel, O. Arroyo, y A. Javernick-Will, “Seismic safety of informally constructed reinforced concrete houses in Puerto Rico”, Earthquake Spectra, vol. 39, n.o 1, pp. 5-33, sep. 2022, doi: 10.1177/87552930221123085.

[13] C. Purushothama, G. Mucedero, D. Perrone, y R. Monteiro, “Evaluation of rapid visual screening assessment of existing buildings using nonlinear numerical analysis”, Journal Of Building Engineering, vol. 76, p. 107110, jun. 2023, doi: 10.1016/j.jobe.2023.107110.

[14] Federal Emergency Management Agency, "Rapid Visual Screening of Buildings for Potential Seismic Hazards: A Handbook, 3rd ed (FEMA P-154)," 2015. [En línea]. Disponible: https://www.fema.gov/sites/default/files/2020-07/fema_earthquakes_rapid-visualscreening-of-buildings-for-potential-seismic-hazards-a-handbook-third-edition-femap-154.pdf

[15] J. Saavedra y M. Ocmín, "Aplicación de manual FEMA P-154 para el análisis de vulnerabilidad sísmica en edificaciones del hospital Luis Negreiros en el Callao," Tesis de licenciatura, Universidad Peruana de Ciencias Aplicadas, 2023. [En línea]. Disponible: http://hdl.handle.net/10757/669875

[16] D. Carhuaricra, "Evaluación del Riesgo Sísmico de las Viviendas Autoconstruidas del Jr. Los Tulipanes, AA. HH Techo Propio, Distrito de Yanacancha – Pasco, Aplicando el Método FEMA P-154," Tesis de licenciatura, Universidad Nacional Daniel Alcides Carrión, 2023. [En línea]. Disponible: http://repositorio.undac.edu.pe/handle/undac/3607.

[17] Instituto Nacional de Defensa Civil (INDECI), "Resolución Jefatural," Lima, Perú, 2010. [En línea]. Disponible: https://cdn.www.gob.pe/uploads/document/file/1128342/fil20170504172426200200731-107894-2vhayk.pdf

[18] M. González, "Análisis de vulnerabilidad sísmica de las viviendas de la zona de Villa Huacariz de la ciudad de Cajamarca usando el método INDECI," Tesis de licenciatura, Universidad Nacional de Cajamarca, Cajamarca, Perú, 2022. [En línea]. Disponible: http://hdl.handle.net/20.500.14074/5308.

[19] C. Huaco, "Comportamiento de una edificación de albañilería construido con ladrillo artesanal frente a cargas laterales," Tesis de licenciatura, Universidad Nacional de Ingeniería, Facultad de Ingeniería, Lima, Perú, 2005. [En línea]. Disponible: http://hdl.handle.net/20.500.14076/3120.

[20] J. Alvarez y X. Pulgar, "Análisis de vulnerabilidad sísmica de los módulos escolares públicos en el distrito de Villa María del Triunfo mediante el método Índice de vulnerabilidad (FEMA P-154) y su validación mediante cálculo de distorsiones laterales," Tesis de licenciatura, Universidad Peruana de Ciencias Aplicadas, Lima, Perú, 2019. [En línea]. Disponible: http://hdl.handle.net/10757/626377.