Victor Reynoza, José Acero*

EVALUATION AND SEISMIC RISK OF CONFINED MASONRY BUILDINGS IN THE CITY OF ETEN - CHICLAYO - PERU, 2023

PROCENA I SEIZMIČKI RIZIK ZGRADA ZIDOVA UOKVIRENIH ARMIRANIM ZIDANIM ELEMENTIMA U GRADU ETEN - ČIKLAJO - PERU, 2023

Originalni naučni rad / Original scientific paper
Rad primljen / Paper received: 15.05.2023
https://doi.org/10.69644/ivk-2025-02-0297

Adresa autora / Author's address:
Universidad Católica Santo Toribio de Mogrovejo, Facultad de Ingeniería Civil Ambiental, Lambayeque, Perú
*email: reynozavictor1998@gmail.com

Keywords
- housing
- masonry
- pathologies
- seismic risk

Ključne reči
- zgrade
- zidani objekti
- patologije
- seizmički rizik

Abstract

The results of soil tests, visual inspections and mathematical models of 14 masonry houses belonging to a state programme called 'Techo Propio' (Own Roof), located in the city of Eten, Chiclayo province, Peru, are presented. In order to evaluate the damage to the houses, the probable causes of their predominant pathologies are determined.

Results show that in most of the houses the most affected structural elements are walls (4.31 %), followed by columns (2.79 %) and beams (2.24 %). The predominant pathologies are efflorescence (2.01 %), concrete spalling (0.62 %), fissures (0.51 %) and cracks (0.30 %), being aesthetically serious.

Through the studies and data collection of the masonry units, soil mechanics, wall density, and structural modelling, it is possible to determine the seismic risk to which the houses are subjected, with 57.1 % of the houses at high seismic risk and 42.9 % at medium seismic risk. This result demonstrates the vulnerability to which these houses are exposed in the event of a seismic event.

Izvod

Prikazani su rezultati ispitivanja tla, vizualnih pregleda i matematičkih modela 14 zidanih kuća koje su deo državnog programa pod nazivom „Techo Propio" (Vlastiti krov), smeštenih u gradu Eten, pokrajina Čiklajo, Peru. Kako bi se procenila oštećenja kojima su kuće izložene, utvrđeni su verovatni uzroci njihovih dominantnih patologija.

Rezultati pokazuju da su u većini kuća najviše pogođeni konstrukcioni elementi zidovi (4,31 %), zatim stubovi (2,79 %) i gredice (2,24 %). Dominantne patologije su eflorescencija (2,01 %), ljuštenje betona (0,62 %), pukotine (0,51 %) i prsline (0,30 %), koje su estetski ozbiljne.

Uvidom u studije i prikupljenih podataka o elementima zidova od opeke, mehanike tla, gustine zidova i modeliranja konstrukcija, omogućeno je utvrđivanje seizmičkog rizika kojem su kuće izložene, pri čemu je 57,1 % kuća sa visokim seizmičkim rizikom, a 42,9 % srednjeg seizmičkog rizika. Ovaj rezultat pokazuje opasnosti kojima su ove kuće izložene u slučaju seizmičkog događaja.

INTRODUCTION

In Peru, the demand for housing is on the rise. According to the National Institute of Statistics and Informatics (INEI), the country currently has a total population of 32 million 626 thousand inhabitants, a rate of 1.7 % /1/. The state, in response to this need, has created the Techo Propio (*Own Roof*) Programme, whose purpose is to enable low-income families to have access to safe and comfortable housing.

However, it has become evident that this type of housing throughout the region presents problems due to inadequate construction processes and lack of technical supervision, including spalling in the concrete structures, the presence of saltpeter on the roof and walls, the settling of the house, etc., causing discomfort and concern among the affected residents. Of these types of problems, in the district of Eten, cracking in the masonry walls stands out.

CONSTRUCTION PATHOLOGIES

Anomalies or pathologies in the construction are those deteriorations or injuries that constructive elements are part of a building present.

For the evaluation of the incidence of pathologies in structural elements (walls, columns and beams), a technical evaluation sheet is prepared (Fig. 1), in order to be able to quantify the damage in which they are found with respect to the total building. The results are shown in Table 1 and the percentages in Fig. 6.

Concrete spalling

According to the American Concrete Institute (ACI), it defines a crawl space as an empty space that is present in the concrete, either due to the construction process, inadequate mix design or poor gradation of materials /2/ (Fig. 2).

Efflorescence

This pathology is one of most common in dwellings, due to the area where it is located, or the humidity concentrated within. The ACI explains it as an accumulation of whitish salts originating in the superficial part of the structural element (Fig. 3), either in walls or concrete structures, and precipitate by the action of evaporation, /2/.

Fissures

They are elongated openings, with a separation of up to 1 mm which only affect the superficial part of the structural element (Fig. 4). Their presence is caused by temperature changes, inefficient load distribution, soil movement and tension between its reinforcements, /3/.

TECHNICAL EVALUATION SHEET

Evaluation and Seismic Risk of Confined Masonry Buildings in the city of Eten – Chiclayo – Peru, 2023

USAT Universidad Católica Santo Toribio de Mogrovejo

I. LOCATION

Location - Google Maps (coordinates)	Photo of the house

Location link

II. GENERAL INFORMATION

THESIS STUDENT:		DATE:	
OWNER:		SAMPLE N°:	
ADDRESS:			

III. DESCRIPTION OF THE HOUSE

AREA (m2) :		LENGTH :		WIDHT :	
NUMBER OF FLOORS :					
CONSTRUCTION SYSTEM :					
AGE :					

IV. PATHOLOGIES IN THE HOUSE

	STRUCTURAL ELEMENTS							
	WALLS		COLUMNS		BEAMS		SUMMARY	
PATOLOGIAS	AREA WITH PATHOLOGIES	AREA WITH PATHOLOGIES	AREA WITH PATHOLOGIES	AREA WITH PATHOLOGIES	AREA WITH PATHOLOGIES	AREA WITH PATHOLOGIES	TOTAL AREA OF STRUCTURES (m2)	
CONCRETE SPALLING								
EFFLORESCENCE								
FISSURES								
CRACKS								

V. EVALUATIVE SUMMARY OF THE HOUSE

SAMPLE N°:	AFFECTED AREA (m2)	UNAFFECTED AREA (m2)	%AFFECTED	%UNAFFECTED

SOURCE: ADAPTED FROM THE THESIS "EVALUACIÓN E INDENTIFICACIÓN DE LAS PATOLOGÍAS EN VIVIENDAS AUTOCONSTRUIDAS DE ALBAÑILERÍA CONFINADA - URBANIZACIÓN NUESTRA SEÑORA DE GUADALUPE, PUNO - 2021"

Figure 1. Technical data sheet for the evaluation of pathologies in 'Techo Propio' housing units.

Figure 2. Concrete spalling - house N°12.

Cracks

These are openings with a separation greater than 1 mm (Fig. 5). Compared to the crack, this affects the structure in its entire width and can affect the seismic response capacity of any structural element, /3/.

Figure 3. Efflorescence in walls - house N° 06.

Figure 4. Fissures in walls - house N°10.

Figure 5. Cracks in walls - house N° 06.

Fissures and cracks can originate from different causes, such as seismic joints (SJ), mortar-brick junctions (MBJ), brick notching (BN), plaster thickness (PT), deficient housing design (DHD), inadequate masonry units (IMU), differential settling (DS), point loads (PL), uniform loads on walls with varying sections (ULV), different loads on walls (DLW), deflection in slabs or beams where walls are supported (DSB), lateral thrust between adjacent walls (LTW), and thermal contraction (TC), /4/.

According to the data obtained in the field, the results of the origin of cracks and fissures are presented in Table 1.

Table 1. Percent. of incidence according to the origin of cracks/fissures.

	SJ	MBJ	BN	PT	DHD	IMU	DS	PL, ULV, DLW, DSB, LTW, TC
House 01	80	100	-	-	-	100	-	-
House 02	11	78	-		56	78		-
House 03	-	64	-	21	57		43	-
House 04	18	82	-	9	73	82		-
House 05	14	71	-		57	71		-
House 06	-	100	-		60	100		-
House 07	-	100	-		50	100		-
House 08	-	100	-		100	100		-
House 09	-	100	-		100	100		-
House 10	-	25	-		56	25	31	-
House 11	-	30	-	20	50	30	60	-
House 12	10	70	-	10	70	70	5	-
House 13	-	100	-	17	100	100		-
House 14	-	50	-	25	75			-

According to ACI - 224R, cracks are classified from an aesthetic point of view as acceptable (e < 0.15 mm) and unacceptable (0.15 mm < e < 0.30 mm). According to SIKA, cracks are classified as cracks (e < 1 mm), moderate fissures (1 mm < e < 6 mm), and severe fissures (e > 6 mm).

Based on the data obtained in the field, the classification results of cracks and fissures are shown in Table 2.

Table 2. Percentage of incidence according to the condition of cracks/fissures.

	Structural			Aesthetic	
	slight	moderate	severe	slight	grave
House 01	10	70	20	-	100
House 02	67	22	11	-	100
House 03	79	7	14	-	100
House 04	-	36	64	-	100
House 05	14	29	57	-	100
House 06	-	-	100	-	100
House 07	50	50	-		100
House 08	-	-	100	-	100
House 09	-	-	100	-	100
House 10	75	25	-	-	100
House 11	70	20	10	-	100
House 12	30	40	30	-	100
House 13	50	33	17	-	100
House 14	50	50	-	-	100

After processing the evaluative data, the percentage of pathologies affecting the studied houses are determined, with 0.62 % in concrete spalling, 2.01 % in efflorescence, 0.51 % in cracks, 0.30 % in fissures, as shown in Table 3.

Table 3. Percentage of area with pathology in structural elements.

	Concrete spalling	Efflorescence	Fissures	Cracks
House 01	0.48	-	0.31	0.14
House 02	-	-	0.17	0.30
House 03	-	-	0.59	0.07
House 04	0.80	2.77	0.18	0.46
House 05	0.09	2.21	0.15	0.37
House 06	0.70	5.85	0.13	0.51
House 07	0.13	1.11	0.12	0.15
House 08	0.19	0.05	0.03	0.18
House 09	0.21	3.39	0.03	0.24
House 10	-	0.55	1.17	0.22
House 11	-	4.37	0.65	0.27
House 12	5.25	2.07	3.19	0.98
House 13	0.80	3.20	0.31	0.25
House 14	-	2.62	0.16	0.11
Summary	0.62	2.01	0.51	0.30

With respect to the structural element most affected by the area presenting the pathology, the following percentages are obtained: 4.31 % for walls, 2.79 % for columns, and 2.24 % for beams (Fig. 6).

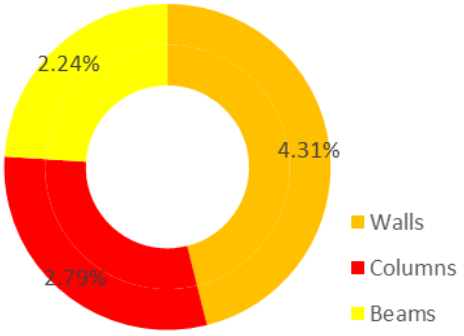

Figure 6. Summary of the structural element most affected by the area representing the pathology.

METHODOLOGY FOR VERIFICATION OF RESULTS

Based on inspection reports, tests are defined to determine probable causes of existing pathologies in studied buildings.

Identification of existing materials

Masonry units used for housing construction are mostly of artisanal type, coming from two sources: Culpón Brickworks and María Luisa Brickworks.

In the information gathering process, it is confirmed that the bricks are type IV and V, the suction tests exceed the values established in the NTP 339.613-2017 standard, and the compressive strength in brick piles (f'm) has values lower than those indicated in RNE, E - 070 Albañilería, with values of 30.40 kg-f/cm^2 and 17.43 kg-f/cm^2, respectively, /5-6/.

Soil mechanics studies

The tests carried out are: granulometric analysis /7-8/, liquid and plastic limit /9/, direct shear test /10/.

According to the results, under the AASHTO method, it is obtained that the soil of the houses has a POOR surface classification, up to a depth of 0.70 m. While at a depth greater than 0.70 m, 80 % is poor and 20 % is regular.

The bearing capacity obtained demonstrates an allowable stress of the soil which indicates a regularly stable ground for construction.

Wall density

From the calculations, it is found that for the studied area (Zone 4, soil type S2), a minimum wall density of 0.008438 is required, and all the studied houses exceed the minimum established.

Modelling and seismic verification

The modelling performed indicates that drifts in the X and Y directions meet the permissible limit in 71.5 % of cases, while 28.5 % do not.

The deflections in the beams and slabs of the houses, in their entirety, are lower than the maximal permissible deflection, indicating no problems.

SEISMIC RISK

To determine the seismic risk, the methodology of Kuroiwa /12/ and Blondet /14/ is used which analyses the structural and non-structural vulnerability of masonry buildings /12-13/.

The results indicate that 57.1 % of studied houses are in a high seismic hazard level, while 42.9 % are in a medium level (Table 4). This demonstrates the vulnerability of these houses to seismic activity.

Table 4. Seismic vulnerability, hazard, and risk.

House no.	Classification		Result	
01	vulnerability	medium	risk seismic	medium
	hazard	medium		
02	vulnerability	medium	risk seismic	medium
	hazard	medium		
03	vulnerability	medium	risk seismic	high
	hazard	high		
04	vulnerability	high	risk seismic	high
	hazard	high		
05	vulnerability	high	risk seismic	high
	hazard	high		
06	vulnerability	high	risk seismic	high
	hazard	high		
07	vulnerability	medium	risk seismic	medium
	hazard	medium		
08	vulnerability	medium	risk seismic	medium
	hazard	medium		
09	vulnerability	medium	risk seismic	medium
	hazard	medium		
10	vulnerability	high	risk seismic	high
	hazard	medium		
11	vulnerability	high	risk seismic	high
	hazard	high		
12	vulnerability	high	risk seismic	high
	hazard	medium		
13	vulnerability	high	risk seismic	high
	hazard	medium		
14	vulnerability	medium	risk seismic	medium
	hazard	medium		

REFERENCES

1. INEI, State of the Peruvian population 2020, National Institute of Statistics and Informatics, 2020.
2. ACI 116R-00, Terminology of Cement and Concrete, ACI Standard, 2002.
3. Moya, D.A.P., Dias, J.E., *La planeación y ejecución de las obras de construcción dentro de las buenas prácticas de la administración y programación (Proyecto Torres de la 26-Bogotá)*, Bachelor's thesis, Catholic University of Colombia, Faculty of Civil Engineering, Bogotá, Colombia, 2015.
4. Concha, R. (2010), *Pathological processes*, In: Exposed Brick Facades, La Sombra Creativa, Madrid, Spain, 2010: 297-318.
5. Chicchón Saldaña, J.M., Rivasplata Samamé, L.F., *Características físicas y mecánicas del ladrillo artisanal de arcilla king kong del distrito de Monsefú, provincial de Chiclayo, Región de Lambayeque*, Bachelor's thesis, University Ricardo Palma, Faculty of Engineering, Lima, Peru, 2020.
6. Guerra Paucar, C.E., *Calidad de las Unidades de albañilería de arcilla según norma E.070 en la Provincial de Chiclayo*, Bachelor's thesis, César Vallejo University, Faculty of Engineering, Chiclayo, Peru, 2017.
7. EN N.T.P. 399.128: 1999. Soil. Test method for particle size analysis, 1999.
8. EN N.T.P. 339.127.1998. Soil. Test method for determining the moisture content of a soil, 1998.
9. EN N.T.P. 339.129.1998. Soil. Plastic limit of a soil, 1998.
10. EN N.T.P. 339.171.2002. Soil. Test method for the direct shear test of soils under consolidated undrained conditions, 2002.
11. Ministry of Transport and Communications (MTC), Technical Standard for Buildings 070. Masonry (NTE - 070), National Building Regulations, Lima, 2019.
12. Kuroiwa, J., Disaster Reduction - Living in Harmony with Nature, United Nations Development Programme (UNDP) (in Spanish), Lima, 2002.
13. Mosqueira Moreno, M.Á., Tarque Ruíz, S.N., *Recomendaciones técnicas para mejorar la seguridad sísmica de viviendas de albañilería confinada de la costa peruana*, Master's thesis, Pontifical Catholic University of Peru, Lima, 2005.
14. Loaiza, C., Blondet, M., Confined Masonry Building, World Housing Encyclopedia Technical Report, 2002. https://world-housing.net/wp-content/uploads/WHEReports/wh100021.pdf