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**FACULTAD DE INGENIERÍA**  
**ESCUELA DE INGENIERÍA CIVIL AMBIENTAL**



**Evaluación y riesgo sísmico de edificaciones de albañilería confinada en la  
ciudad de Eten – Chiclayo – Perú, 2023**

**TRABAJO DE INVESTIGACIÓN PARA OPTAR EL GRADO ACADÉMICO DE  
BACHILLER EN INGENIERÍA CIVIL AMBIENTAL**

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## Resumen

Se presentan los resultados de los ensayos de suelo, inspecciones visuales y modelos matemáticos de 14 viviendas de albañilería pertenecientes a un programa estatal denominado “Techo Propio”, ubicadas en la ciudad de Eten, provincia de Chiclayo, Perú. Con el propósito de evaluar el daños en las que están sometidas las viviendas se determinan las causas probables de sus patologías predominantes.

Los resultados demuestran que en la mayoría de viviendas, el elemento estructural más afectado son los muros (4,31%), seguido de las columnas (2,79%) y las vigas (2,24%). Las patologías predominantes son las eflorescencias (2,01%), las cangrejas (0,62%), las fisuras (0,51%) y grietas (0,30%), siendo estas estéticamente graves.

A través de los estudios y recopilación de datos de las unidades de albañilería, mecánica de suelos, densidad de muros y modelamiento estructural, se logró determinar el peligro sísmico en lo cual están sometidas las viviendas, teniendo un 57,1% de las viviendas en riesgo sísmico alto y el 42,9% en riesgo sísmico medio. Este resultado demuestra la vulnerabilidad a la que están expuestas estas viviendas ante una acción sísmico.

**Palabras clave:** viviendas, albañilería, patologías, riesgo sísmico.

### **Abstract**

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

The results show that in most of the houses the most affected structural element is the 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%), which are aesthetically serious.

Through the studies and data collection of the masonry units, soil mechanics, wall density, and structural modelling, it was 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.

**Keywords:** housing, masonry, pathologies, seismic risk

## **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) Program, 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

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

For the evaluation of the incidence of pathologies in the structural elements (walls, columns, and beams), a technical evaluation sheet was prepared (Figure 1), in order to be able to quantify the damage in which they are found with respect to the total of the building. The results are shown in Table 1 and the percentages in Figure 5.


TECHNICAL EVALUATION SHEET							
Evaluation and Seismic Risk of Confined Masonry Buildings in the city of Eten – Chiclayo – Peru, 2023							
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	
<b>SOURCE:</b> ADAPTED FROM THE THESIS "EVALUACIÓN E IDENTIFICACIÓN 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"

### ***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] (Figure 2).



Figure 2. Concrete Spalling – House N°12

### ***Efflorescence***

This pathology is one of the most common in dwellings, due to the area in which they are located, or the humidity that concentrates in them. The ACI explains it as an accumulation of whitish salts, which originates in the superficial part of the constructive element (Figure 3), either in walls or concrete structures, and precipitates by the action of evaporation [2].



Figure 3. Efflorescence in walls – House N° 06

### ***Fissure***

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



Figure 4. Fissures in walls - House N°10

### ***Crack***

These are openings with a separation greater than 1 mm (Figure 4). Compared to the crack, this affects the structure in its entire width and can affect the seismic response capacity of any construction element [3].



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. Percentage of incidence according to the origin of the cracks/fissures.

	% Incidence according to the origin of the 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 ( $e < 0.15\text{mm}$ ) and unacceptable ( $0.15\text{mm} < e < 0.30\text{mm}$ ). According to SIKA, cracks are classified as cracks ( $e < 1\text{mm}$ ), moderate fissures ( $1\text{mm} < e < 6\text{mm}$ ), and severe fissures ( $e > 6\text{mm}$ ).

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 the cracks/fissures

	% Incidence according to the condition of the 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 were 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 the structural elements

	% Area with pathology in the 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%
<b>Summary</b>	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 were obtained: 4.31% for walls, 2.79% for columns, and 2.24% for beams (Figure 6)

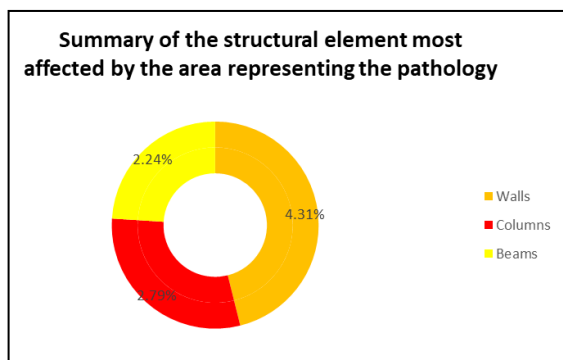


Figure 6. Summary of the structural element most affected by the area representing the pathology

## Methodology for verification of results

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

### Identification of existing materials

The masonry units used for housing construction are mostly of artisanal type, which come 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 the RNE, E - 070 Albañilería, with values of 30.40 kg-f/cm<sup>2</sup> and 17.43 kg-f/cm<sup>2</sup> 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 was 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 0.70m, 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 has been 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 [11].

### **Modeling and seismic verification**

The modeling 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 maximum permissible deflection, which indicates no problems.

### **Seismic Risk**

To determine the seismic risk, the methodology of Kuroiwa (2002) and Blondet (2002) was used, which analyzes the structural and non-structural vulnerability of masonry buildings [12] [13].

The results indicate that 57.1% of the 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

Vivienda	Classification		Result	
	Vulnerability	Hazard	Risk Seismic	
01	MEDIUM	MEDIUM	Risk Seismic	MEDIUM
	MEDIUM	MEDIUM		
02	MEDIUM	MEDIUM	Risk Seismic	MEDIUM
	MEDIUM	MEDIUM		
03	MEDIUM	HIGH	Risk Seismic	HIGH
	HIGH	HIGH		
04	HIGH	HIGH	Risk Seismic	HIGH
	HIGH	HIGH		
05	HIGH	HIGH	Risk Seismic	HIGH
	HIGH	HIGH		
06	HIGH	HIGH	Risk Seismic	HIGH
	HIGH	HIGH		
07	MEDIUM	MEDIUM	Risk Seismic	MEDIUM
	MEDIUM	MEDIUM		
08	MEDIUM	MEDIUM	Risk Seismic	MEDIUM
	MEDIUM	MEDIUM		
09	MEDIUM	MEDIUM	Risk Seismic	MEDIUM
	MEDIUM	MEDIUM		
10	HIGH	MEDIUM	Risk Seismic	HIGH
	MEDIUM	MEDIUM		
11	HIGH	HIGH	Risk Seismic	HIGH
	HIGH	HIGH		
12	HIGH	MEDIUM	Risk Seismic	HIGH
	MEDIUM	MEDIUM		
13	HIGH	MEDIUM	Risk Seismic	HIGH
	MEDIUM	MEDIUM		
14	MEDIUM	MEDIUM	Risk Seismic	MEDIUM
	MEDIUM	MEDIUM		

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