DEVELOPMENT OF FRAGILITY FUNCTION FOR TYPOLOGIES OF CONFINED MASONRY DWELLING IN METROPOLITAN LIMA AND CALLAO CITIES

Erika FLORES [1,2*], Miguel Diaz[1,2], Carlos ZAVALA[1,2]

[1] *Civil Engineering Faculty, National University of Engineering, Lima, Peru.*

[2] *Japan-Peru Center for Earthquake Engineering Research and Disaster Mitigation, Lima, Peru.*

Received: 01/08/2019 Accepted: 12/08/2019

ABSTRACT

Development of Fragility functions are a widely used tool to estimate the vulnerability through the probability of response damage occurrence of a structure at different seismic demand. These functions are very useful for researchers, engineers, insurance companies, territorial planning planners and decision-makers. The aim of this research is to develop a methodology to estimate the vulnerability of theses confined masonry dwelling through the fragility function. An experimental database of confined masonry wall of two kind of informal brick and statistical database were used.
This research present typologies of a dwelling according to the type of material, number of story, and wall density respectively which are based on a statistical database. Besides, it describes a methodology to find the fragility functions based on experimental data tests that replicate the behavior of confined masonry walls and thus find the probability of the damage caused in this type of dwellings that exist in a great majority of the city of Metropolitan Lima and Callao.

Keywords: Fragility function, confined masonry dwellings, Statistical database survey, wall density, experimental data test

1. INTRODUCTION

Quantifying the vulnerability of dwellings through fragility functions is very useful to estimate the seismic risk of a city. Also, design preparedness plans are essential for the protection of resilient individuals and communities. Earthquake records in Peru show that the city of Lima had great experiences in large earthquakes, produced in the years 1940, 1966 and 1974, earthquakes with a maximum magnitude of approximately 8.0, causing loss of life and damage in urban areas. Faced with this natural disaster, it is necessary to find a function that quantifies the vulnerability of housing and/or buildings to a certain seismic intensity.

Studies conducted by the Japan-Peru Center for Earthquake Engineering Research and Disaster Mitigation (CISMID) under the SATREPS project (cooperation from Japanese Government to the National University of Engineering (UNI)) had concluded that the coastal region of Metropolitan Lima and Callao or Tacna department will suffer a potential event of great magnitude of approximately 8.5.

A research conducted by National Fund for Scientific Development (FONDECYT) and CISMID-UNI had concluded that 83% of a dwelling of metropolitan Lima and Callao are built with masonry [4] where the majority of these are built without an engineer supervisor.

Therefore, we need to be prepared for an unexpected seismic event, quantifying vulnerability characterizing the types of dwelling that represent of metropolitan Lima and Callao.

2. METHODOLOGY

Several methods exist to develop of fragility function. This research has developed a fragility function base on the analytic method take into account experimental method also.

Figure 2 shows the methodology that consists in to follow five steps to find fragility function. The first step is to classify the common characteristic of the area of study like structural system, type of material, wall density and number of story through the experimental database.

The second step is to analyses the mechanical characteristic of the material, the structural behavior of the wall, the capacity curves of the dwelling calibrated using tetra lineal model and establish the limit state of the damage base on distortion.

* Corresponding author:
eflorest@uni.edu.pe

The third step is to establish and scale ten seismic records since 0.025g to 1.00g every 0.025g.

The four steps consist to find the seismic response of confine masonry dwellings through the capacity curve per floor and with the seismic record scaled to find the non-linear dynamic analysis responses by a computing program.

Finally, the fifth step consists to find fragility function through the database of the maximum seismic response and count for each PGA the number of times that reaches the distortions for each state of accumulated damage and by a distribution Lognormal

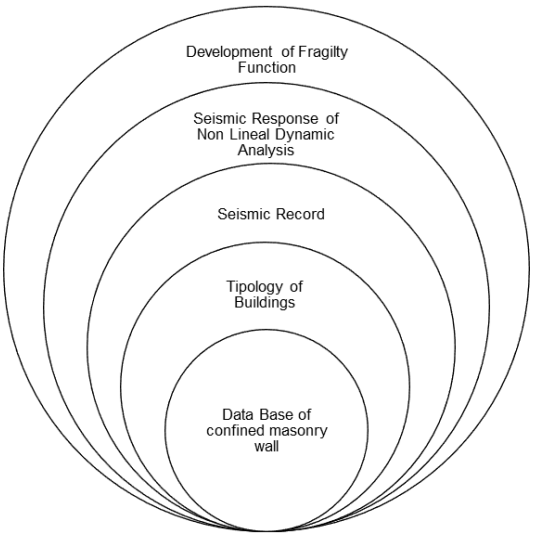


Figure 2. Methodology to find fragility function

2.1. Characteristic of dwellings in Metropolitan Lima and Callao

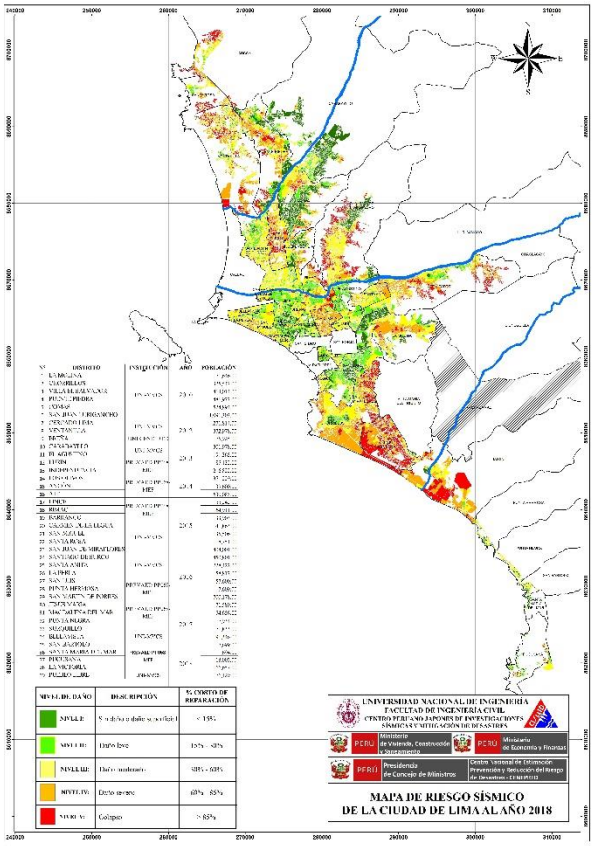
CISMID has been carrying out studies to find the vulnerability and seismic risk since 2010 thanks to agreements with state institutions by 2018, forty districts have been evaluated in Metropolitan Lima and Callao as shown in Figure 1.

The result of the studies carried out in metropolitan
Lima and Callao have obtained a large database with the characteristic of representative dwellings such as type of material, number of story, type of use and structural system.

The predominant material used for construct dwellings in metropolitan Lima and Callao is masonry made by fired clay with 82.9% as shown in Figure 3.

In Figure 4, confined masonry dwellings of two story are predominant with 45.84%, 01-floor dwellings with 28.18%, 03 story dwellings with 19.91% and 3.84 % for 04 story dwellings.

78.8% of the building has a type of use dwellings as shown in Figure 5.



(CISMID 2018)

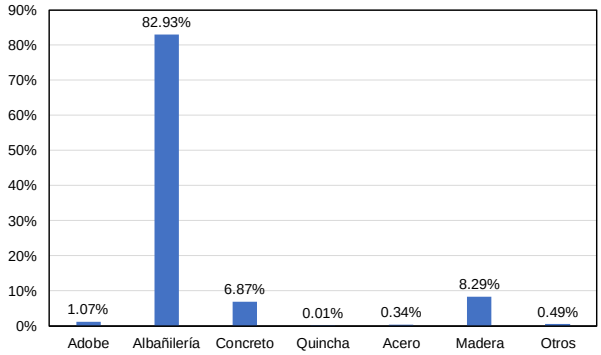


Figure 3 type of material.[4]

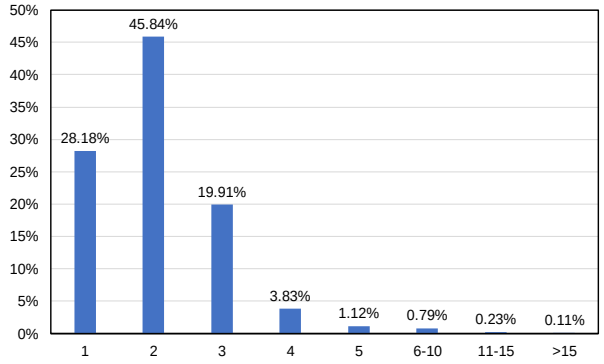


Figure 4 Number of story.[4]

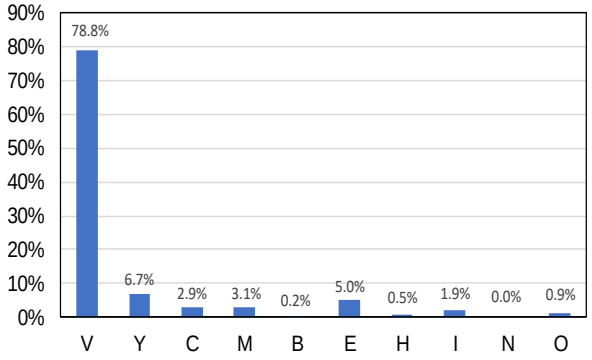


Figure 5 Type of the Use.[4]

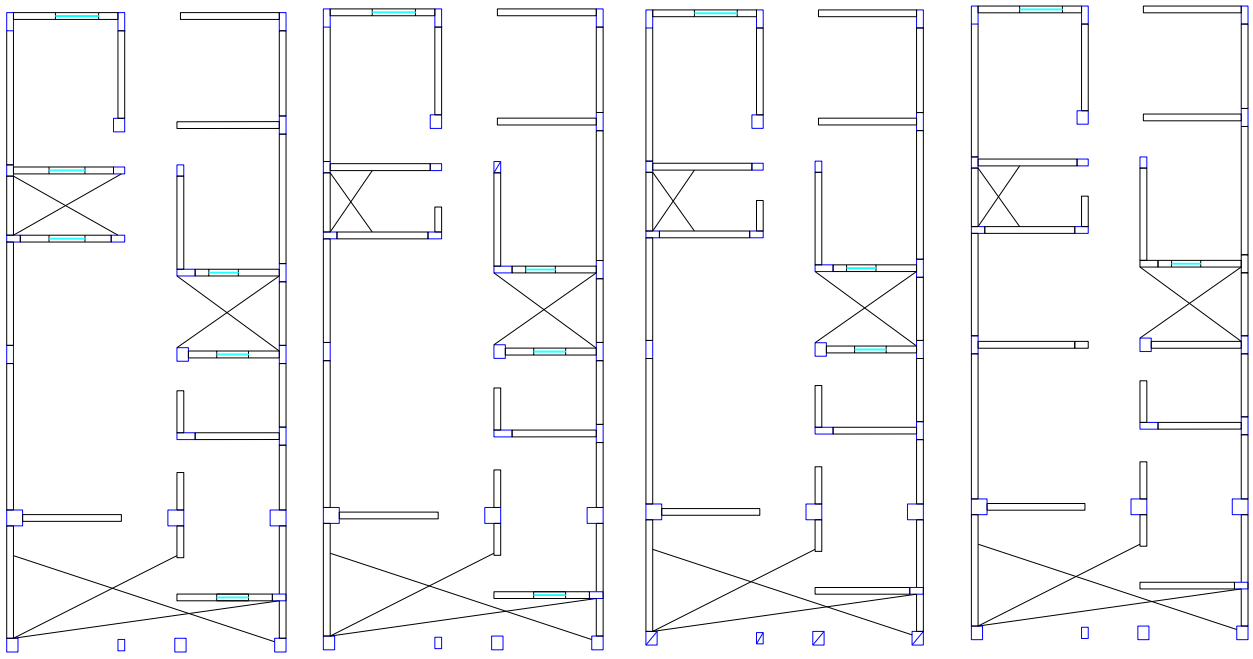
On the other hand, it has been calculated the density of confined masonry wall of 30 planes of dwellings between 02 story and 03 story. These dwellings are located in different districts of Metropolitan Lima and Callao. The districts are San Juan de Lurigancho, San Martin de Porres, El Rímac, Independencia, Los Olivos and La Punta where 87% of dwelling does not meet the minimum requirements wall density located in the short direction of the dwelling. However, the wall density located in a large direction accomplishes 100% the minimum requirement of wall density.

2.2. Proposal for typology of dwellings

The type of dwelling in the Metropolitan Lima and Callao are generally rectangular with an area in the plant between 90m² and 120mm² approximately. 83% of dwelling have masonry as the predominant material however they are considered informal buildings due to these dwellings use two kind of brick that it does not allow two use in load-bearing walls: solid brick (Handmade) and tubular brick (Industrial). The structural system is made of confined masonry wall with the number of stories between 01 to 04 story with wall density of 1.5%, 2%, 2.5%, and 3%. The total number of dwelling to evaluate are 32 typologies of confined masonry dwelling.

Note

V: Dwelling	C: Commerce	B: Firefighter	H: Health	N: Wasteland
Y:House-Deal	M: Multifamilyr	E: Education	I: Manufaturer	O: Others



(a) (b) (c) (d)

Figure 6 View of typical dwellings in confined and informal masonry wall densities (a) 1.5%, (b)2%, (c)2.5% y (d) 3%

3. RESULT OF EXPERIMENTAL DATA BASE

3.1. Calibration of Tetra Lineal Model

From the database of Structure Laboratory of CISMID [1], the result of the experimental test was studied and the capacity curve of confined masonry wall for two types of brick, handmade solid brick (ML1) and industrial tubular brick (ML2) have been calibrated. The capacity curves were adjusted a tetra lineal model or Quad lineal model adapted by Professor Saito [7] that can replicate the hysteresis behavior of confined masonry wall. Also, to reproduce the analytic model were obtained three parameters to control the hysteresis curve as we can observe in the Table 1.

Table 1. Parameters for Tetra Lineal Model

Parameters	ML1	ML2
bo	0.50	0.43
b1	0.35	0.048
b2	0.00	0.00

Where: bo is a parameter to control the stiffness degradation, b1 is a parameter to control the slip ratio and b2 is the parameter to control the strength degradation ratio.

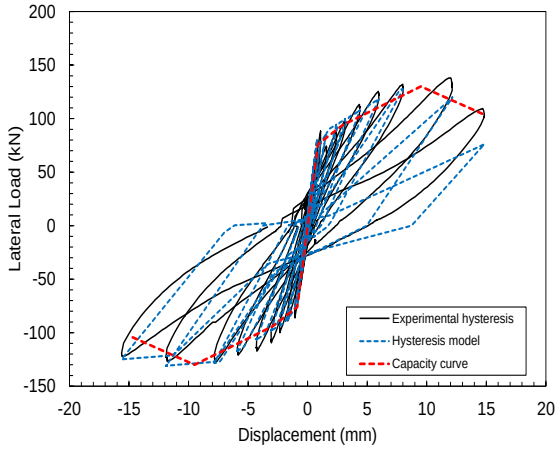


Figure 7 Calibrated Tetra lineal Model of confined masonry wall –ML1

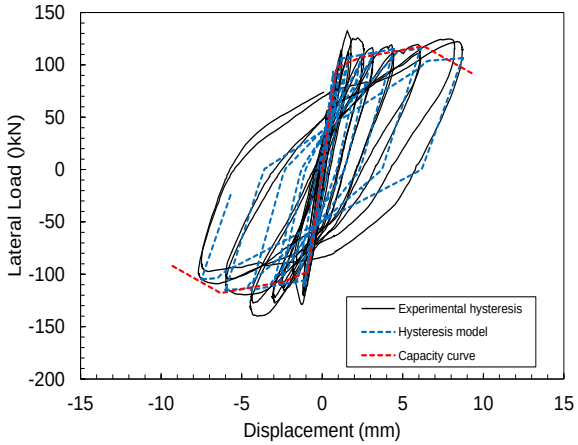


Figure 8 Calibrated Tetra lineal Model of confined masonry wall –ML2

3.2. Limit damage state and seismic performance

Table 2 shows the limit state in terms of distortion and seismic performance for confined masonry wall made by handmade solid brick (ML1) and industrial tubular brick (ML2).

Table 2.Damage and Limit State proposed by Zavala et al [9]

Distortion ($x10^{-3}$) ML1	Distortion ($x10^{-3}$) ML2	Damage State	Performance Level
$\gamma < 0.48$	$\gamma < 0.47$	No damage	Operational (O)
$0.48 \le \gamma < 1.25$	$0.47 \le \gamma < 0.67$	Slight	Immediate Occupancy (IO)
$1.25 \le \gamma < 2.86$	$0.67 \le \gamma < 1.00$	Moderate	Life safety (LS)
$2.86 \le \gamma < 4$	$1.00 \le \gamma < 1.82$	Severe	Collapse prevention (CP)
$\gamma \ge 8$	$\gamma \ge 5$	Collapse	Collapse (C)

4. EARTHQUAKE RECORD

It has been compiled 07 earthquake record and 03 synthetic records developed by Pulido under SATREPS Project [6]. These earthquake records were normalized and scaled the maximum horizontal component between 0.25gals to 1000gals to get more seismic response for each typology propose of dwellings, see Table 3

Table 3. Earthquake record from Lima - Perú

Record Name	Date	Type	Mw
prq-6610171641	17/10/66	Record	8.1
prq-7005311523	31/05/70	Record	6.6
prq-7410030921	03/10/74	Record	6.6
sco-7410030921f	03/10/74	Record	6.6
mol7411090759	09/11/74	Record	6.0
Atico230601	23/06/01	Record	6.9
ICA15082007	15/08/07	Record	7.0
CMA_5_1	--	Synthetic (SATREPS)	8.6
CMA_7_1	--	Synthetic (SATREPS)	8.6
DHN_5_1	--	Synthetic (SATREPS)	8.6

5. NON-LINEAL DYNAMIC ANALYSIS

32 typologies of the dwelling were analyzed under non-linear dynamic analysis. The capacity curve for shear deformation by the tetra-linear or Quad linear model was obtained for each story in the 32 dwellings based on equations developed by Diaz et al [5]. For non-lineal dynamic analysis, it had used a computer program for multiple degrees of freedom and obtain the seismic response in terms of drift developed by Diaz as shown in Figure 9.

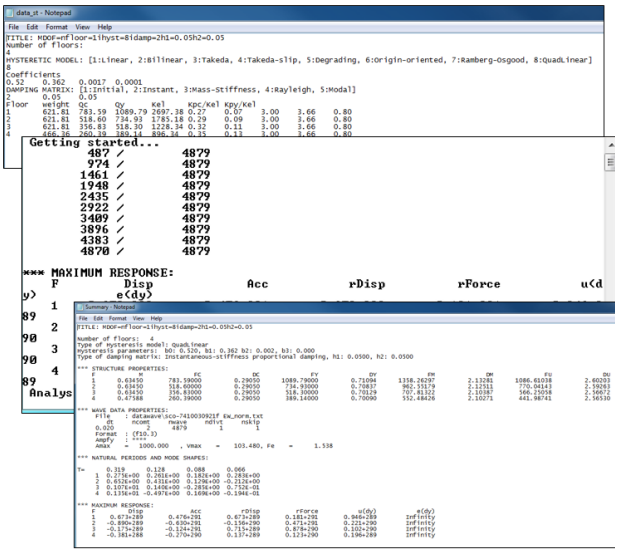


Figure 9.Program of Analysis

Finally, a big database in terms of maximum distortion of 32 typologies of dwelling are found.

6. FRAGILITY FUNCTION

Fragility function represents a probability of a building exceed a certain limit state of damage based for a specified ground motion level

The Eq (1) represents mathematically a fragility function that it's a lognormal cumulative distribution function.

$$F_i(D) = \emptyset\left(\frac{\ln(D/\theta_i)}{\beta_i}\right) \quad (1)$$

$$\theta_i = e^{\frac{1}{M}\sum_{m=1}^{M}\ln(D_i)} \quad (2)$$

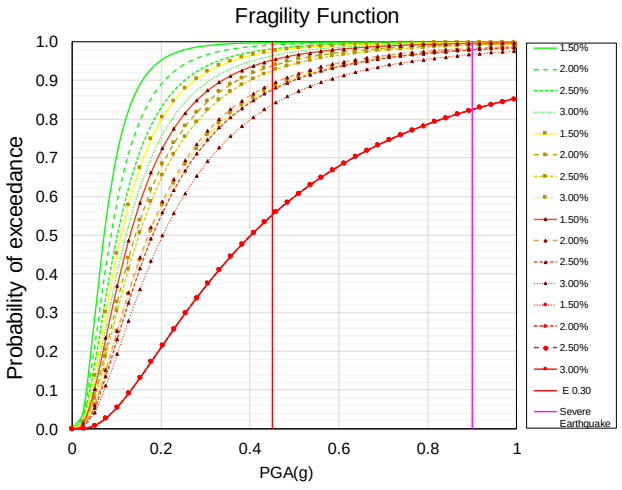
Where $F_i(D)$: is the probability that a structure exceeds a certain limit state of damage under a seismic demand, D: is a seismic intensity, Ø: is the standard cumulative normal distribution function (Gaussian), θ_i: is the average probability distribution value the damage state, β_i: The standard logarithmic deviation or dispersion factor

The fragility functions of confined masonry dwellings built with unit of handmade solid brick (ML1) from 01 to 04 stories, and walls density of 1.5%, 2%, 2.5% and 3% are developed and showed in Figure 10.

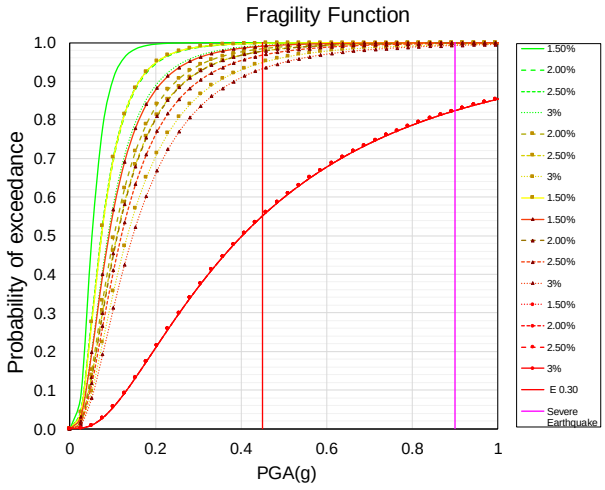
The different colors of each fragility function represent every limit damage state or performance of level mentioned in Table 2.

The green color of fragility function are those dwelling which reach a performance level of Immediate Occupancy, the yellow color of fragility function are those dwelling which reach a performance level of Life Safety, the orange color of fragility function are those dwelling which reach a performance level of Collapse Prevention and the red color of fragility function are those dwelling which reach a performance level of collapse.

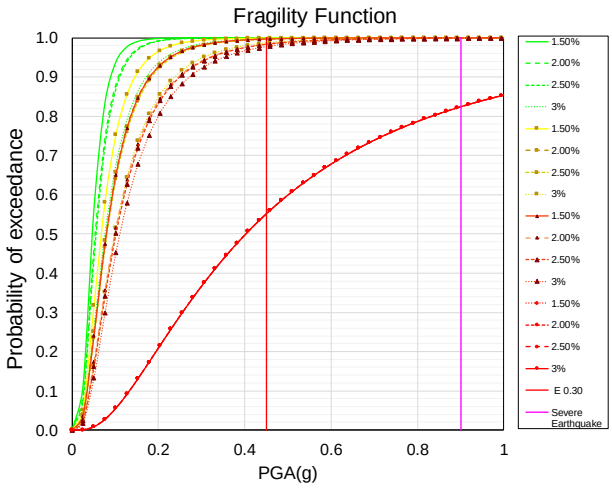
Furthermore, it has compared the probability of to reach the different damage state for 16 confined masonry dwellings proposed. There are two perpendicular line that represent two different scenery through peak ground acceleration (PGA) as 0.45g (red color) considered by Peruvian seismic standard NTP E0.30 in the coast region and 0.9g for a severe earthquake expected. The result is shown in Table 4 and Table 5.



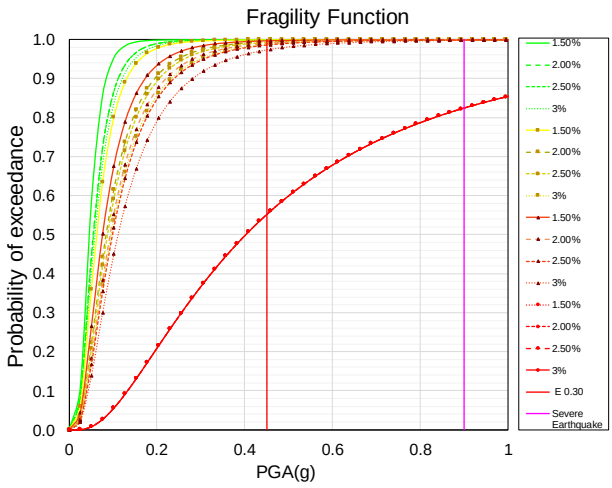
(a) 01 Story



(b) 02 Story



(c) 03 Story



(d) 04 Story

Figure 10. Fragility function for confined masonry wall with unit of handmade solid brick (ML1)

Table 4.Probability to reaching or exceeding a state of damage for PGA 0.45g

N°	WD=1.5%				WD=2%			
Pisos	IO	LS	CP	C	IO	LS	CP	C
1	2%	2%	39%	56%	5%	5%	33%	56%
2	2%	2%	39%	56%	5%	5%	33%	56%
3	0%	0%	44%	56%	0%	1%	42%	56%
4	0%	0%	44%	56%	0%	0%	43%	56%
N°	WD=2.5%				WD=3%			
Pisos	IO	LS	CP	C	IO	LS	CP	C
1	6%	5%	32%	56%	8%	4%	28%	56%
2	6%	5%	32%	56%	8%	4%	28%	56%
3	0%	1%	42%	56%	1%	1%	42%	56%
4	1%	1%	43%	56%	1%	1%	41%	56%

Table 5.Probability to reaching or exceeding a state of damage for PGA 0.9g

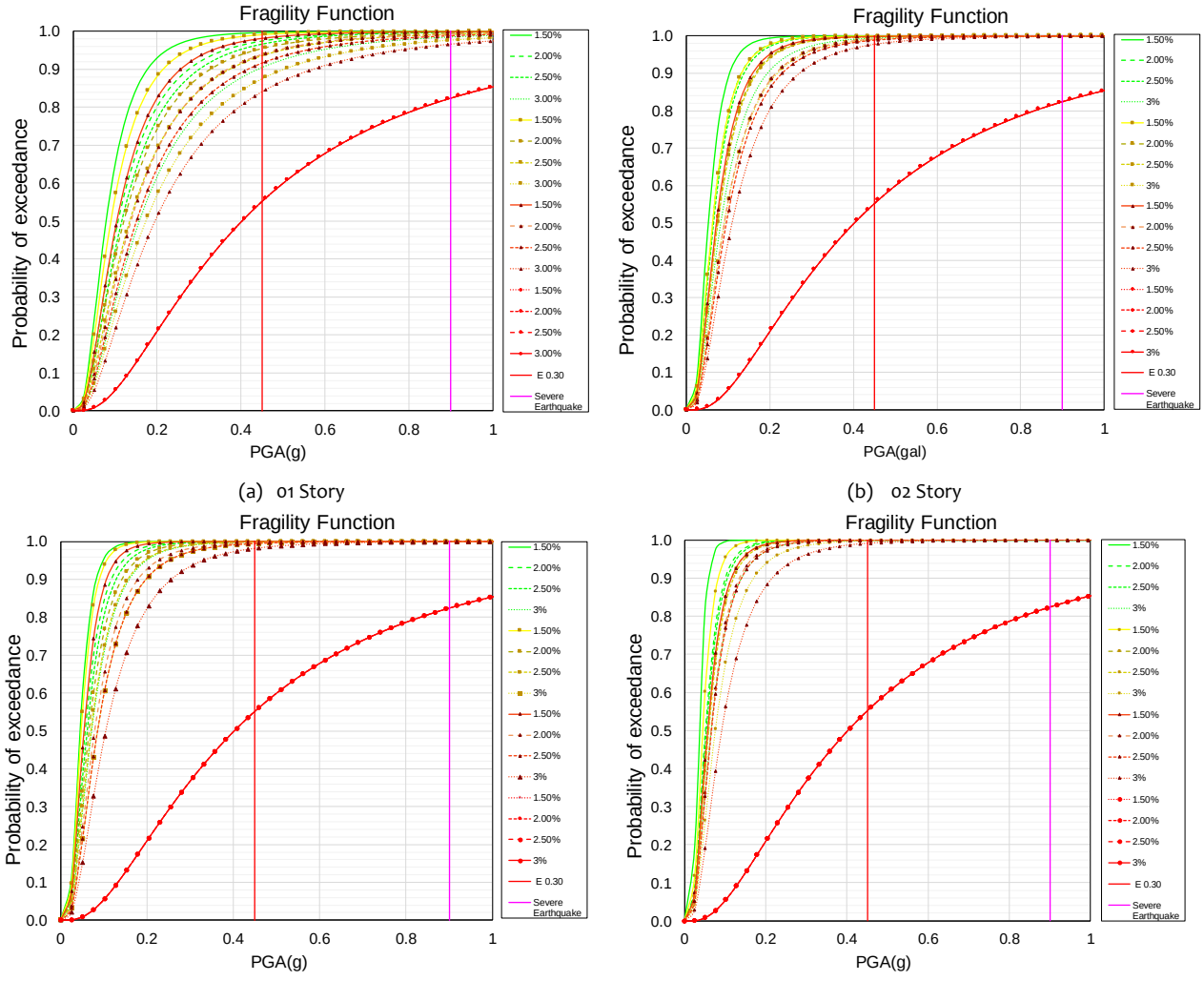
N°	WD=1.5%				WD=2%			
Pisos	IO	LS	CP	C	IO	LS	CP	C
1	0%	0%	17%	83%	1%	1%	15%	83%
2	0%	0%	17%	83%	1%	1%	15%	83%
3	0%	0%	17%	83%	0%	0%	17%	83%
4	0%	0%	17%	83%	0%	0%	17%	83%
N°	WD=2.5%				WD=3%			
Pisos	IO	LS	CP	C	IO	LS	CP	C
1	1%	1%	15%	83%	2%	1%	14%	83%
2	1%	1%	15%	83%	2%	1%	14%	83%
3	0%	0%	17%	83%	0%	0%	17%	83%
4	0%	0%	17%	83%	0%	0%	17%	83%

The fragilities function of confined masonry dwellings with the unit of industrial tubular brick (ML2) from 01 to 04 Story, and with walls density of 1.5%, 2%, 2.5%, and 3% are developed and showed in Figure 11.

The different colors of each fragility function represent every limit damage state or performance of level mentioned in Table 2.

The green color of fragility function are those dwelling which reach a performance level of Immediate Occupancy, the yellow color of fragility function are those dwelling which reach a performance level of Life Safety, the orange color of fragility function are those dwelling which reach a performance level of Collapse Prevention and the red color of fragility function are those dwelling which reach a performance level of collapse.

Furthermore, it has compared the probability to reach different damage state for 16 confined masonry dwellings proposed. There are two perpendicular line that represent two different scenery through peak ground acceleration (PGA) as 0.45g (red color) considered by Peruvian seismic standard NTP E0.30 in the coast region and 0.9g for a severe earthquake expected. The result is shown in Table 6 and Table 7.



(a) 01 Story (b) 02 Story

(c) 03 Story (d) 04 Story

Figure 11. Fragility function for confined masonry wall with unit of industrial tubular brick (ML2)

Table 6.Probability to reaching or exceeding a state of damage for PGA 0.45g

N°	WD=1.5%				WD=2%			
Pisos	IO	LS	CP	C	IO	LS	CP	C
1	1%	1%	42%	56%	2%	2%	38%	56%
2	0%	0%	44%	56%	0%	1%	43%	56%
3	0%	0%	44%	56%	0%	0%	44%	56%
4	0%	0%	44%	56%	0%	0%	44%	56%
N°	WD=2.5%				WD=3%			
Pisos	IO	LS	CP	C	IO	LS	CP	C
1	3%	2%	36%	56%	3%	3%	28%	56%
2	0%	1%	43%	56%	0%	1%	42%	56%
3	0%	0%	43%	56%	0%	1%	42%	56%
4	0%	0%	44%	56%	0%	1%	43%	56%

Table 7.Probability to reaching or exceeding a state of damage for PGA 0.9g

N°	WD=1.5%				WD=2%			
Pisos	IO	LS	CP	C	IO	LS	CP	C
1	0%	0%	17%	83%	0%	0%	16%	83%
2	0%	0%	17%	83%	0%	0%	17%	83%
3	0%	0%	17%	83%	0%	0%	17%	83%
4	0%	0%	17%	83%	0%	0%	17%	83%
N°	WD=2.5%				WD=3%			
Pisos	IO	LS	CP	C	IO	LS	CP	C
1	1%	0%	16%	83%	1%	1%	14%	83%
2	0%	0%	17%	83%	0%	0%	17%	83%
3	0%	0%	17%	83%	0%	0%	17%	83%
4	0%	0%	17%	83%	0%	0%	17%	83%

CONCLUSION

A methodology to develop fragility function is described in the paper, which is related to a combination of the analytic and experimental methods.

According to the statistic of the database: the predominant material of dwelling in Metropolitan Lima and Callao is masonry with 82.9% of total buildings and the major percent of dwellings of 02 story is 45.84% and also with the type of use which is 78.8% for dwellings.

Dwellings between 01 to 04 floors with wall density of 1.5%, 2%.2.5% and 3% are proposed which 16 dwellings of handmade solid brick and 16 dwellings of industrial tubular brick, giving in total 32 dwellings proposed.

Parameters to control the hysteresis of the tetra-lineal model in both types of walls. Confined masonry wall of solid brick and tubular brick were found.

07 earthquake record and 03 synthetic waves were used previously normalized and scaled for non-linear dynamic analysis in which fragility function has been determined for each wall density and type of material for 32 typologies of the dwelling of metropolitan Lima and Callao.

There are two peak ground acceleration, 0.4g and 0.9g for the dwelling of 01, 02, 03 and 04 story built with 1.5%, 2%, 2.5%, and 3% of wall density and two type of material handmade masonry and industrial tubular units.

It is observed that seismic response of confined handmade masonry dwellings for all story in an seismic scenery with a peak ground acceleration of 0.4g has 56% of collapse damage, while collapse prevention decrease as wall density (WD) increases since 42% (WD:1.5%), 40% (WD: 2%),39% (WD: 2.5%) and 37% (WD: 3%) on average for all story. However, the percentage of life safety performance increase as wall density increases as well as Immediate Occupancy on average. On another hand, a peak ground acceleration of 0.9g expected in Lima, these dwellings has on average 83% collapse damage, 16% in collapse prevention and 0% in life safety and immediate Occupancy.

the seismic response of confined Industrial tubular masonry dwellings for all story in an seismic scenery with a peak ground acceleration of 0.4g has 56% of collapse damage, while collapse prevention decrease as wall density (WD) increases since 43% (WD:1.5%), 42% (WD: 2%),41% (WD: 2.5%) and 39% (WD: 3%) on average for all story. However, the percentage of life safety performance level increase as wall density increases as well as Immediate Occupancy on average. On another hand, a peak ground acceleration of 0.9g expected in Lima, these dwellings has on average 82% collapse damage, 17% in collapse prevention and 0% in life safety and immediate Occupancy.

Dwellings built with industrial tubular units have a higher percentage of damage due to the limit state referred in this research.

The dwellings with less percentage of damage are buildings with highest wall density, in this case 3% of wall density

This fragility function is a tool very useful to estimate the economic losses and evaluate seismic risk under different seismic scenery.

ACKNOWLEDGEMENT

The author would like to express my gratitude to Dr. Zavala and Dr. Diaz for their time and support in this research. Furthermore, the Structural Laboratory of CISMID, the National Training Service for the Construction Industry (SENCICO) and the Peruvian Ministry of Economy and Finance which was included in the National Budget PP-068 and National Fund for Scientific Development (FONDECYT) for the financial support of experimental tests

REFERENCES

[1] Cárdenas L, Roy R, Estacio L and Zavala C 2014 Implementation of Database of Masonry Walls Test – Review of Existing Test Data in Peru. Journal of Disaster Research, **9**(6)

[2] SENCICO 2006 Standard E-070. Masonry. Ministry of Construction, Housing and Sanitation. Peru

[3] CISMID 2017 Tests of full-scale walls and elaboration of corresponding fragility curves oriented to the development of knowledge about seismic behavior of nonengineered masonry walls and to enable the estimation of losses for earthquake scenario, Report commissioned by SENCICO

[4] Diaz M 2019 Report on statistical analysis and target study Area in Lima Metropolitan and Callao. Project FONDECYT-CISMID-FIC-UNI Development a digital tool for feasibility of confined masonry dwelling retrofitting in multi seismic scenarios based on assessment of vulnerability and risk

[5] Diaz M, Zavala C, Flores E and Cardenas L 2019 Development Of Analytical Models For Confined Masonry Walls Based On Experimental Results In Peru, International symposium on Earthquake Engineering

[6] Pulido N, Tavera H, Perfettini H, Chlieh M, Aguilar Z, Aoi S, Nakai S and Yamazaki F 2011 Estimation of Slip Scenarios for Megathrust Earthquakes: A Case Study for Peru, in Effects of Surface Geology on Seismic Motion, pp 1-6

[7] Saito 2019 Technical Manual Version 6.1 of Structural Earthquake Response Analysis (STERA)

[8] SENCICO 2006 Norma E-070. Masonry. Ministry of Construction, Housing and Sanitation. Peru

[9] Zavala C, Diaz M and Flores E 2019 Damage Limit State for confined masonry wall base on experimental test in Lima city, International symposium on Earthquake Engineering

[10] Zavala C, Lavado L, Taira J, Cardenas L and Diaz M 2014 Comparison of Behaviors of Non-Engineered Masonry Tubular Block Walls and Solid Engineered Walls. Journal of Disaster Research, **9**(6)

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