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EFFECT OF ELECTRO-WELDED WIRE MESH ON THE SEISMIC VULNERABILITY OF THIN RC SHEAR WALLS IN LIMA, PERU

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Abstract: The probability of damage states with respect to a ground motion index is predicted through the seismic fragility curves. Using fragility curves, it is possible to estimate the vulnerability of structures to seismic hazard. In this study, an analytical approach was adopted to construct fragility curves for thin RC shear walls that are the vertical components of the lateral-force-resisting system to earthquakes typically used in Lima, Peru since 1998. The main characteristic of these walls is the use of electro-welded wire mesh as main reinforcement instead of conventional rebar. The thin RC shear walls were modeled based on the results of experiments. A series of non-linear dynamic response analyses was performed using strong motion records obtained in Lima, Peru and the damage ratios were estimated with respect to damage states. The fragility curves for the walls were constructed assuming that the damage ratios follow lognormal distributions. The fragility curves constructed in the present study are helpful for predicting the damage state of buildings composed of the thin RC walls especially in Lima, Peru.

1. INTRODUCTION

The study of seismic loss is a matter of research in many countries located in seismic-prone regions. Every study follows a similar flowchart during the process of loss estimation: estimation of intensity measures, structural responses, damage estimation, statistical analysis, construction of fragility curves and finally loss assessment. To evaluate the damage to structures, fragility curves are widely employed and developed for RC buildings (Jovanoska 2000), bridges (Karim and Yamazaki 2001), expressway embankments (Maruyama et al. 2010), and other types of structures (Chiou et al. 2011).

Withman (1973) defined the damage probability matrices, and the ATC Project (1985) also defined damage probability matrices for 78 categories of structures. Jaw and Hwang (1988) introduced the fragility curves, and Nocevski (1993) developed empirical and analytical fragility curves. Similar approaches to construct fragility curves are presented by Karim and Yamazaki (2001) and others.

During the 2010 Chile Maule earthquake, some buildings, which resist lateral seismic forces with thin walls, suffered from severe damage and in some cases collapsed (EERI 2010). In Lima City, many similar types of buildings have been built since 1998, and the number of these types of buildings has been increasing over the years. However, the last big earthquake that hit Lima city occurred in 1974. Therefore, it is difficult to know the actual behavior of these buildings during an earthquake and the loss associated with their fails.

The fragility curves can be developed based on analytical, empirical, expert's opinion and combinational approaches. The objective of this study is to develop analytical fragility curves based on numerical simulations and evaluate the influence of the use of electro-welded wire mesh as main reinforcement instead of conventional rebar for the thin RC shear walls. Fragility curves describe the conditional probability of a certain damage state for a given intensity of ground motion index and can be expressed as

$$P_{ik} = P\left[X \geq x_i \middle| Y = y_k\right] \tag{1}$$

where P_{ik} is the conditional probability of a certain damage level x_i for a given ground motion intensity y_k. X is the variable that reflects the damage state and Y is the variable that reflects the ground motion intensity.

The response characteristics of the thin RC shear walls were evaluated in the previous study (Quiroz et al. 2012). These walls were regarded as the prototype of those used in low-rise and mid-rise buildings in Lima, Peru. The numerical model of the wall is developed using a multi degree-of-freedom system and macro models that represent the overall behavior of the RC elements. A series of non-linear dynamic response analyses is carried out using Peruvian records. Regression analyses are performed to reveal the relationship between the damage ratios of the walls and the ground motion index to construct fragility curves. Finally, the influences on the fragility curves due to the type of material used as main reinforcement of the wall are discussed and the probabilities of a certain damage state for three hazard levels areis estimated.

2. PROTOTYPES AND NUMERICAL MODEL

A thin RC shear wall was selected as a prototype of those used in low-rise and mid-rise in Lima, Perú. The dimensions of the prototypes were a height of 2400 mm (per floor), a length of 2650 mm and a thickness of 100 mm. The walls present the edge reinforcement consisted of conventional rebar. In the case of main reinforcement, two types of models are considered. The first wall is called MQE257EP and it presents electro-welded wire mesh, which is made of non-ductile material, as main reinforcement. The second wall is called MFIEN3EP and it presented conventional rebar as main reinforcement. A single layer of main reinforcement is used in both directions for both cases. Figure 1 shows a general view of the walls and Table 1 shows the distribution of reinforcement. The number of stories considered in the analysis is five.

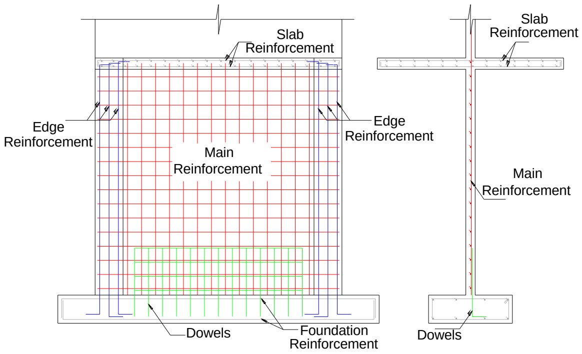


Figure 1 General characteristics of the specimens considered in the study

Table 1 Distribution of reinforcement in walls

Prototype	Main Reinforcement	ρ_h and ρ_v	Dowels	Edge Reinforcement
MQE257EP	QE257	0.257%	QE84/257	3 #4
MFIEN3EP	#3 @ 250	0.284%	#3 @ 250	

As can be observed from Table 1, the horizontal reinforcement ratio (ρ_h) and vertical reinforcement ratio (ρ_v) is almost similar for both walls. The wall MQE257 has the main reinforcement called QE257, which is formed by wires of 7 mm in the horizontal and vertical direction spaced at 150 mm. This wall has dowels which consists of a mesh QE84/257 formed by wires with a diameter of 4 mm in the horizontal direction and wires with a diameter of 6 mm in the vertical direction, both spaced at 150 mm. In case of the wall MFIEN3EP, the main reinforcement consists of corrugated bars with a diameter of 9.5 mm (#3) spaced at 250 mm in both directions. The dowels present a similar configuration as the wall MQE257 (#3 @ 250 mm) but they are distributed only in vertical direction.

The randomness of the structural characteristics is usually considered through the variation of the built-in materials properties, but in the present study, this effect has not been considered. Then, uncertainty in the capacity of the structural element was reduced by selecting material strengths based on the experiments and an appropriate inelastic model.

The compression strength of concrete was set to be 17.16 MPa that is typically used in these walls. The following properties were considered for the reinforcement based on the test (Quiroz et al. 2012). In case of the conventional reinforcement, the yielding stress was set to be 450 MPa with an associated strain of 0.002. As for the electro-welded wire mesh, the yield strain was 0.0035 with a yield stress of approximately 485 MPa. The main difference between these two types of reinforcement is the strain at the maximum strength. The strain of conventional reinforcement is 4.5 times larger than that of electro-welded wire mesh. Figure 2 shows a comparison of the two types of reinforcement.

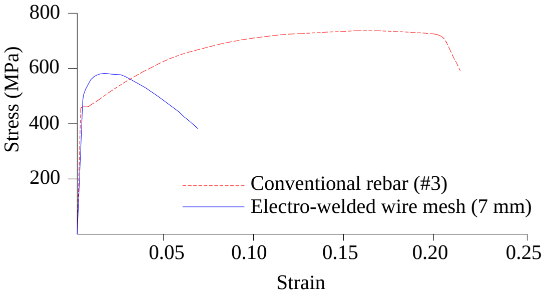


Figure 2 Schematic comparisons of conventional reinforcement and electro-welded wire mesh

The numerical model represents the effect of non-linearity of walls by modeling with the concentrated springs idealized by a trilinear backbone curve and hysteretic rules.

The definition of the bearing characteristics and their modeling of the hysteretic behavior of the cross-sections is of particular importance in defining damage under seismic motions. The bearing characteristics of a cross-section are given through the moment-curvature relationship. The three-parametric model proposed by Park et al. (1987), which is based on a tri-linear curve, was adopted to model the relationship. The three parameters α, β, and γ were estimated in the previous study (Quiroz et al. 2012).

To predict the hysteretic curve of the prototypes, the nonlinear behaviors of materials should be modeled numerically. In the case of concrete, unconfined concrete is assumed because the thickness of the walls is small and does not allow any type of confinement. The Kent and Park model was considered in this study (Kent and Park 1971). The tensile strength of concrete was neglected. The ultimate strain was set to be 0.0035 and the other parameters have been estimated using the expressions of Kent and Park (1971). For reinforcement, the uniaxial behavior of conventional reinforcement and electro-welded wire mesh is modeled by the trilinear model. The behavior is considered to be the same for compressive and tensile stresses.

3. DAMAGE LEVELS

To construct the seismic fragility curves, it is necessary to define structural damage levels. Many approaches have been used to define damage indices, e.g. one of those approaches considers three categories: non-cumulative, cumulative and combined damage indices. The structural parameters related to the categories mentioned before are the maximum deformation, hysteric behavior, and deformation/energy absorption. The first category has the advantage of simplicity in estimation process. Typical structural responses used in that category are drifts and displacement ductility ratios.

Because the damage to structure is related to local deformations, the drift can be used to show different damage states. The drift is calculated as the ratio between the relative displacement of a story and the height of the story. In the literature, it is possible to find many drift limits for walls. Farrar et al. (1993) proposed that the failure occurs with the drifts of 0.85 - 1.50% for low-rise walls with reinforcement ratio of smaller than 0.25%. Duffey et al. (1994) established that an 80% of reduction in ultimate capacity occurs at the drift of 1.34%, and a reduction of 50% occurs at the drift of 1.84% based on statistical analysis of their experimental results on light reinforced low-rise walls. Ghobarah (2004) stated that structural collapse of buildings with low-rise walls with low ductility can occurs at the drift of more than 0.80%.

For the present study, the maximum drift among at the all stories is considered as damage index and the definition of damage states by Ghobarah (2004) was employed because the drifts associated with the damage states are close to those observed during the experiments of Zavala (2004). Table 2 shows the definition of damage states proposed by Ghobarah based on the amount of drift.

Table 2 Definition of damage states with respect to the drift proposed by Ghobarah (2004)

State of damage	Drift limit (%)
No damage (ND)	0 – 0.1
Light (L)	0.1 – 0.2
Moderate (M)	0.2 – 0.4
Severe (S)	0.4 – 0.8
Collapse (C)	> 0.8

4. EARTHQUAKE GROUND MOTIONS

In order to consider the uncertainty of the ground motion, a way to overcome this is considering various records that reflect the seismicity of a specific place.

In the present study, a dataset of Peruvian records was used. This dataset consists of nineteen acceleration time histories recorded by Japan Peru Center for Earthquake Engineering and Disaster Mitigation, National University of Engineering, Peru (CISMID) and Geophysical Institute of Peru (IGP). The number of events is 14, and each record consists of the two horizontal components and one vertical component. The acceleration records of horizontal components are applied to the numerical models. All the records have been recorded in dense gravel soil, which represents the typical soil of Lima, and most of them consist of very high frequency contents. The dataset includes the ground motion record during the severe earthquake occurred in Lima after 1951. The magnitudes vary from 4 to 8. The magnitudes of the earthquake events are shown in Table 3. The origin of several of the records is associated withto the process of subduction between the Nazca and South American plates and presents a wide range of magnitudes and epicentral distances.

Table 3 Dataset of Peruvian ground motion records

Event	Year	M_W	M_S	M_L
Lima Eq.	1951	-	5.5	6
Ancash Eq. ^{1}	1970	-	7.8	-
Nov-71	1971	5.6	-	-
Jan-74	1974	6.5	6.6	-
Lima Eq. ^{1}	1974	-	7.6	-
Lima & Callao Eq. ^{1}	1966	8.1	8	-
Nov-74	1974	-	7.2	-
Mar-04	2004	-	-	5
Jul-04	2004	-	-	5.4
Mar-05	2005	-	-	5.7
Feb-06	2005			5.4
Lamas Eq.	2005	-	-	7
Pisco & Ica Eq.	2007	7.9	-	7
Callao Eq.	2008	5.3	-	5.3

In the Table 3, the superscript 1 indicates the records used to draw the inelastic design spectrum of the Seismic Peruvian standard E.030 (Ministry of Housing Peru 2003).

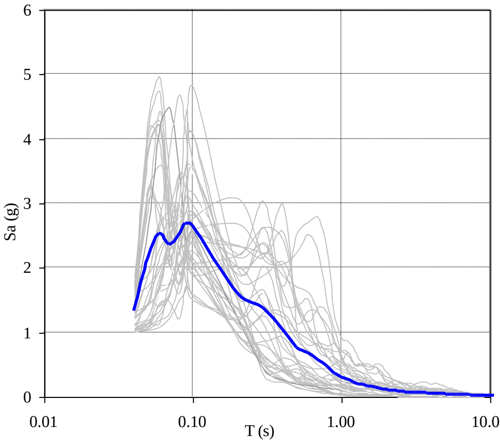


Figure 3 Acceleration response spectra (normalized to have PGA of 1g) with 5 percent damping ratio for Peruvian records

Figure 3 shows the acceleration response spectra for Peruvian earthquakes, which are normalized to have PGA of 1g, with the damping ratio of 5%. The mean amplitude is also shown with a thick line. Although the large variations in the spectral shape can be caused by many factors, such as soil conditions and source-to-site distance, the mean amplitude of spectral shapes is different from event to event. Based on Figure 3, the ground motion records in Peru mainly consist of shorter period contents.

5. FRAGILITY CURVES

A difficult task in the analysis of structures is the determination of their structural response. IDARC2D (Reinhorn et al. 2009), a macro-element program, is used in the simulation of the structural response. IDARC2D has been extensively validated against laboratory testing of structural systems and components types, and it is used for the inelastic static and dynamic response analysis of RC structures.

The non-linear dynamic analysis is carried out using a combination of the Newmark-Beta integration method and the pseudo-force method. In the numerical analysis, the values for time increment step, damping value and damping type are 0.005 s, 5% and Rayleigh damping, respectively.

As is mentioned before, the fragility curves can be constructed with respect to different ground motion indices, e.g. PGA, PGV, AI, duration time, etc. In the present study, PGA was selected as the ground motion index because this parameter presented a better correlation with the drift than others. The damage ratio for each damage state under a certain excitation level is obtained. Base on these data, fragility curves for the walls are constructed assuming a lognormal distribution. This distribution was used by other researchers (Mehanny, and El Howary 2010).

The cumulative probability P_R of occurrence of the damage equal or higher than a damage state is given by

$$P_R = \Phi\left[\frac{\ln Y - \lambda}{\zeta}\right] \qquad (2)$$

where Φ is the standard cumulative normal distribution, Y is the ground motion index (PGA), λ and ζ are the mean and standard deviation of ln Y. These two parameters of the distribution are obtained by the least-squares method on a lognormal probability paper.

The values of PGA for all records were scaled to have different excitation levels. Hence, the PGA for the records was scaled from 100 cm/s^2 to 1500 cm/s^2 with the interval of 100 cm/s^2. The scaled records were applied to the numerical model to obtain the damage index (maximum drift). Using the damage indices, the number of occurrence for each damage state was estimated under each excitation level. Finally, the damage ratio was obtained for every damage state. As an example, Figure 4 shows the number of occurrences of each damage state under different excitation levels for the wall MQE257EP and MFIEN3EP.

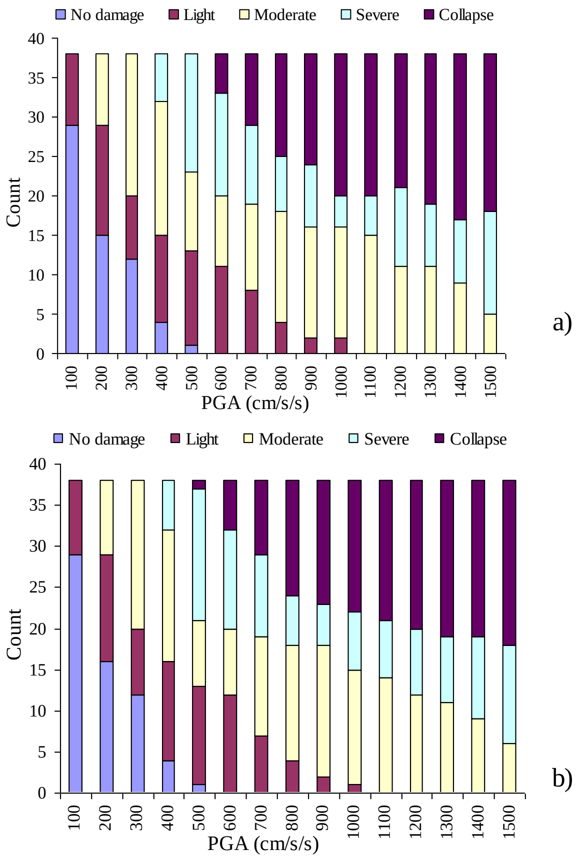


Figure 4 Number of occurrences of each damage state under the Peruvian records for the walls a) MQE257EP and b) MFIEN3EP

5.1 Influence of material used as main reinforcement

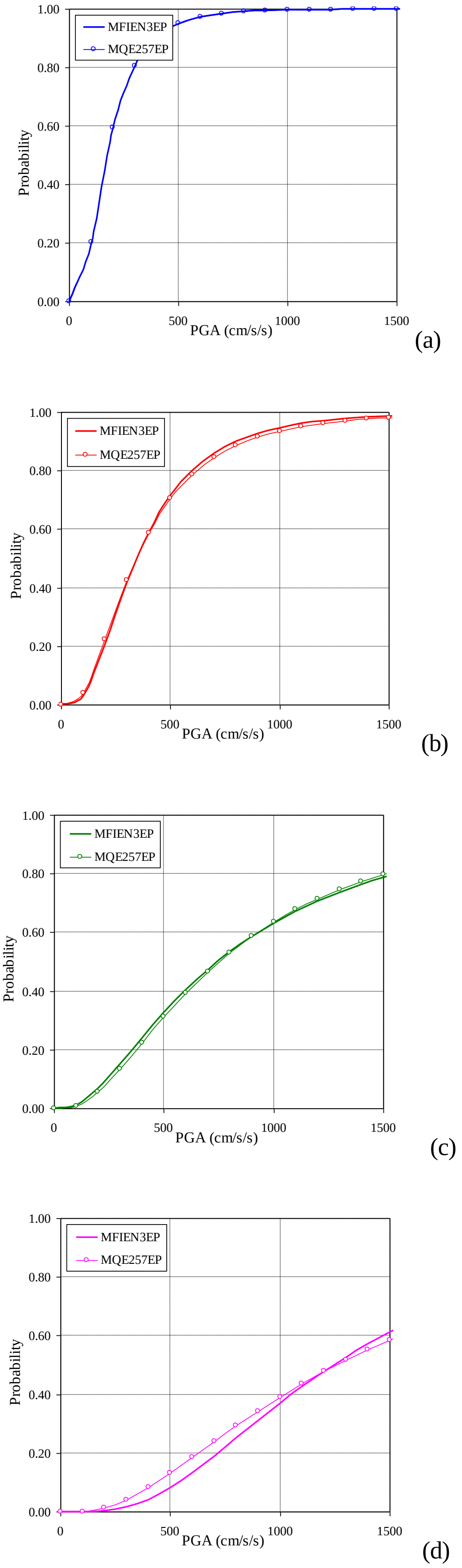
The use of electro-welded wire mesh as main reinforcement is a subject of controversy in the last years in Peru. From 1998 to 2004, many buildings were built whose lateral resistance system to earthquake consist of thin RC shear walls reinforced with electro-welded wire mesh as main reinforcement. For this reason, the influence of the use electro welded-wire mesh instead of conventional reinforcement as the main reinforcement in the fragility curves is evaluated.

The fragility curves obtained for the walls MFIEN3EP and MQES57EP are presented. As can be observed, the amount of main reinforcement is almost the same for those walls but the material used in the every wall is different. Table 4 shows the parameters of fragility curves for thin RC shear walls.

Table 4 Parameters of fragility curves for the thin RC shear walls

Prototype	Damage state							
	D > Light		D > Moderate		D > Severe		D = Collapse	
	λ	ξ	λ	ξ	λ	ξ	λ	ξ
MQE257EP	5.14	0.65	5.83	0.70	6.62	0.83	7.13	0.82
MFIEN3EP	5.16	0.65	5.84	0.66	6.61	0.88	7.13	0.65

Figure 5 presents the fragility curves for the walls with respect to PGA considering Peruvian records for different damage states. As can be observed, the change in the probability of exceeding a damage state with respect to the material used as main reinforcement is rather small. It is also observed that the slope of the curves gets steeper for first damage levels.



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

Figure 5 Comparison of the fragility curves for the walls MFIEN3EP and MQE257EP with a) light, b) moderate, c) severe and d) collapse damage states

5.2 Seismic performance

Finally, in order to evaluate the probability of being in each damage state, it is important to evaluate representative values of intensity. In the work of Silva (2008), the three levels of peak ground accelerations are presented (Table 5).

Table 5 Levels of hazard presented by Silva (2008)

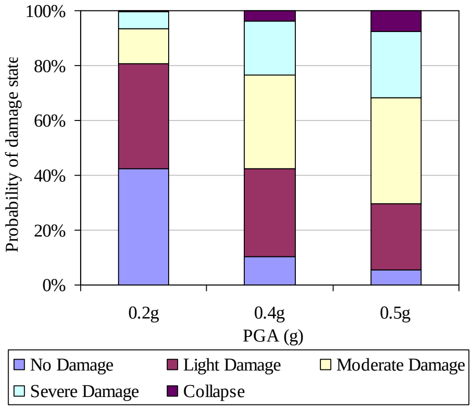
Ground Motion	Return Period (Years)	PGA (g)
Frequent	50	0.2
Rare	475	0.4
Very rare	970	0.5

Based on the fragility curves presented before, the probability of being in each damage state at each specified hazard level is obtained. Table 6 shows the comparison for the walls MFIEN3EP and MQE257EP. Figure 6 shows the damage probabilities for PGA equal to 0.2g, 0.4g, and 0.5g for the same walls.

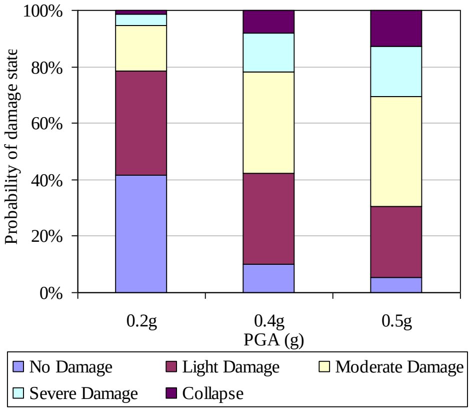
Table 6 Comparison of probability of each damage state for the three levels of seismic intensity

Damage State	PGA					
	MFIEN3EP			MQE257EP		
	0.2g	0.4g	0.5g	0.2g	0.4g	0.5g
No Damage	42.4%	10.3%	5.4%	41.7%	10.1%	5.3%
Light Damage	38.2%	32.0%	24.3%	36.8%	32.1%	25.1%
Moderate Damage	12.9%	34.3%	38.5%	16.2%	36.0%	39.1%
Severe Damage	6.3%	19.5%	24.1%	4.1%	13.9%	17.8%
Collapse	0.2%	3.9%	7.8%	1.2%	7.9%	12.7%

From Table 6, it is observed that in case of frequent earthquake, the damage is around 42% in no damage, 37% in light damage level and 14% in moderate damage for both walls. For a rare earthquake event, approximately 67% of the walls show light and moderate damage states and 10% of them without damage. In case of a very rare earthquake, approximately 63% of the wall MFIEN3EP and 57% of the wall MQE257EP show moderate and severe damage states. The probability of collapse is approximately 8% for the wall MFIEN3EP and 13% for the wall MQE257EP.



(a)



(b)

Figure 6 Damage probabilities for PGA equal to 0.2g, 0.4g, and 0.5g for the walls a) MFIEN3EP and b) MQE257EP

6. CONCLUSIONS

The use of fragility curves is a useful tool to estimate the structural damage in a certain type of structures due to the effect of future events. In the present study, the fragility curves for thin RC shear walls for low-rise and mid-rise buildings constructed in Lima is constructed thorough a series of numerical simulations. The PGA was selected as a seismic index, and the variation of the types of material used as main reinforcement were considered. The damage index is defined with respect to the drift, and it was classified into 4 damage states. The fragility curves presented in this study help to predict the damage that buildings composed of thin RC walls especially in Lima, Peru. From the analysis of the fragility curves obtained, the following conclusions can be drawn:

It was observed that the use of electro-welded wire mesh as main reinforcement gives similar damage probability compared with the wall consisted of the conventional reinforcement. This indicates that the use of electro-welded wire mesh is acceptable with the viewpoint of seismic resistance. The use of electro-welded wire mesh as main reinforcement can reduce the price of buildings.

The walls behave practically in moderate and light damage (94%) under the moderate earthquake. In case of the severe earthquake, the walls behave in severe and moderate damage (94% in average). The probability of collapse is approximately 6% in average for the both walls.

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