COMPARISON OF NUMERICAL FRAGILITY CURVES FOR THIN RC WALLS USED IN LIMA, PERU CONSIDERING VARIATIONS OF GROUND MOTION DATASETS

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ABSTRACT

In this study, an analytical approach was adopted to construct fragility curves for thin RC walls that are the vertical components of the lateral-force-resisting system of buildings to earthquakes typically used in Lima, Peru since 1998. The main feature of these walls is the use of electro-welded wire mesh as main reinforcement instead of conventional bars. The numerical models were constructed based on the results of experiments. A series of non-linear dynamic response analyses was performed using two ground motion datasets. The damage ratios were estimated with respect to four damage states performing seismic response analyses. The fragility curves were obtained assuming that the damage ratios follow lognormal distributions. Comparing the fragility curves obtained from the two datasets, the effects of ground motion characteristics to the responses of RC shear walls are discussed in this paper.

Keywords: thin RC wall, ground motion index, damage state, fragility curve.

1. INTRODUCTION

During the 2010 Chile Maule earthquake, some buildings, which resist lateral seismic forces with thin walls, suffered severe damage and in some cases collapsed. In Lima City, Peru, 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 real behaviors of these buildings during an earthquake and the loss associated with their fails.

The study of seismic loss is a matter of research in many countries located in seismic-prone regions. To evaluate the damage to structures, fragility curves are widely employed and developed for RC buildings, bridges and other structures.

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The objective of this study is to develop analytical fragility curves based on numerical simulations and evaluate the influence of two ground motion datasets. The first consists of strong motion records obtained in Lima, Peru, and the second compiles the overseas events, such as in Japan, United States, and Taiwan.

The response characteristics of the thin RC Peruvian walls were evaluated in our previous study (Quiroz et al. 2013). 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. 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 of the two datasets of ground motion records on the fragility curves are discussed and the probabilities of a certain damage state for three hazard levels are estimated.

2. NUMERICAL MODEL OF THE THIN RC WALL

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 presents 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. We assume a five-story building composed of the thin RC walls as a prototype of mid-rise building in Lima, Peru.

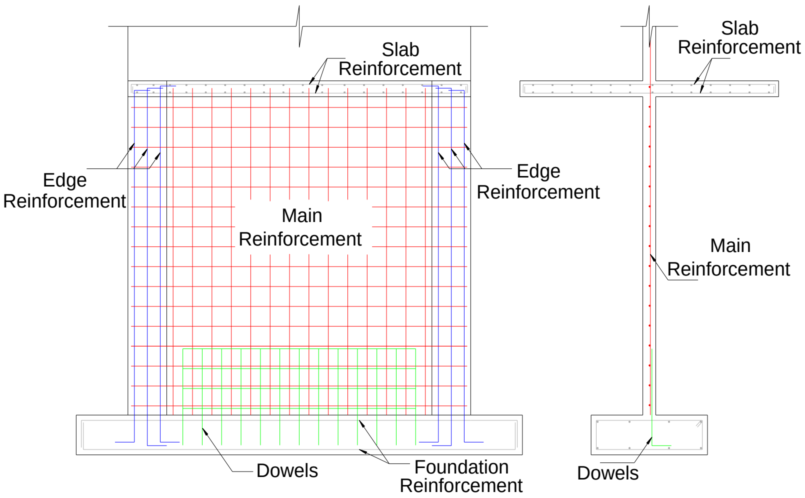

Figure 1: General characteristics of the specimens considered in the study

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	

Table 2: Definition of damage states with respect to the drift proposed by Ghobarah

State of damage	Drift limit (%)
No damage (ND)	0.0 – 0.1
Light (L)	0.1 – 0.2
Moderate (M)	0.2 – 0.4
Severe (S)	0.4 – 0.8
Collapse (C)	> 0.8

The 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. 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. More details specifications are in the reference (Quiroz et al. 2013).

The numerical model represents the effects of nonlinear behavior by modeling with the concentrated springs idealized by a trilinear backbone curve and hysteretic rules. 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 our previous study (Quiroz et al. 2013).

3. DEFINITION OF DAMAGE LEVELS

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 drift of 0.85 - 1.50% for low-rise walls with reinforcement ratio of smaller than 0.25%.

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 by Zavala (2004). Table 2 shows the definition of damage states proposed by Ghobarah based on the amount of drift.

Table 3: Dataset of Peruvian ground motion records

Event	Year	MW	MS	ML	Lat. (S)	Long. (W)	Hipoc. Dist. (Km)	No. of records
Lima Eq.	1951	-	5.5	6	12.21	76.94	53.61	1
Ancash Eq. [1]	1970	-	7.8	-	9.36	78.87	367.00	1
Nov-71	1971	5.6	-	-	11.34	77.79	128.21	1
Jan-74	1974	6.5	6.6	-	12.39	76.29	128.56	2
Lima Eq. [1]	1974	-	7.6	-	12.50	77.98	115.00	2
Lima & Callao Eq. [1]	1966	8.1	8	-	10.70	78.70	239.00	1
Nov-74	1974	-	7.2	-	12.52	77.59	80.08	1
Mar-04	2004	-	-	5	13.01	77.45	127.42	1
Jul-04	2004	-	-	5.4	11.19	78.24	171.79	1
Mar-05	2005	-	-	5.7	11.88	76.14	158.33	1
Feb-06	2005	-	-	5.4	11.02	76.10	196.68	1
Lamas Eq.	2005	-	-	7	5.80	76.20	712.82	2
Pisco & Ica Eq.	2007	7.9	-	7	13.67	76.76	-	2
Callao Eq.	2008	5.3	-	5.3	12.25	77.25	58.36	2

[1] Used to draw the inelastic design spectrum of Peruvian standard E.030 (Ministry of Housing Peru 2003)

4. EARTHQUAKE GROUND MOTION RECORDS

In order to consider the uncertainty of the ground motion, various records that reflect the seismicity of a specific place are collected. Since the current study focuses on the effects of the ground motion variability on the wall response, two datasets of ground motion records are considered.

In case of the dataset of Peruvian records, nineteen acceleration time histories recorded by Japan Peru Center for Earthquake Engineering and Disaster Mitigation (CISMID), National University of Engineering, Peru and Geophysical Institute of Peru (IGP) were selected. The number of events is 14. The horizontal components of the acceleration records are applied to the numerical model. All the records have been recorded in dense gravel soil, which represents the typical soil in Lima, and most of them consist of very high frequency contents. The specifications of the earthquake events are shown in Table 3. As can be observed in Table 3, the number of records in Lima, Peru is very limited. To consider more ground motions, a set of overseas ground motion records was also considered in this study.

The dataset of ground motion records during overseas events were mainly compiled by Karim and Yamazaki (2001; 2003) to construct the fragility curves of bridge piers, and the authors added 33 records of the 1994 Hokkaido Toho-oki Earthquake (Mw = 8.2) and 25 records of the 2011 off the Pacific of Tohoku Earthquake (Mw = 9.0).

Figure 3 shows the acceleration response spectra for Tohoku earthquake and Peruvian records, which are normalized to have PGA of 1g, with the damage ratio of 5%. The mean amplitude is also shown for each event with a thick line.

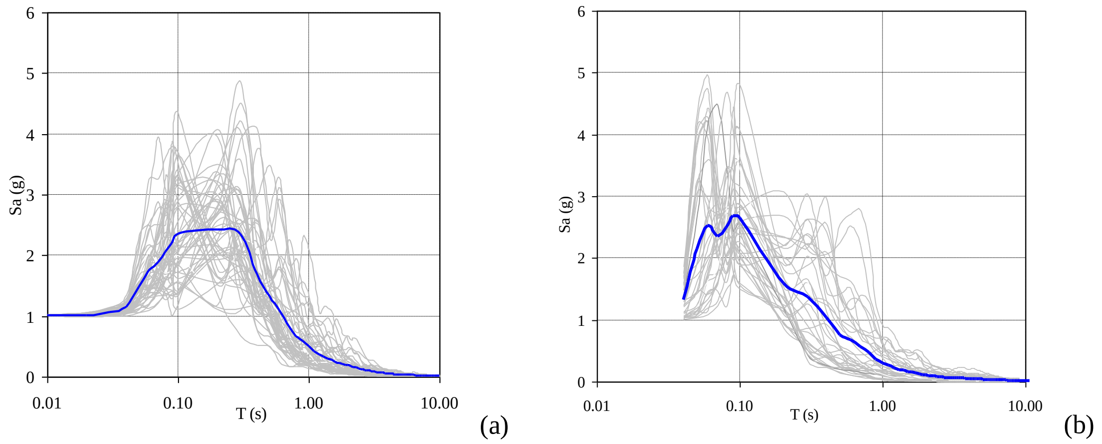

Figure 3: Acceleration response spectra (normalized to have PGA of 1g) with the damping ratio of 5% for a) Tohoku earthquake and b) Peruvian records

5. DEVELOPMENT OF FRAGILITY CURVES

The non-linear dynamic response analysis is carried out using IDARC2D program (Reinhorn et al. 2009) considering a combination of the Newmark-Beta integration method and the pseudo-force method.

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. Based on these data, fragility curves for the walls are constructed assuming a lognormal distribution. The cumulative probability P_R of the occurrence of damage equal or higher than a certain damage state is given by

$$P_R = \Phi\left[(\ln Y - \lambda)/\zeta\right] \tag{1}$$

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. The two statistical parameters of the distribution, λ and ζ, are obtained by plotting ln Y against the inverse of Φ on lognormal probability papers, and performing least-squares fitting of the plot.

The values of PGA for all records in the two datasets 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 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.

Table 5: Parameters of fragility curves for the wall MQE257EP with respect to PGA

Event	Damage state							
	D > Light		D > Moderate		D > Severe		D = Collapse	
	λ	ξ	λ	ξ	λ	ξ	λ	ξ
Chibaken Toho-Oki	4.55	0.38	5.33	0.33	5.97	0.31	6.33	0.37
Kushiro-Oki	4.66	0.32	5.32	0.31	5.94	0.42	6.34	0.44
Northridge	4.86	0.46	5.52	0.35	6.00	0.19	6.38	0.29
Hokkaido Toho-oki	4.48	0.52	5.29	0.33	5.87	0.49	6.32	0.45
Kobe	4.77	0.26	5.45	0.33	6.03	0.26	6.36	0.26
Chi-Chi	4.71	0.28	5.42	0.28	6.01	0.24	6.33	0.25
Tohoku	4.53	0.49	5.39	0.40	6.16	0.37	6.68	0.41
All overseas records	4.70	0.37	5.38	0.33	5.99	0.36	6.41	0.37
Peruvian records	5.14	0.65	5.83	0.70	6.62	0.83	7.13	0.82

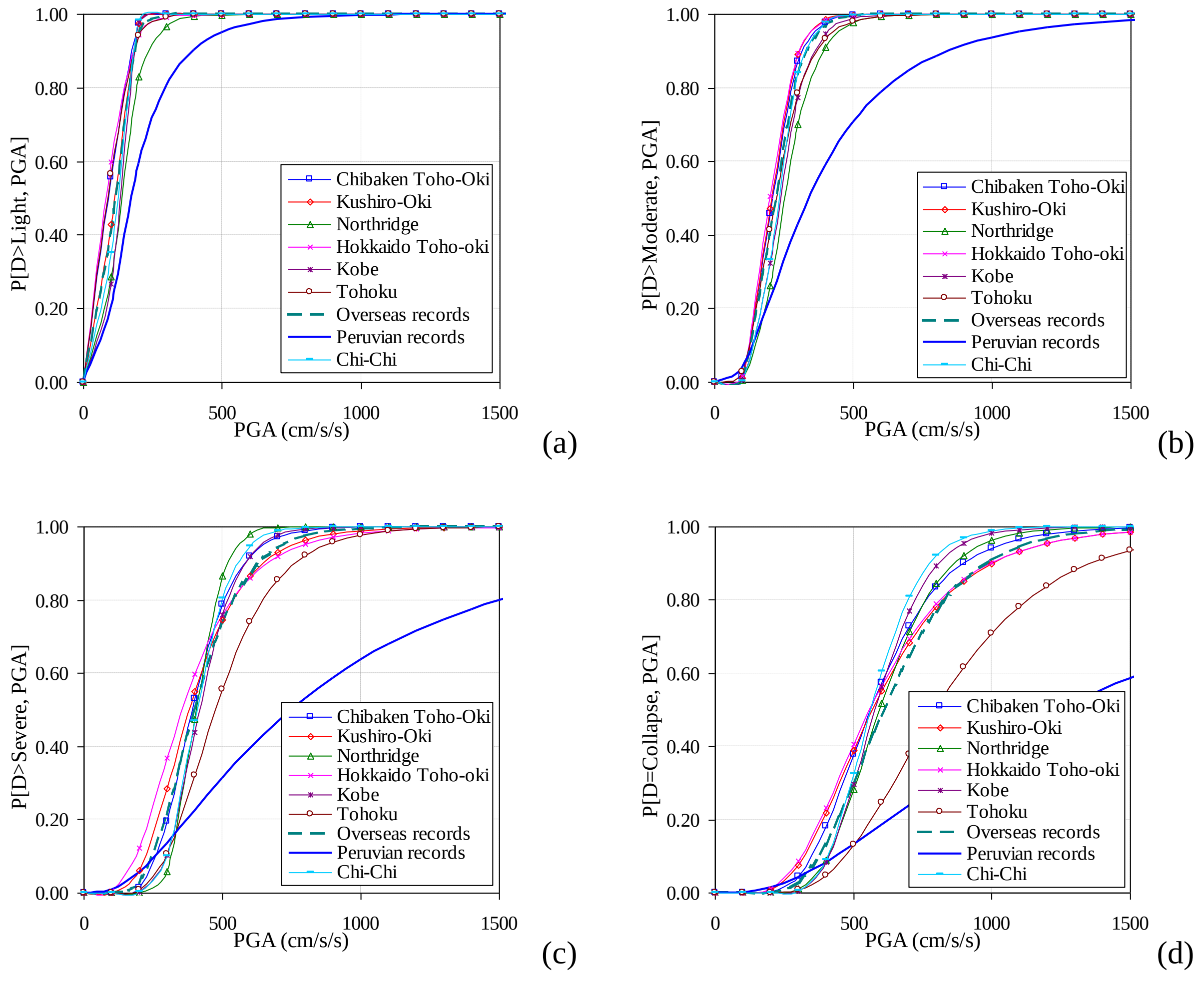

Figure 5: Comparisons of the fragility curves for overseas events and Peruvian records for a) Light, b) moderate, c) severe and d) collapse in case of the wall MQE257EP

5.1. Influence of variations of ground motion datasets

Table 7: 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

Table 8: Comparison of probability of being in each damage state for the three levels of seismic intensity in case of Northridge, Chi-Chi events and Peruvian records

Damage State	PGA								
	Northridge			Chi-Chi			Peruvian		
	0.2g	0.4g	0.5g	0.2g	0.4g	0.5g	0.2g	0.4g	0.5g
No Damage	18.10%	0.80%	0.20%	2.10%	0.00%	0.00%	41.70%	10.10%	5.30%
Light Damage	57.40%	9.00%	2.50%	67.00%	2.60%	0.30%	36.80%	32.10%	25.10%
Moderate Damage	24.50%	46.70%	13.10%	30.80%	53.60%	21.50%	16.20%	36.00%	39.10%
Severe Damage	0.00%	35.50%	58.30%	0.10%	36.00%	48.40%	4.10%	13.90%	17.80%
Collapse	0.00%	8.10%	26.00%	0.00%	7.90%	29.80%	1.20%	7.90%	12.70%

Tables 5 shows the values of λ and ζ with respect to every overseas event and Peruvian records in case of the wall MQE257EP. Similar values were also found in the case of the wall MFIEN3EP. Figure 5 presents the fragility curves for the wall MQE257EP with respect to PGA considering overseas events and Peruvian records for different damage states. It can be observed that the probability of being or exceeding a certain damage state is a little bit higher especially for smaller accelerations under Peruvian records (less than 300 cm/s^2 in average). In case of larger accelerations, the probability is higher in case of overseas events and the slope of the fragility curves gets steeper for all damage levels, especially in the last two damage states. As can be observed in Fig. 3, the acceleration response spectra from Peruvian records present larger amplitudes at shorter periods than those from overseas records. This periodical characteristics of input ground motions affect the differences of fragility curves.

5.2. Seismic performance

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 7). Based on the fragility curves presented before, the probability of being in each damage state at each specific hazard level is obtained.

Table 8 shows the comparison for the wall MQE257EP for the Northridge, Chi-Chi and Peruvian records. As can be observed, almost 100% of the walls are in the states of moderate, light, and no damage in case of frequent earthquake (0.2g). In case of the rare earthquake (0.4g), approximately 92% of the walls are in the states of severe damage, moderate, light, and no damage. Finally, in case of very rare earthquake (0.5g), the probability of collapse under overseas records is around 28% while it is around 13% under Peruvian records.

6. CONCLUSIONS

In the present study, the fragility curves for the Peruvian thin RC walls employed for low- and mid-rise buildings constructed 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 contribute to predict the damage to buildings composed of thin RC walls especially in Lima, Peru.

In order to construct the fragility curves, two statistical parameters were estimated for the walls MFIEN3EP and MQE257EP. The values estimated were very similar for the two walls under the two input ground motion datasets.

Peruvian records give a little bit higher probability of being or exceeding a damage state than overseas events under smaller accelerations. For larger accelerations, the probability is higher under overseas records. Also, the slope of the fragility curves constructed using overseas events get steeper for all damage levels, especially in the last two damage stages.

The walls behave practically in moderate and light damage (97%) for frequent earthquake. In case of rare earthquake, the walls behave in severe, moderate and light damage with a probability of 92% for overseas events and 82% for Peruvian records. The probability of no damage in case of Peruvian records is around 10%. For the same level of hazard, the probability of collapse is around 8% for the two datasets.

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