SEISMIC FRAGILITY FUNCTION FOR LOW STOREY RC BUILDING IN INDONESIA CONSIDERING ACTUAL CONCRETE STRENGTH

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Abstract

Reinforced Concrete (RC) building becomes the most populated building type in the world, including in Indonesia. However, the history of the earthquake in Indonesia shows that the vulnerability of RC building is high and contributed to the loss of many lives. Inadequate concrete works become one of the main causes of the low quality of RC building that contributes to the damage of RC buildings. To reduce the risk of RC building due to earthquake, the effective assessment tool that can predict and observe the damage probability as well as the performance of the selected typical building under earthquake excitation is important, named seismic fragility function. Some fragility function has been developed in Indonesia. However, the fragility function for low storey RC building that built based on the actual concrete strength in Indonesia is yet available. Hence, this study aimed at developing the seismic fragility function that can show the performance of low storey RC building type based on the actual concrete strength in Indonesia. The development of fragility function used the numerical analytical method based on Incremental Dynamic Analysis (IDA) by using the Applied Element Method (AEM). AEM enables the observation of damage patterns to justify the damage state from no damage, slight, moderate, severe, till total collapse state. The derivation of fragility function used the lognormal distribution function. Then the multiple fragility curve was developed. The results show that RC building with strong concrete (26 MPa) will collapse at 0,65g while the one with weak concrete (10 MPa) will collapse faster at 0.31g.

Keywords: Reinforced Concrete Building; Seismic Fragility Function; Actual Condition; Concrete Strength

1. Introduction

Indonesia is one of the most prone earthquake regions in the world. Earthquake causes economic, socio-cultural, and life losses in many provinces in Indonesia. Most of the loss comes from the damage and collapse of Reinforced Concrete Building with Masonry Wall (RCBM), which is the predominant type of building used by people in many cities in Indonesia [1]. The RCBM is damaged easily due to the poor construction method, low concrete strength, following by the lack of supervision effort, especially for huge numbers of low rise RCBM used as the residential building [1]–[4].

Big earthquake on 30th September 2009 in Padang City shows that RC buildings with masonry walls are vulnerable to earthquake load. The damages were varied from minor to total collapse. The majority of buildings suffered significant cracking in masonry infill, and out of plan failure is often observed. The failure due to the development of the plastic hinge at the top and bottoms of the column were majorly found. The recent 2018 Lombok earthquake also shows that the performance of RC buildings with a masonry wall, especially low rise one is weak towards the seismic load. Based on the data of the Indonesia National Disaster Agency (BNPB), 2337, housing suffered heavy damage and over 5909, 6736 moderates, and slight.

To reduce the risk of RC buildings due to future mega-earthquake, Indonesia needs the assessment tools that can predict the damage probability of RC building under particular PGA as well as observing its performance based on actual concrete strength. Based on the investigation on actual concrete strength of existing RC building, in Padang City, have found that the are many buildings that use inadequate concrete strength. Statistically, the predominant concrete strength is around 16 MPa, where the minimum requirement by Indonesia National Standard is 17 MPa.

It may be best to assess the existing buildings one building at the time due to its uniqueness of the quality. However, this technique may not always be feasible if the building inventory is enormous. An alternative to individual building analysis is the fragility analysis of buildings. Fragility analysis provides information on the probability of exceedance of predefined performance under different earthquake intensity measures. Such analysis results in fragility curves, which, when available for buildings with different structural characteristics, provide convenient seismic assessment tools

2. Review of Fragility Function and Concrete Quality in Indonesia

2.1 Review of Some Fragility Function in Indonesia

Some fragility functions have been developing for seismic assessment tools in Indonesia. However, most of the available fragility function in Indonesia was based on the empirical method, which provides the damage information based on the specific one-time earthquake event, when the performance of the undamaged structure keeps unknown for a different or future earthquake. Some of them were developed by using the analytical method. However, consideration of the actual condition seems to be neglected — furthermore, the fragility functions that are validated with actual damage data yet available.

As the awareness of RC building vulnerability raised after the 2009 Earthquake in Padang City, some researchers built some assessment tools to inform the vulnerability of some typical buildings in Indonesia.

Hakam (2010) developed a vulnerability curve for housing in West Sumatra (see Fig. 1). The damage data for the building were based on building damage data of the 2009 Earthquake in West Sumatra. However, the curve was based on the empirical data, which is in another side can show the actual damage, but it cannot show the probability damage of housing in the future for a different earthquake — the type of building that addressed on the curve also unclear and very general, especially for types of building structural system. The provided information also limited to severe damage only [5].

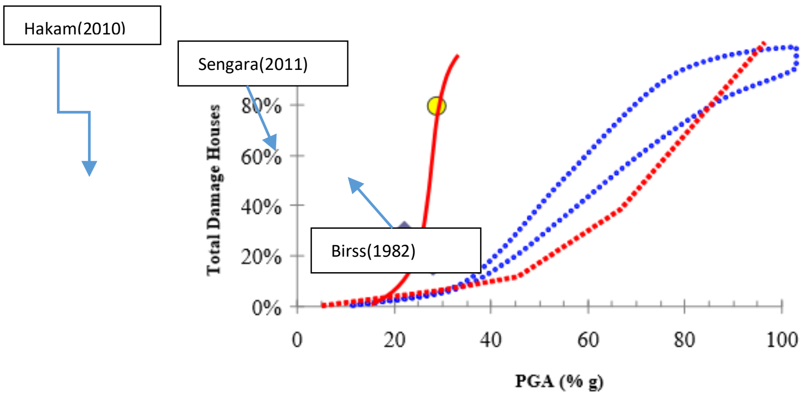


Fig. 1. –Vulnerability Curves for Residential Building in West Sumatra (—), Sengara, 2011 (blue dot), Birss, 1985 (red dots), for Masonry Structure [5]

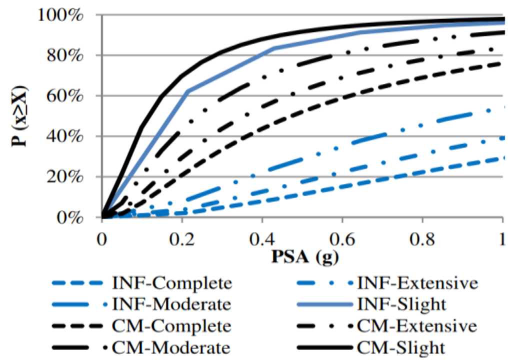


Fig. 2. – Fragility Curves for Two Types of Residential Buildings in Jakarta City [6]

Irsyam et al. derived fragility curves, as shown in Fig. 2, for two types of low-rise buildings that dominate the residential building population in Jakarta. The fragility curves are derived based on FEMA 154 procedures for a different level of damage (i.e., Slight, Moderate, Extensive, and Complete Damages), and the ground motion intensity is expressed regarding Peak Surface Acceleration (PSA) [6]. Unfortunately, the process of the derivation of the curve is not explained clearly, and the curve also seems not well fitted.

The review shows the fragility function of RC buildings with masonry walls that can predict the damage due to future earthquakes and well fitted, also based on actual conditions and valid yet available.

2.2 Concrete Quality in Padang City, Indonesia

Juliafad et al. investigated the quality of concrete on the existing building and under-construction buildings. The findings show that many buildings, especially non-engineering residential buildings, use poor quality concrete. The investigation found the existing concrete is porous, fragile, and does not have adequate strength. The concrete compressive strength test for concrete cube from existing and demolished building show that the concrete strength tends to be inadequate as the minimum requirement for concrete strength according to Indonesian Nasional Standard. The Indonesia Nasional Standard requires 17 MPa as the minimum concrete strength for structural elements[7].

Hence, this study developed the fragility function that provided information about the performance of typical RC building in Padang City, Indonesia, with different strengths of concrete based on the actual condition.

2. Research Methodology

After conducted a literature review and found the pre-dominant local compaction method, the compression strength of concretes was determined. Each concrete strength was used as the input concrete material for the structural model. The structural model was developed based on the actual data from the existing Infill Masonry RC Building in Padang City.

After selected strong ground motion records based on its magnitude, frequency, and its duration, the Incremental Dynamic Analysis was conducted by using the Applied Element Method. Damage patterns based on HAZUS damage measures were used to judge the damage level of selected buildings [8].
Figure 3 shows the research methodology flowchart :

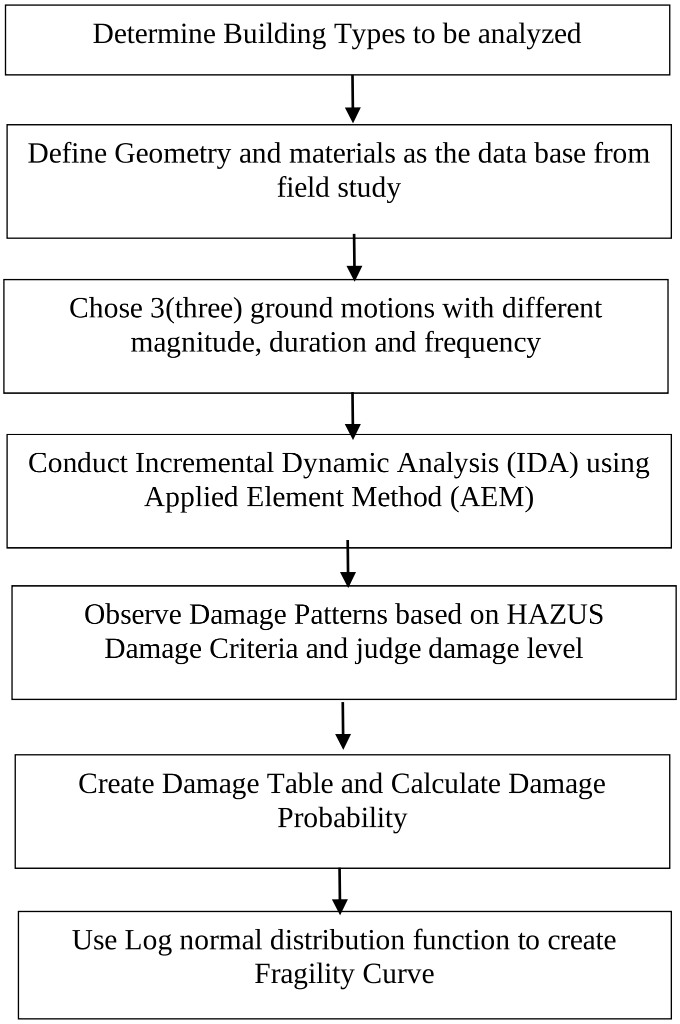


Fig.3. The Research methodology flowchart

3. Result and Discussion

3.1.Numerical Model Development

Typical building type that available in Padang City is low rise RC building with a red brick masonry wall. This building type covers more than 80% of the building population. Low rise RC building is single storey, and two storey building, where the single storey building normally is used as a residential building while the two storey can be found along the main road functioned as shop-residential building. Figures 4 and 5 show a typical low rise building that analyzed in this study.

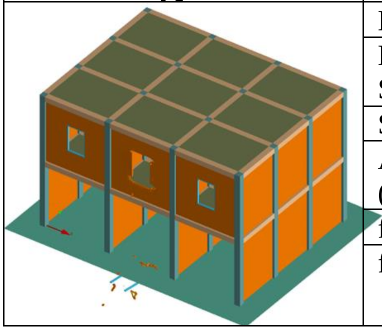
Type 1	**Cross Section**	**Column**	**Beam**	**Slab**
	Dimension (mm)	330x330	330x300	140
	Longitudinal Steel	4P12 ;2P 12	3P12 ;2P12	P10-100
	Stirrups	P8-100	P8-100	
	Actual diameters (mm)	11.83	11.52	10.48
	fy[kg/mm2]	33.62	33.62	47.55
	fu/fy	1.24	1.24	0.68

Fig.4. – Typical Two Storey RC building in Padang City, Indonesia

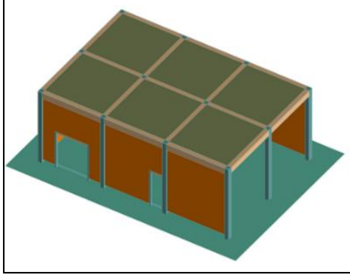
Type 2	**Cross Section**	**Column**	**Beam**	**Slab**
	Dimension (mm)	260x260	260x330	t=120
	Longitudinal Steel	6P12	6P12	P10-200
	Stirrups	P8-110	P10-120	
	Actual diameters (mm)	11.83 7.6	11.83 7.6	9.1
	fy[kg/mm2]	22.06	24.89	47.55
	fu/fy	1.76	1.4	0.68

Fig.5. –Typical Single Storey RC building in Padang City, Indonesia

Table 1. –Input Material Properties for Numerical Model of Type 1 and Type2 RC building

Concrete Input Material	Point 1 (weak)	Point 3 (strong)	Formula based on Indonesia Building Code* and ACI 318M
fc`[MPa]	8	27	Figure 5.9.
ft [MPa]	1.98	3.64	$0.7\sqrt{f_c`}$
E[MPa]	13293.6	24421.9	$4700\sqrt{f_c`}$
G[MPa]	5539.	10175.8	$G=\dfrac{E}{2(1+\nu)}$
fv[MPa]	1	3.5	$0.13\sqrt{f_c`}$

Steel material and brick material properties are based on the tensile strength, and brick compression testing Mortar for the brick of the wall uses the mortar strength data from mortar compression strength testing as well.

Table 2. –Input of Brick and Mortar Material

Masonry Wall Input Material	Mortar	Brick
fc`[kg/mm2]	2.017	0.8
ft [kg/mm2]	0.0217	0.08

E [kg/mm2]	79.74	13.14
G [kg/mm2]	33.225	7.57
fv [kg/mm2]	0.504	0.019

To ensuring the building performances and damages can represent the wide range of earthquake characteristics, this study used 3 actual ground motion records with different magnitude and frequency (see Table 1). Those ground motion records are Kobe, Loma Prieta, and El Centro earthquakes.

Table 3. –Ground Motion Records

Ground motion	**Duration (s)**	**Time Step**		**Main Period (s)**	**Frequency (Hz)**
		Step (s)	***Total data***		
Kobe	40.96	0.01	4096	0.47	2.13
El Centro	50.0	0.01	4000	0.25	4
Loma Prieta	39.955	0.005	7991	0.15	6.67

Each ground motion record and detail is presented in Fig. 6, 7, and 8, consequently.

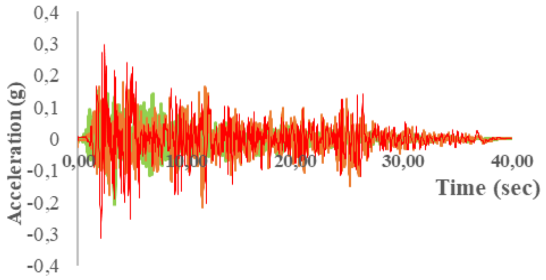


Fig. 6. –Time history of the El Centro earthquake

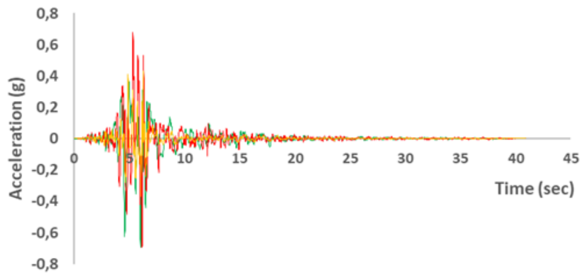


Fig. 7. – Time history of the Kobe earthquake

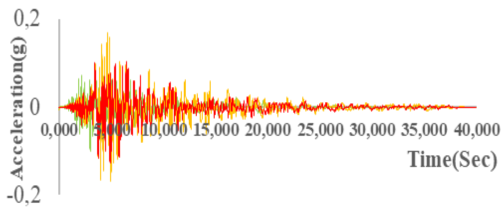


Fig. 8. –Time history of Loma Prieta earthquake

The numerical tools that were used in some previous researches were based on the Finite Element Method (FEM) approach. FEM simulation has a limitation on performing the actual damage patterns of the masonry wall, especially out of plane failure. The features of numerical tools that can give a better damage description are essential to justify the damage level of the numerical model. This research used the Applied Element Method (AEM), which is utilized in Extreme Loading Structure (ELS) software as a numerical analysis tool. AEM can show the damage of the numerical model from no-damage till collapse state. AEM capable of showing the out of the plane failure of the masonry wall and the crack patterns from slightly damage till the total collapse state. Incremental Dynamic Analysis was used in this study. IDA method is a dynamic analytical technique that incrementally magnifies or increase the ground motion records step by step till collapse state [9]–[13].

Figure 9-10 shows that damage patterns of selected RC Buildings model for each scaled el Centro ground motion started from 0.1g, 0.2g, 0,3g, and 0,8g. The judgment for damage level used HAZUS damage criteria.

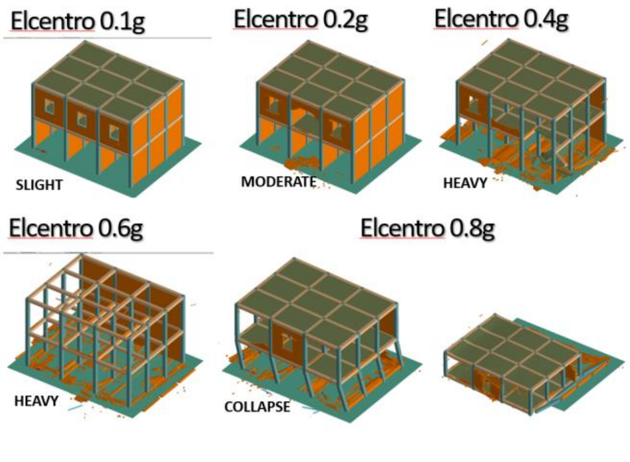


Fig.9. – Damage Patterns of RC building Type 1 for target ground motion increments

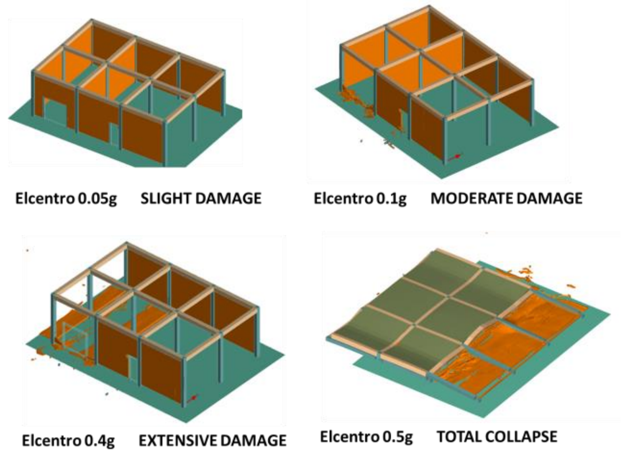


Fig.10. – Damage Patterns of RC building Type 2 for target ground motion increments

Fig.10 shows the damage patterns of RC building one storey with a rigid roof and symmetric layout. On the rear part is used for housing, and in the front is used for a shop. Due to the wide opening on the one side of the building, at 0.05g of target earthquake, had been observed the small crack near the frame of the opening. Hence, at this intensity, the building considered suffered slight damage. Next, at the 0.1g intensity, a small crack at the brittle brick wall leading to the loss of its stability, and this building was extensively damaged due to out of plane failure at the masonry wall, as seen in Fig.10.

With the increasing of earthquake intensity, at 0.4g, more brick masonry wall was damaged. This level, where many walls are falling off, is called extensive damage. Finally, at 0.5g, the total collapse of structure (structural members and wall) happened.

Fig.9 shows the damage patterns and collapse behavior of typical 2 storey buildings, which commonly find in Padang City. This type of building usually uses as hybrid buildings, where the 1st storey is used for shop, and the 2nd storey might be used for residential or office. As we can see from the collapse behavior, the soft storey effect caused the collapse of the building. This behavior also found in many buildings in the last September 2009 Earthquake.

3.2. Derivation of Fragility Function for Low Storey RC Building with Different Concrete Strength.

This subchapter discusses the fragility function of typical RC buildings in Padang City under earthquake load with different strength of concrete material properties.

Before developing a fragility function, the damage level table has to be arranged, and the cumulative damage probability should be calculated. These table for strong concrete are presented in Table 5.16

Table 4–.Cumulative Damage Probability for Strong Concrete Low Storey RC Building

Damage Level	**Peak Ground Acceleration (%g)**												
	0.05	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1	1.1	1.2
No Damage	6	1	0	0	0	0	0	0	0	0	0	0	0
Slight	6	6	1	0	0	0	0	0	0	0	0	0	0
Moderate	4	9	11	9	1	0	0	0	0	0	0	0	0

Extensive	0	0	4	7	14	12	8	6	2	1	1	0	0
Complete	0	0	0	0	1	4	8	10	14	15	15	16	16
	16	16	16	16	16	16	16	16	16	16	16	16	16

The cumulative probability value for each damage state and each PGA value (Table 5) then were derived by using lognormal distribution eq.1 [14] to obtain the value of median (μ) and standard deviation (β) for typical low storey RC building with masonry wall in Padang City for each level of damage state (see table 6)

$$P[ds/PGA] = \frac{1}{2}[1 + erf\left(\frac{\ln PGA - \mu}{\beta\sqrt{2}}\right) \quad \text{Eq.1)}$$

Where

erf = complementary error function

μ = mean = ln PGA, ds

PGA, ds = Median value of PGA at which the building reaches the threshold of the damage state ds.

β = Standard Deviation of ln PGA

The fragility curve in Fig.11 informed the probability of RC building, which built using strong concrete. By using this curve, it can be predicted that if the concrete of the building is strong, at 0.4g earthquake probability of building to be collapse is less than 10%.

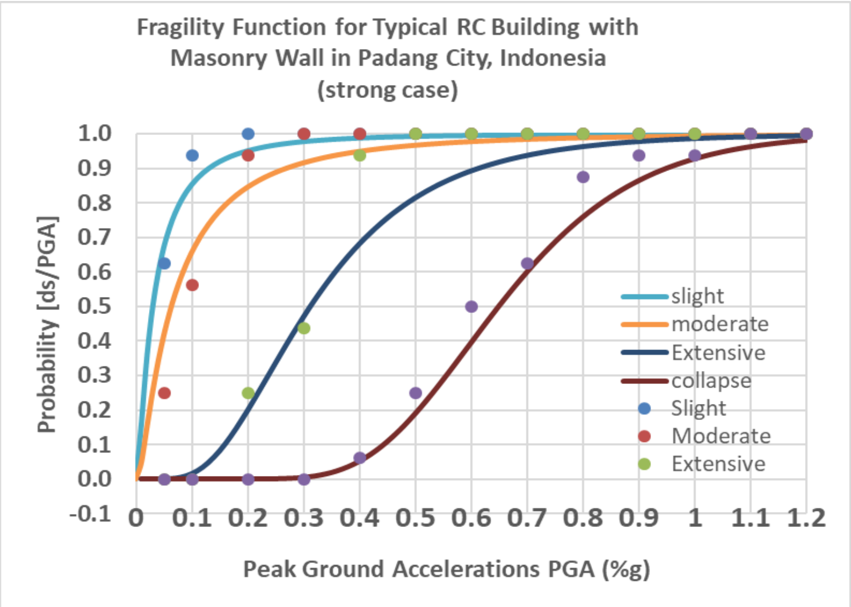


Fig.11. –Fragility Function for Typical RC Building with Strong Concrete

Next, will be discussed the performance and probability of some damage levels are being exceeded under some earthquake excitation for RC building in Padang city, which were contained weaker concrete strength. Table 5 presents the damage level for each percentage of PGA, and table 6 presents the cumulative damage probability for each PGA. The fragility curve for weak concrete is presented in Fig.12.

Table 5–.Damage Table for 1 storey RC building type in Padang

Damage Level	Peak Ground Acceleration (%g)												
	0.05	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**	**1**	**1.1**	**1.2**
No damage	2	0	0	0	0	0	0	0	0	0	0	0	0
Slight	5	1	0	0	0	0	0	0	0	0	0	0	0
Moderate	8	7	3	1	0	0	0	0	0	0	0	0	0
Extensive	0	7	10	11	8	5	3	1	0	0	0	0	0
Complete	0	0	2	3	7	10	12	14	15	15	15	15	15
	15	15	15	15	15	15	15	15	15	15	15	15	15

Table 6 –Cumulative Damage Probability for 1 storey RC building type in Padang

Cumulative Damage Probability	Peak Ground Acceleration (%g)												
	0.05	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**	**1**	**1.1**	**1.2**
Slight	0.87	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Moderate	0.53	0.93	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Extensive	0.00	0.47	0.80	0.93	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Complete	0.00	0.00	0.13	0.20	0.47	0.67	0.80	0.93	1.00	1.00	1.00	1.00	1.00

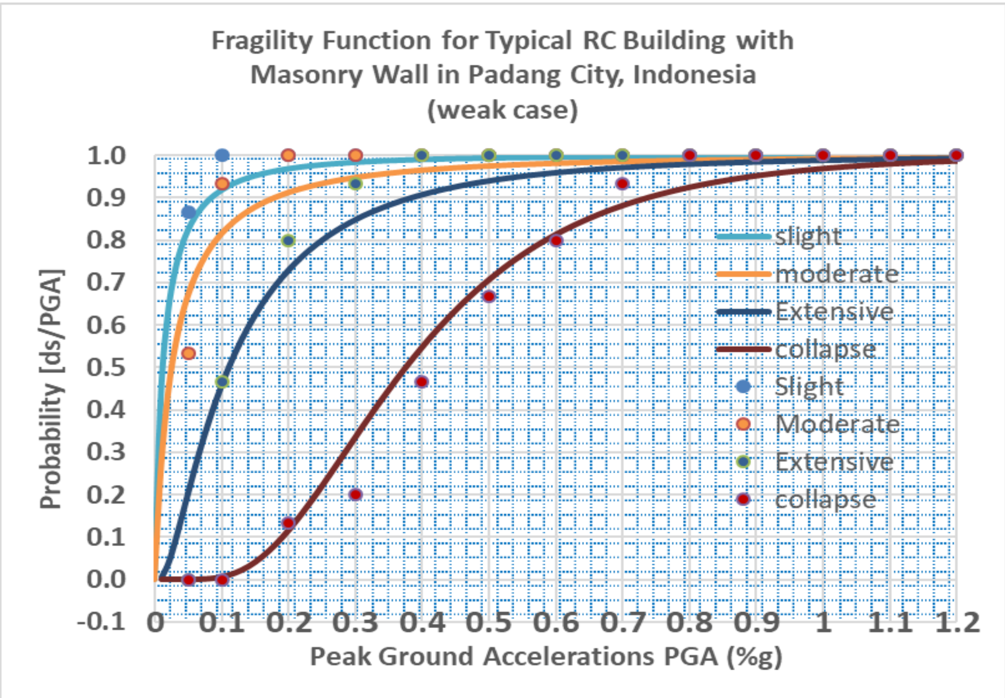


Fig.12. – Fragility Function for Typical RC Building with Weak Concrete

Fragility curve in Fig.13. shows the multi fragility curves performed the probability of damage of strong and weaker concrete of RC buildings in Padang City in one curve.

The curve shows that the strength of concrete influences the probability of damage to RC building due to the earthquake. From the curve, information about the different performances of different types of RC buildings based on concrete strength can be extracted. For example, at 0.5g earthquake, weaker concrete RC building has 50% higher probability of being collapsed compare to a strong concrete building.

While, for extensive damage, weaker concrete RC building started to be damaged extensively from earlier PGA level than the strong one. While the predominant strength of RC building will belay between the weak and the strong curve.

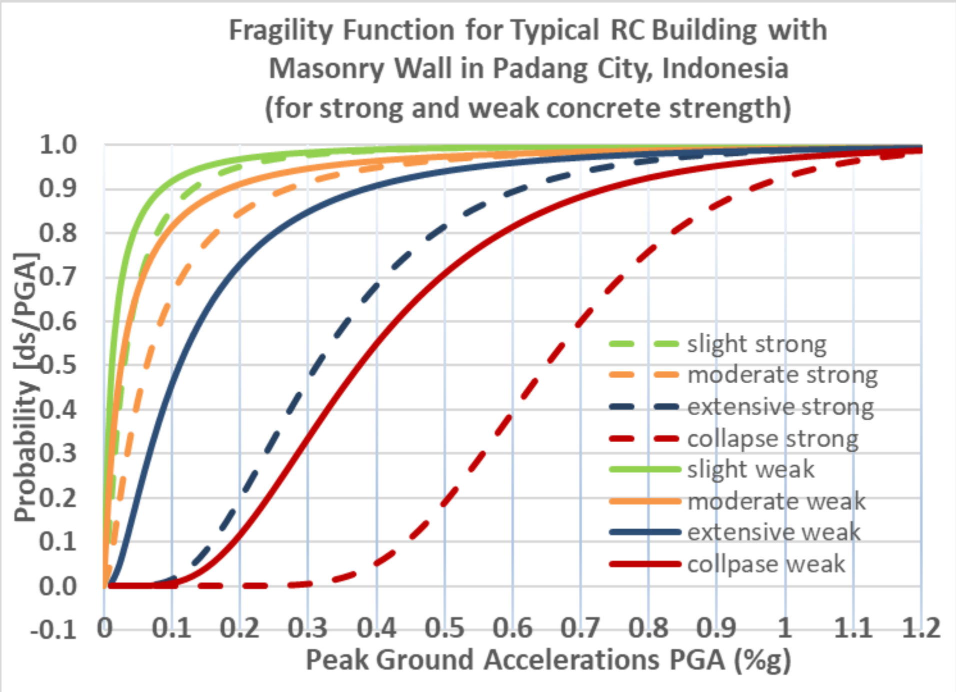


Fig.13. –Multi Fragility Function for Typical RC Building with Masonry Wall with Weak and Strong Concrete in Padang City, Indonesia

4. Conclusion

This research obtained fragility functions and fragility curves for typical low storey RC buildings with masonry walls with different strength of concrete (weak and strong) in Padang city.

The development of fragility function used the numerical, analytical method based on Incremental Dynamic Analysis (IDA) by using the Applied Element Method (AEM). AEM enables the observation of damage patterns to justify the damage state from no damage, slight, moderate, severe, till total collapse state. The derivation of fragility function used the lognormal distribution function. The results show that with the 50% of probability to be damaged, RC buildings with strong concrete (26 MPa) will collapse at 0,65g while the one with weak concrete (10 MPa) will collapse faster at 0.31g. Based on this study, the Indonesian government can use the fragility function based on the actual condition that obtained as the tools to make a vulnerability map and the preparedness for earthquake disaster.

5. Acknowledgment

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6. References

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