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SEISMIC VULNERABILITY ASSESSMENT OF HOSPITAL BUILDING AS CRITICAL FACILITIES IN NORTH SIDE OF JAKARTA USING HAZUS METHOD

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ABSTRACT
Jakarta as the capital city of Indonesia is surrounded by many active faults which leads it to be one of the most earthquake-prone areas in Indonesia. Several devastating earthquakes occurred in 1699, 1780, 1883, and 1903. Hence, vulnerability assessment of the hospital building as one of the critical facilities in Jakarta, particularly in the north side of Jakarta whose geological condition is in the form of soft soil, is necessary. The study aims to analyze the vulnerability of the hospital building to get each fragility curve form and analyze the probability of the damage into the hospital buildings using HAZUS method. The method developed by the National Institute of Building Sciences (NIBS) is suitable for use in risk assessment due to variety of disasters, including earthquakes. The study begins with a survey of the hospital building, followed by analysis of its vulnerability using HAZUS methods. The fragility curve results of the 10 hospital buildings in the north side of Jakarta showed that the higher number of the stories building and the longer code used, the higher percentage of vulnerabilities, especially at a complete and extensive level. Based on the building damage probability analysis, the highest value for the probability of slight, moderate, extensive and complete level respectively are 27% (Manuela Hospital), 60% (Royal Progress 9-storey Hospital), 32% (Atmajaya Hospital) and 39% (Atmajaya Hospital).

*Keywords***:** Damage probability; Earthquake; Fragility curve; HAZUS method; Hospital building

1. INTRODUCTION

Indonesian earthquake map 2010 shows that Jakarta is one of earthquake-prone region in Indonesia. The probability is increased compared to the one mentioned in SNI 03-1726-2002, which is 0,15g rises to about 0,2g. The number is even higher based on previous research (Muntafi, et al., 2015), which shows that based on seismic hazard analysis of Jakarta result during period of 500 years has reached PGA value of 0.236g. The vulnerability of buildings in the north side of Jakarta, especially critical facilities that stand on soft soil, need to be assessed. Hospital building as an important building during the earthquake is expected to remain in normal operation. Based on the past earthquake events, there are a number of hospital buildings which were damaged by earthquake shaking.

Method of Hazard-US (HAZUS) is a method developed by the National Institute of Building Sciences (NIBS) which is suitable to be used in the risk assessment as a result of various disasters, including earthquakes. Therefore we need a vulnerability analysis

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of the hospital buildings as one of the mitigation efforts using HAZUS method. The study aims to analyze the vulnerability of the hospital building to get each fragility curve form and analyze the probability of damage into the hospital buildings using HAZUS method.

2. METHODOLOGY

This study uses US-HAZUS methodology to determine the probability of damage to each hospital building in the north side of Jakarta, precisely in North Jakarta and West Jakarta which is caused by the earthquake.

2.1. Building Vulnerability Based on HAZUS

HAZUS method is issued by The Federal Emergency Management Agency (FEMA) in 1999 to estimate the losses caused by the earthquake in the US. HAZUS for earthquakes version was launched in 2003. HAZUS-earthquake is one of analysis model to determine the level of buildings vulnerability to an earthquake that generates fragility curves with high accuracy and flexibility to be applied to analyze the level of building vulnerability.

2.2. Seismic Design Level

The regulations applied in the seismic design of each type of building are different from one another, starting from the Pre-code, Low-code, Moderate-code, to High-codes. The assumption of code classification for engineering building in Indonesia is clearly presented in the following diagram:

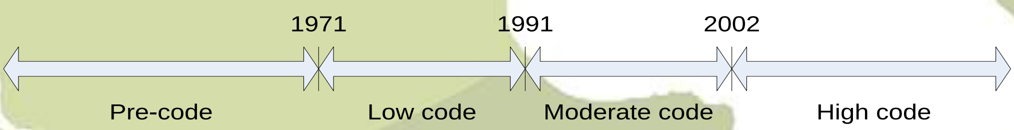

Figure 1 Diagram of Indonesian building code

where:

Pre-code : design of the building without considering earthquake load
Low-code : design of buildings using Indonesian Concrete Regulation, 1971
Moderate-code : design of buildings using SK SNI T-15-1991-03 or SNI 03-2847-1992
High-code : design of buildings using SNI 03-2847-2002 or SNI 03-2847-2013

2.3. Building Types Based on HAZUS

HAZUS classified the type of buildings into 36 models based on the type of structure, material, function of the building, and the number of stories which are presented in Table 1.

Table 1 Building classification based on HAZUS

No	Label	Description	Height			
			Range		Typical	
			Name	Stories	Stories	Feet
1	W1	Wood, Light Frame (≤ 5.000 sq. Ft)		1 – 2	1	14
2	W2	Wood Commercial and Industrial (> 5.000 sq. Ft)		All	2	24
3	S1L	Steel Moment Frame	Low-Rise	1 – 3	2	24
4	S1M		Mid-Rise	4 – 7	5	60
5	S1H		High-Rise	8 +	13	156

No	Label	Description	Height			
			Range		Typical	
			Name	Stories	Stories	Feet
6 7 8	S2L S2M S2H	Steel Braced Frames	Low-Rise Mid-Rise High-Rise	1 – 3 4 – 7 8 +	2 5 13	24 60 156
9	S3	Steel Light Frame		All	1	15
10 11 12	S4L S4M S4H	Steel Frame wit Cast-in Place Concrete Shear Walls	Low-Rise Mid-Rise High-Rise	1 – 3 4 – 7 8 +	2 5 13	24 60 156
13 14 15	S5L S5M S5H	Steel Frame With Unreinforced Masonry Walls	Low-Rise Mid-Rise High-Rise	1 – 3 4 – 7 8 +	2 5 13	24 60 156
16 17 18	C1L C1M C1H	Concrete Moment Frame	Low-Rise Mid-Rise High-Rise	1 – 3 4 – 7 8 +	2 5 12	20 50 120
19 20 21	C2L C2M C2H	Concrete Shear Walls	Low-Rise Mid-Rise High-Rise	1 – 3 4 – 7 8 +	2 5 12	20 50 120
22 23 24	C3L C3M C3H	Concrete Frame with Unreinforced Masonry Infill Walls	Low-Rise Mid-Rise High-Rise	1 – 3 4 – 7 8 +	2 5 12	20 50 120
25	PC1	Precast Concrete Tile-Up Walls		All	1	15
26 27 28	PC2L PC2M PC2H	Precast Concrete Frames with Concrete Shear Walls	Low-Rise Mid-Rise High-Rise	1 – 3 4 – 7 8 +	2 5 12	20 50 120
29 30	RM1L RM1M	Reinforced Masonry Bearing Walls with Wood or Metal Deck Diaphragms	Low-Rise Mid-Rise	1 – 3 4 +	2 5	20 50
31 32 33	RM2L RM2M RM2H	Reinforced Masonry Bearing Walls with Precast Concrete Diaphragms	Low-Rise Mid-Rise High-Rise	1 – 3 4 – 7 8 +	2 5 12	20 50 120
34 35	URML URMM	Unreinforced Masonry Bearing Walls	Low-Rise Mid-Rise	1 – 2 3 +	1 3	15 35
36	MH	Mobile Homes		All	1	10

2.4. Response Spectrum

A. Elastic design response spectrum

Elastic spectrum is a spectrum which is based on a certain elastic response. This spectrum is the most frequently used spectrum, because the adopted design of earthquake-resistant buildings is based on the strength based design.

B. Inelastic design response spectrum

Chopra (1995) presents the conversion sequence from the elastic to the inelastic response with specific formula used in each phase. At the time of the natural vibrating period under acceleration time of 0.5 seconds or constant, equation (1) applies as follows:

$$f_y = A/\sqrt{2\mu - 1} \tag{1}$$

As for the natural vibrating period over 0.5 seconds, the acceleration is considered constant, since the fact that spectral response is in the form of acceleration response spectrum, which results in the equation below.

$$f_y = A/\mu \tag{2}$$

where:
A = acceleration
μ = ductility factor structure

C. Inelastic Spectral Displacement
Inelastic spectral displacement (SD) is a parameter used to determine the structural and non-structural damage on drift-sensitive component (NIBS, 2002). The value of inelastic spectral displacement is obtained by empirical formulas as follows:

$$S_D = 9.8 * S_A * T^2 \tag{3}$$

where:
SA = Inelastic Spectral Acceleration (g)
SD = Inelastic Spectral Displacement (inches)
T = Time Period (sec)

2.6. Building Damage Probability
Prior to the probability value, then calculated first damage probability estimates from any damage level based on an earthquake scenario. In Hazus method, cumulative damage probability values obtained in accordance with equation 4 as follows:

$$P[ds / S_d] = \Phi\left[\frac{1}{\beta_{ds}} \ln\left(\frac{S_d}{\bar{S}_{d.ds}}\right)\right] \tag{4}$$

where:
$P[ds / S_d]$ = value of the damage probability, d_s
S_d = inelastic spectral displacement (inches)
$\bar{S}_{d.ds}$ = the median of spectral displacement when the buildings were damaged,-d_s
β_{ds} = normal-log deviation standard of damage level spectral displacement
Φ = cumulative normal standard of distribution function

2.7. Fragility Curve Based on HAZUS
Fragility curve is a curve that shows how much the probability of the building vulnerability due to earthquake for the damage level of slight, moderate, extensive, and complete (NIBS, 2002). By using fragility curve, we can determine how strong the building can survive in facing an earthquake so as to minimize the risk of the damage to buildings.

3. RESULTS AND DISCUSSION
There are 10 hospital buildings under research, which are scattered to best represent each district/administration city in north side of Jakarta (5 Hospitals in North Jakarta and 5 Hospitals in West Jakarta).

3.1. Hospital Building Classification
Hospital buildings studied belong to the type of building concrete moment frame with storey height varies, ranging from 2 to 10 stories. Building code used in each hospital building varies ranging from Pre-code, Low-code, Moderate-code up to High-code. Classification of determining the seismic design level of each hospital building is based on field data, project data, and the construction of each hospital as presented in Table 2.

Table 2 Type of building and seismic design level classification

No.	Name of Hospital	Address	Stories	Asumption of Building type	*Seismic Design Level*
1	RS Atmajaya	Jl. Pluit Raya no.2, North Jakarta	2	C1L	Low
2	RS Pluit	Jl. Raya Pluit Selatan no.2, North Jakarta	8	C1H	Moderate
3	RS Royal Progress (2-storey)	Jl. Sunter Paradise, North Jakarta	2	C1L	Low
4	RS Royal Progress (9-storey)		9	C1H	High
5	RS Islam Jakarta Sukapura	Jl. Tipar Cakung no.5, North Jakarta	2	C1L	Low
6	RS Ibu dan Anak Ibnu Sina	Jl. Dr. Nurdin I/III Grogol, West Jakarta	2	C1L	Low
7	RS Manuela	Jl. Mangga Besar VII/23, West Jakarta	4	C1M	Moderate
8	RS Harapan Kita	Jl. S. Parman 84 Kav.87, West Jakarta	4	C1M	Low
9	RS Bhakti Mulia	Jl. K.S. Tubun no.79, Slipi, West Jakarta	3	C1L	Moderate
10	RS Medika Permata Hijau	Jl. Raya Kebayoran Lama No.64, West Jakarta	5	C1M	Moderate

The above table shows that there are three types of hospital building, which are C1L, C1M, and C1H. While the seismic design level used has 3 variations, i.e. low, moderate, and high.

3.2 Response Spectrum Design and Performance Point

In the example of calculations on Royal Progress 9-storey hospital, elastic response spectrum during period (T) of 0,03 seconds shows that elastic spectral acceleration (SA) values is 0.232g. Building ductility factor (μ) is used according to the type of building and the code used. Since the hospital was designed with high code, then f_y value can be calculated as follows:

$$f_y = A/\sqrt{2\mu - 1} = 0.232/\sqrt{2.5-1} = 0.077g$$

For the period value (T) over 0.5 seconds, f_y is calculated using equation (2) as follows:

$$f_y = A/\mu = 0.655/5 = 0.131g$$

The value of inelastic spectral displacement (SD) is calculated using equation (3), as shown in the following calculation:

$$S_D = 9.8 * S_A * T^2$$

$$S_D = 9.8 * 0.077 * (0.03)^2 = 0.001 \text{ in}$$

The performance point for the calculation of the probability of damage is obtained from the intersection of inelastic response curve (Figure 2) and the capacity curve in order to obtain the coordinates of the point of intersection (SD, SA), as shown in Figure 3.

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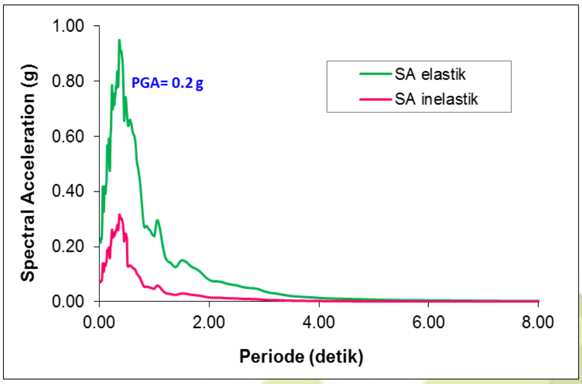

Figure 2 Spectral acceleration curve for Royal Progress 9-storey Hospital

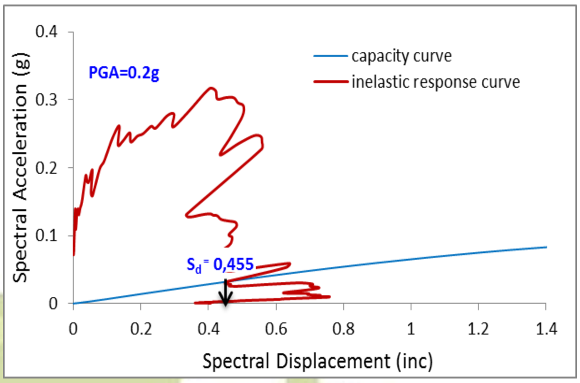

Figure 3 Performance point for Royal Progress 9-storey Hospital

3.4 Fragility Curve

Fragility curve parameter at each level of damage based on the type of building and the design earthquake level for each hospital is presented in Table 3.

Table 3 Structural Fragility Curve Parameter– High/Moderate/Low-Code Seismic Design Level based on HAZUS for Hospital Building in North side of Jakarta

No	Name of Hospital	Type	Level	***Structural Fragility Curve Parameter -High/Moderate/Low Code - Seismic Design Level***							
				Slight		***Moderate***		***Extensive***		***Complete***	
				$\hat{S}_{d.S/S}$	β_S	$\hat{S}_{d.S/M}$	β_M	$\hat{S}_{d.S/E}$	β_E	$\hat{S}_{d.S/C}$	β_C
1	RS Atmajaya	C1L	Low	0.17	0.64	0.22	0.64	0.39	0.64	0.67	0.64
2	RS Pluit	C1H	Moderate	0.14	0.64	0.23	0.64	0.59	0.64	1.15	0.64
3	RS Royal Progress (2-storey)	C1L	Low	0.17	0.64	0.22	0.64	0.39	0.64	0.67	0.64
4	RS Royal Progress (9-storey)	C1H	High	0.14	0.64	0.28	0.64	0.83	0.64	2.03	0.64
5	RS Islam Jakarta Sukapura	C1L	Low	0.17	0.64	0.22	0.64	0.39	0.64	0.67	0.64
6	RS Ibu dan Anak Ibnu Sina	C1L	Low	0.17	0.64	0.22	0.64	0.39	0.64	0.67	0.64
7	RS Manuela	C1M	Moderate	0.17	0.64	0.28	0.64	0.7	0.64	1.38	0.64
8	RS Harapan Kita (RSAB)	C1M	Low	0.15	0.64	0.23	0.64	0.48	0.64	0.8	0.64
9	RS Bhakti Mulia	C1L	Moderate	0.23	0.64	0.33	0.64	0.63	0.64	1.22	0.64
10	RS Medika Permata Hijau	C1M	Moderate	0.17	0.64	0.28	0.64	0.7	0.64	1.38	0.64

Damage probability value is obtained by S_{ds} data input and β_{ds} as listed in Table 3, while Sd value is obtained from inelastic response curve and capacity curve plot. The level of slight damage to the PGA of 0.2g can be described as follows:

$$P\left[ds / S_d\right] = \Phi\left[\frac{1}{0.64}\ln\left(\frac{0.455}{0.140}\right)\right] = NORMSDIST[1.84] = 0.9672$$

The result of cumulative probability calculation of the Royal Progress (9-storey) Hospital is presented in Table 4 below.

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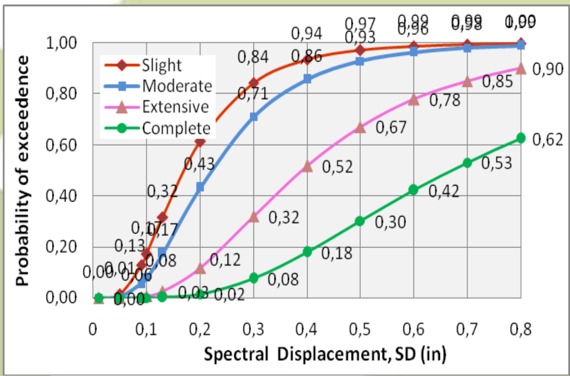
Table 4 Result of building damage cumulative probability of
Royal Progress (9-storey) hospital for PGA of 0.2g with C1H building type

Damage State	**S_d**	**$\hat{S}_{ds}$**	**β_{ds}**	**$X = S_d/\hat{S}_{ds}$**	**Ln (X)**	**$Y = [Ln(X)]/\beta_{ds}$**	$P[ds/S_d]$
Slight	0.455	0.140	0.640	3.2500	1.178655	1.84	0.9672
Moderate	0.455	0.280	0.640	1.6250	0.485508	0.76	0.7760
Extensive	0.455	0.830	0.640	0.5482	-0.601128	-0.94	0.1738
Complete	0.455	2.030	0.640	0.2241	-1.495494	-2.34	0.0097

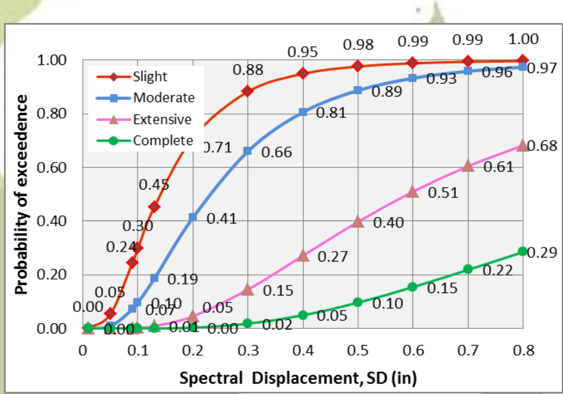
Cumulative Probability (φ [Y])	P [S/ S_d]	P [M/ S_d]	P [E/ S_d]	P [C/ S_d]
	0.9672	0.7760	0.1738	0.0097

where:
P [S/S_d] = probability of slight damage occurrence
P [M/S_d] = probability of moderate damage occurrence
P [E/S_d] = probability of extensive damage occurrence
P [C/S_d] = probability of complete damage occurrence

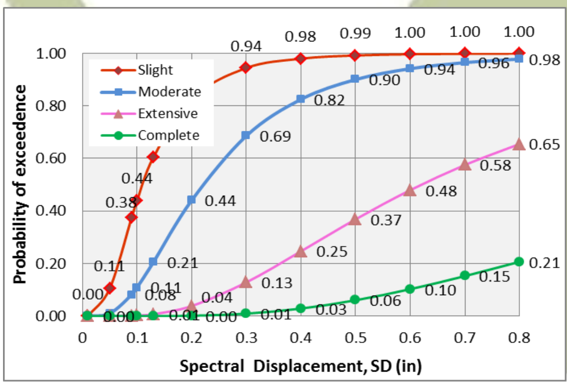
Fragility curve is obtained from the calculation of cumulative probability presented in Table 4. Fragility curve for each hospital buildings in the north side of Jakarta studied is presented in Figure 4.



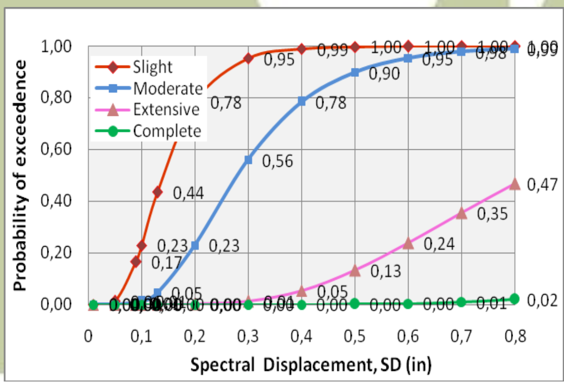
1) Fragility curve of Atmajaya Hospital (C1L, Low-code)



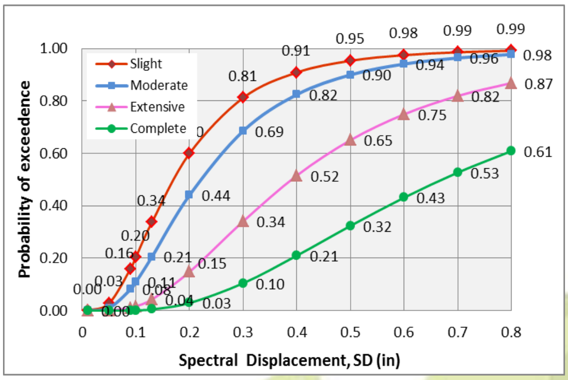
2) Fragility curve of Pluit Hospital (C1H, Moderate-code)



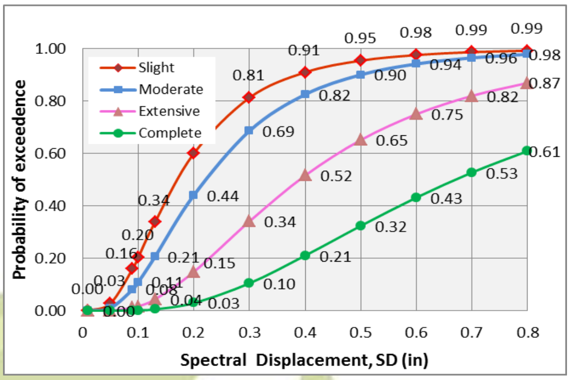
3) Fragility curve of Royal Progress 2-storey Hospital (C1L, Low-code)



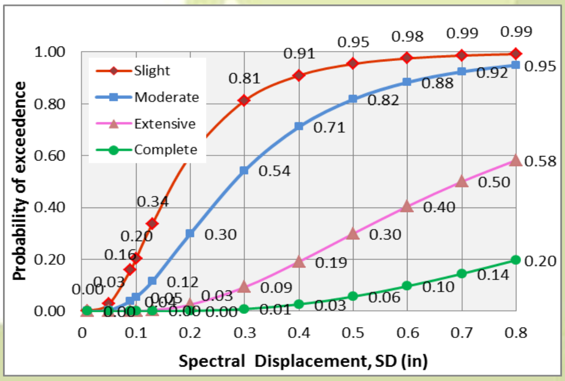
4) Fragility curve of Royal Progress 9-storey Hospital (C1H, High-code)



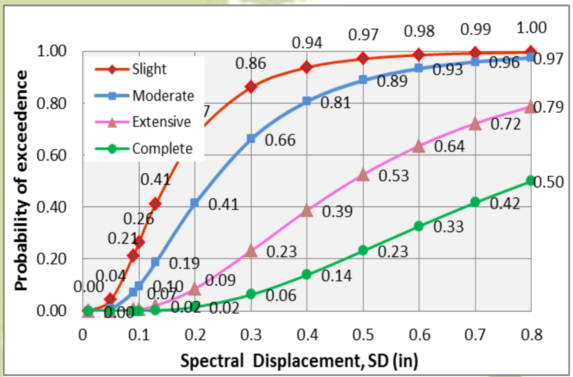
5) Fragility curve of Islam Jakarta Sukapura Hospital (C1L, Low-code)



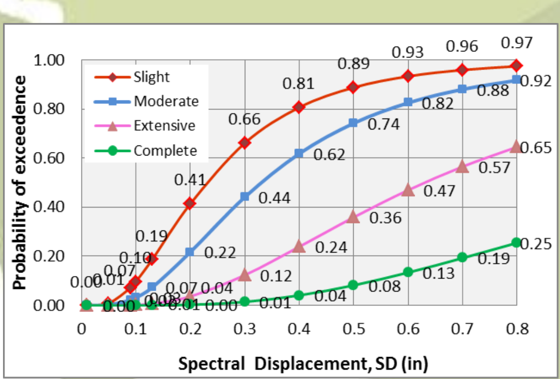
6) Fragility curve of Ibu dan Anak Ibnu Sina Hospital (C1L, Low-code)



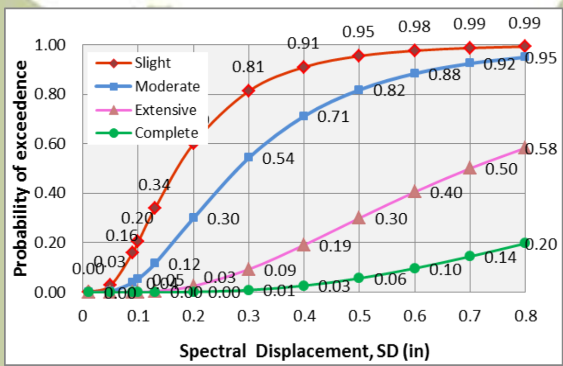
7) Fragility curve of Manuela Hospital (C1M, Moderate-code)



8) Fragility curve of Harapan Kita Hospital (C1M, Low-code)



9) Fragility curve of Bhakti Mulia Hospital (C1L, Moderate-code)



10) Fragility curve of Medika Permata Hijau Hospital (C1M, Moderate-code)

Figure 4 Fragility curve of each hospital building damage level

Figure 4 shows the variation model of fragility curve at each hospital building for each level of damage influenced by the type and code building. For example, Pluit and Royal Progress (9-storey) hospital have the same type of building, i.e.: C1H. Vulnerability percentage at complete and extensive level in Pluit hospital is greater than Royal Progress (9-storey) hospital, while the percentage of vulnerabilities at slight and moderate level are smaller. This is because Pluit hospital uses Moderate-code, while the Royal Progress (9-storey) uses High-code.

3.5 Probability of Each Building Damage Level

The probability value of each level of building damage is obtained by substraction of the damage probability ranging from complete damage level to the slight one. Results of discrete calculation for each level of damage in Royal Progress (9-storey) hospital is presented in Table 5.

Table 5 Result of each damage level probability (PGA 0.2g)
For Royal Progress (9-storey) Hospital, Jakarta

No	Damage probabilty	Damage level	Damage probability	Probability value
1	P [C] = P[C/S$_d$]	Complete	= 0.0097	0.0097
2	P [E] = P[E/S$_d$]- P[C/S$_d$]	Extensive	= 0.1738 - 0.0097	0.1641
3	P [M] = P[M/S$_d$]- P[E/S$_d$]	Moderate	= 0.7760 - 0.1738	0.6022
4	P [S] = P[S/S$_d$]- P[M/S$_d$]	Slight	= 0.9672 - 0.7760	0.1913
5	P [None] = 1 – P[S/S$_d$]	No damage	= 1 - 0.9672	0.0328

The result of probability calculations for each damage level in each hospital building is presented in Figure 5.

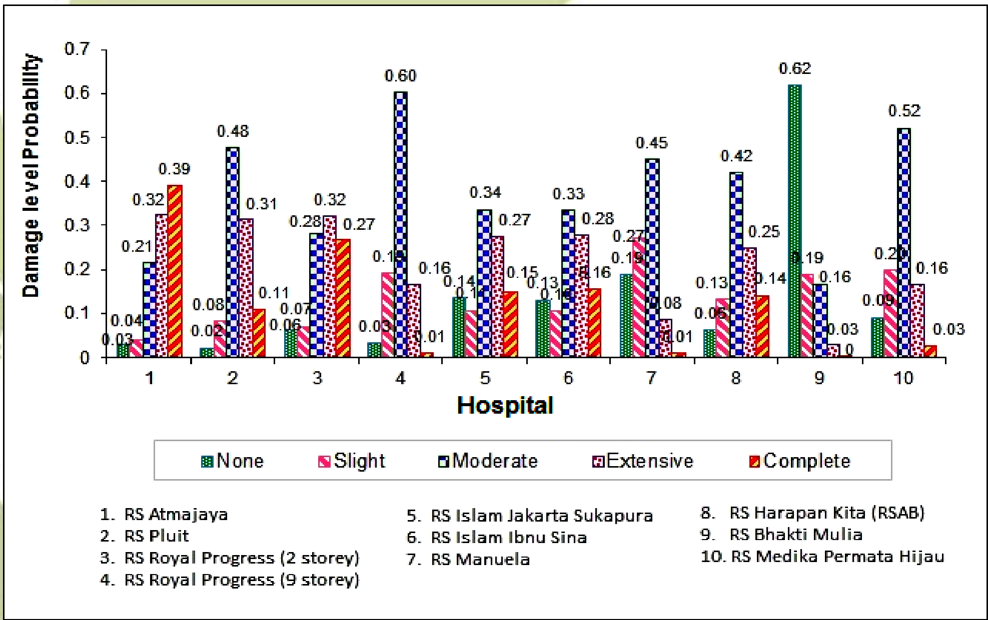


Figure 5 Probability of damage level for each hospital building
in north side of Jakarta

Figure 10 shows that the highest value for the damage probability level at the most extreme level, namely the complete damage level is 0.39 or 39% in Atmajaya Hospital. This is because the Atmajaya hospital was built with low building code and is located on soft soil. Meanwhile, the lowest value at complete damage level is 0.01 or 1% in Royal Progress hospital (9-storey). Those hospital buildings are classified as high-rise buildings (9-storey) and uses moderate building code.

4. CONCLUSION

Conclusions of the study are as follow:

1. The fragility curve results of the 10 hospital buildings in the north side of Jakarta showed that the higher number of the stories building and the longer code used, the higher percentage of vulnerabilities, especially at complete and extensive level.
2. Based on the building probability damage analysis, the highest value for the probability of slight, moderate, extensive and complete damage level respectively are 27% (Manuela hospital), 60% (Royal Progress 9-storey hospital), 32% (Atmajaya hospital) and 39% (Atmajaya hospital).

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