Analytical fragility curve development of maternity and children’s M. Djamil Hospital building Padang due to earthquake and tsunami

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Abstract. M. Djamil Hospital is the largest public medical facility in Padang area with over 800 patient beds. The magnitude 7.6 Western Sumatra earthquake of September 30, 2009 caused the first floor of one housing outpatient services collapsed. Padang city is located in West Sumatra province which is recorded as an earthquake and tsunami prone area in Indonesia. Risk reduction strategy can be implemented by assessing the vulnerability of building through fragility curve. In this study, the fragility curve was carried out to an existing Maternity and Children’s M. Djamil Hospital building due to earthquake and tsunami in sequence. Building’s structural was modelled in ETABS v. 17 and analyzed by using Pushover analysis and Nonlinear Time History analysis. This structural model was subjected through a total of 40 ground motion data from El Centro, Northridge, Kobe and Padang. Each ground motion data was normalized from 0.2g to 2.0g of peak ground acceleration and continued with tsunami load. Analysis results consist of drift at yield point and structure maximum drift, which are then generated into a fragility curve based on Hazus standard. The result of earthquake fragility curve represents that the probability of slight damage level is 100%, moderate 100%, extensive 92% and collapse 5.4%. Meanwhile, earthquake-tsunami fragility curve represents the probability of slight damage level is 100%, moderate 100%, extensive 98% and collapse 11%.

1. Introduction

M. Djamil Hospital is the largest public medical facility in Padang-West Sumatra with over 800 patient beds [1]. The magnitude 7.6 Western Sumatra earthquake of September 30, 2009 caused the first floor of one housing outpatient services collapsed [2]. Located in earthquake and tsunami prone area, two major seismic sources of West Sumatra are the Sumatra fault and the Sunda megathrust zone [3]. Paleogedetic, geodetic and numerical modelling studies conclude that there is high potential megathrust tsunamigenic earthquake in Sunda megathrust zone segment [4][5][6]. With flat topographic and high population density in urban area as additional, Padang will face significant economic and social losses caused by the future tsunamigenic event [7]. The hazard risk elements value (damages, injuries and loss of lives) is full of uncertainties then it is necessary to develop strategies in order to minimize the impact that will occur [8]. Based on past seismic events it can be observed that reinforced concrete buildings significantly fail through its brittle behaviour then causes economic loss and urban resilience decrease. For this reasons, quantitative fragility models of existing building have a key role in seismic risk mitigation [9]. Probability of
structural damage level due to varying hazards magnitudes can be described in the form of a fragility curve [10].

This paper presents the analytical study of Maternity and Children’s M. Djamil Hospital building due to earthquake and tsunami in sequence then develop its results into analytical fragility curve. Building structure were initially modelled in ETABS v.17 and analyzed for earthquake ground motions by linear static analysis to obtain drift value at yield point. Structural model then analyzed for varied earthquake ground motion scales and continued to tsunami load by nonlinear time history to obtain maximum drift value. Drift at yield point and maximum drift value are used to develop fragility curve based on Hazus standard.

2. Case-study application

2.1. Structural model

Maternity and children’s M. Djamil Hospital building is four storey-reinforced concrete structure, with 14.65 meter height, 39.95 meter length and 11.35 meter width. Building’s structure is modelled in ETABS v.17 as an open frame based on as built drawing with detail of elements as below:

| Table 1. Detail of structure elements |
|---------------------------------------|
| **Beam (K-300; f, 390 MPa)**          |
| **Type** | **Dimension (mm)** | **Main Bars (mm)** | **Stirrups (mm)** |
|----------|--------------------|--------------------|-------------------|
| B1       | 350 x 600          | Top 4 + 3 D22      | Ø10-100           |
|          |                    | Middle 2 D13       |                   |
|          |                    | Bottom 4 D22       |                   |
| B2       | 300 x 600          | Top 4 + 2 D22      | Ø10-100           |
|          |                    | Middle 2 D13       |                   |
|          |                    | Bottom 4 D22       |                   |
| B3       | 350 x 550          | Top 4 + 3 D22      | Ø10-100           |
|          |                    | Middle 2 D13       |                   |
|          |                    | Bottom 4 D22       |                   |
| B4       | 300 x 550          | Top 4 + 2 D22      | Ø10-100           |
|          |                    | Middle 2 D13       |                   |
|          |                    | Bottom 4 D22       |                   |
| B5       | 300 x 550          | Top 4 + 2 D22      | Ø10-100           |
|          |                    | Middle 2 D13       |                   |
|          |                    | Bottom 4 D22       |                   |
| B6       | 300 x 550          | Top 3 + 2 D22      | Ø10-100           |
|          |                    | Middle 2 D13       |                   |
|          |                    | Bottom 4 D22       |                   |
| B7       | 300 x 500          | Top 4 D22          | Ø10-100           |
|          |                    | Middle 2 D13       |                   |
|          |                    | Bottom 3 D22       |                   |
| BA       | 250 x 450          | Middle 2 D13       | Ø10-200           |
|          |                    | Bottom 4 D22       |                   |
| BL1/BL2/BL3 | 200 x 600/550/500 | Top 3 D19         | Ø10-150           |
|          |                    | Middle 2 D13       |                   |
|          |                    | Bottom 3 D19       |                   |
| Type | Dimension (mm) | Main Bars (mm) | Stirrups (mm) |
|------|----------------|----------------|---------------|
| K1   | 400 x 600      | 20 D22         | Ø10-100       |
| K2   | 400 x 400      | 16 D22         | Ø10-100       |
| K3   | 400 x 600      | 20 D22         | Ø10-100       |

| Type | Dimension (mm) | Main Bars (mm) | Stirrups (mm) |
|------|----------------|----------------|---------------|
| K1   | 400 x 600      | 16 D22         | Ø10-100       |
| K2   | 400 x 400      | 16 D22         | Ø10-100       |
| K3   | 400 x 600      | 16 D22         | Ø10-100       |

| Type | Dimension (mm) | Main Bars (mm) | Stirrups (mm) |
|------|----------------|----------------|---------------|
| K1   | 400 x 600      | 16 D22         | Ø10-100       |
| K2   | 400 x 400      | 12 D22         | Ø10-100       |
| K3   | 400 x 600      | 16 D22         | Ø10-100       |

| Type | Dimension (mm) | Main Bars (mm) | Stirrups (mm) |
|------|----------------|----------------|---------------|
| K1   | 400 x 600      | 16 D22         | Ø10-100       |

In this study, structure was modelled into 5 models based on analysis needed:
1. Structure model A, used for pushover analysis
2. Structure model B, used for nonlinear time history analysis El Centro and tsunami load
3. Structure model C, used for nonlinear time history analysis Northridge and tsunami load
4. Structure model D, used for nonlinear time history analysis Kobe and tsunami load
5. Structure model E, used for nonlinear time history analysis Padang and tsunami load

Structure model A to E has the same geometry and structures detailing. Model differencing for each analysis type aims to optimize computer’s performance and time efficiency in running software program. Modelling in 3D view and plan view are shown in Figure 1 (a) and (b) below.

![3D view](a)

![Plan view](b)

**Figure 1.** Structure modelling in ETABS (a) 3D view (b) plan view
2.2. Earthquake simulation
In this study, 4 ground motions earthquake data used are El Centro 1940 (PGA 0.36g), Northridge 1994 (PGA 0.6g), Kobe 1995 (PGA 0.34 g) and Padang 2009 (PGA 0.6g). Each ground motion data is characterized into Padang earthquake by using software Seismomatc h. Matched ground motion data is then subjected to be scaled with scale factor interval 0.2 until 2.0, hence there are total 40 ground motion data used.

| Earthquake      | Original PGA | PGA Matched | PGA Scalled                      |
|-----------------|--------------|-------------|----------------------------------|
| El Centro 1940  | 0.36g        | 0.63g       | 0.13 g; 0.25 g; 0.38g; 0.50g; 1.26g |
| Northridge 1994 | 0.60g        | 0.76g       | 0.15g; 0.30g; 0.46g; 0.61g; 0.76g; 0.91g; 1.06g; 1.22g; 1.37g; 1.52g |
| Kobe 1995       | 0.34g        | 0.60g       | 0.12g; 0.24g; 0.36g; 0.48g; 0.60g; 0.72g; 0.84g; 0.96g; 1.08g; 1.20g |
| Padang 2009     | 0.60g        | 0.60g       | 0.12g; 0.24g; 0.36g; 0.48g; 0.60g; 0.72g; 0.84g; 0.96g; 1.08g; 1.20g |

2.3. Tsunami simulation
Tsunami load value is calculated based on FEMA P646-508 2012 with inundation depth 1.50 meter according to BPBD Map 2008. Building is located 2000 meter from coastal line by elevation 11 meter above the sea level. The value of hydrostatic load = 59.485 kN; bouyant force = 7.010 kN; hydrodynamic force = 18.610 kN; impulsive force = 27.916 kN; floating debris impact force = 433.595 kN; damming of accumulated waterborne debris = 1784.560 kN; uplift force = 0.005 kN; and additional retained water loading = 7.010 kN.

3. Methodology
Earthquake and tsunami are simulated to structure model through Pushover analysis and Nonlinear Time History Analysis. Structure response and capacity are then developed into analytical fragility curve by using Hazus standard.

3.1. Pushover analysis
Performance of structure while receiving loads can be described through pushover analysis. Pushover analysis is performed by giving a monotonic lateral load incrementally to the structure until a displacement target reached. In generating fragility curve, capacity curve resulted from pushover analysis is used to get structure drift value at yield point. Capacity curve represents the correlation between base shear of structure, $V$, and its rooftop displacement, $D$. To perform this analysis by using ETABS, monitored point of structure is determined first. Maternity and Children’s M. Djamil Hospital building has symmetrical shape so then the monitored point is choosed at the corner of the structure. There are 3 nonlinear static load cases needed in pushover analysis; gravity load case, pushover in direction-X load case and pushover in direction-Y load case. Gravity load case includes dead load, live load and super imposed dead load. Dead load and super imposed dead load are full load applied with scale factor 1.0, meanwhile live load is applied 25% from its full load with scale factor 0.25. Pushover-X and Pushover-Y load case are applied in acceleration load pattern as load displacement control with the magnitude of monitored displacement determined as 2% from total height of building. Hinge plastics are modelled at the ends of columns and beams in order to dissipate earthquake energy. The collapse mechanism of structure can be shown from the sequence of hinge plastics appear.
3.2. Earthquake nonlinear time history analysis (Earthquake NLTHA)
Nonlinear time history analysis due to earthquake is performed by using ETABS V.17. Each scaled-40 ground motion data from existing earthquake El Centro, Northridge, Kobe and Padang is defined as acceleration load type in Time History Functions to be analyzed as Nonlinear Modal Analysis (FNA). The analysis result needed in developing fragility curve is structure maximum drift value.

3.3. Earthquake and tsunami in sequence nonlinear time history analysis (Earthquake-Tsunami NLTHA)
Tsunami load is given to structure model after earthquake simulation completes. It assumes that there is structure strength decrease due to earthquake, so the initial condition for tsunami loading is start continued from state at end of earthquake nonlinear case. Tsunami load case is defined as Time History Nonlinear Modal Analysis (FNA) with all calculated loads are applied as an uniform load pattern. The analysis result needed is structure maximum drift value due to earthquake and tsunami in sequence.

3.4. Analytical fragility curve development
In this study, fragility curve is developed with Probabilistic Seismic Demand Model (PSDM) through Cloud approach method. Parameters of fragility curve needed are determined from previous pushover analysis, nonlinear time history analysis and Hazus standard as shown in Figure 2 below:

![Fragility Curve Development Flowchart](image)

Figure 2. Fragility curve development flowchart

4. Result and discussion

4.1. Capacity curve
Capacity curve describes the correlation between structure base shear, \( V \) and rooftop displacement, \( D \). Based on pushover analysis in ETABS, the magnitude of rooftop displacement at yield point is 31.458 mm.

There are 3 methods can be used to definite displacement at yield displacement; first yield, significant yield and yield point based on equivalency of energy absorption capacity. Significant yield displacement is used for developing fragility curve, with the magnitude is 37.7 mm. With the total height of building is 14.65 mm, the calculated drift value at yield point is 0.26%.
4.2. Structure ductility

In this study, the ductility of structure can be calculated by dividing each maximum drift value from nonlinear time history with drift value at yield point. This value is generated as regression analysis data to be fragility curve parameters.

**Table 3. Structure ductility due to El Centro earthquake and tsunami**

| PGA Scalled | Earthquake Ductility | Earthquake-Tsunami Ductility |
|-------------|-----------------------|-----------------------------|
| 0.13 g      | 0.16                  | 0.16                        |
| 0.25 g      | 0.16                  | 0.16                        |
| 0.38 g      | 0.16                  | 0.16                        |
| 0.50 g      | 0.16                  | 0.16                        |
| 0.63 g      | 0.16                  | 0.16                        |
| 0.76 g      | 0.16                  | 0.16                        |
| 0.88 g      | 0.16                  | 0.16                        |
| 1.01 g      | 0.16                  | 0.16                        |
| 1.13 g      | 0.16                  | 0.16                        |
| 1.26 g      | 0.16                  | 0.16                        |
Table 4. Structure ductility due to Northridge earthquake and tsunami

| PGA Scalled | Earthquake Ductility | Earthquake-Tsunami Ductility |
|-------------|----------------------|------------------------------|
| 0.15 g      | 0.60                 | 0.72                         |
| 0.30 g      | 0.61                 | 0.72                         |
| 0.46 g      | 0.62                 | 0.73                         |
| 0.61 g      | 0.65                 | 0.73                         |
| 0.76 g      | 0.68                 | 0.74                         |
| 0.91 g      | 0.71                 | 0.75                         |
| 1.06 g      | 0.74                 | 0.75                         |
| 1.22 g      | 0.77                 | 0.76                         |
| 1.37 g      | 0.80                 | 0.77                         |
| 1.52 g      | 0.83                 | 0.77                         |

Table 5. Structure ductility due to Kobe earthquake and tsunami

| PGA Scalled | Earthquake Ductility | Earthquake-Tsunami Ductility |
|-------------|----------------------|------------------------------|
| 0.13 g      | 0.06                 | 0.30                         |
| 0.25 g      | 0.06                 | 0.30                         |
| 0.38 g      | 0.06                 | 0.30                         |
| 0.50 g      | 0.06                 | 0.30                         |
| 0.63 g      | 0.06                 | 0.30                         |
| 0.76 g      | 0.06                 | 0.30                         |
| 0.88 g      | 0.06                 | 0.30                         |
| 1.01 g      | 0.06                 | 0.30                         |
| 1.13 g      | 0.06                 | 0.30                         |
| 1.26 g      | 0.06                 | 0.30                         |

Table 6. Structure ductility due to Padang earthquake and tsunami

| PGA Scalled | Earthquake Ductility | Earthquake-Tsunami Ductility |
|-------------|----------------------|------------------------------|
| 0.13 g      | 1.30                 | 1.29                         |
| 0.25 g      | 1.42                 | 1.41                         |
| 0.38 g      | 1.54                 | 1.53                         |
| 0.50 g      | 1.67                 | 1.65                         |
| 0.63 g      | 1.79                 | 1.78                         |
| 0.76 g      | 1.91                 | 1.90                         |
| 0.88 g      | 2.03                 | 2.02                         |
| 1.01 g      | 2.16                 | 2.14                         |
| 1.13 g      | 2.28                 | 2.26                         |
| 1.26 g      | 2.40                 | 2.39                         |

4.3. Fragility curve development
Fragility curve is a lognormal distribution function describes the correlation between probability of structural damage level due to hazard intensity measure. In this study, intensity measure of multi hazards event used are earthquake ground motion and tsunami force. In general, the equation of fragility curve development:
Fragility = \( P(\text{LS}|\text{IM} = y) \) \hspace{1cm} (1)

with \( \text{LS} \) is limit state or damage level of structure and \( \text{IM} \) is intensity measure of hazard.

Probabilistic Seismic Demand Model (PSDM) is a mathematical relation between hazard intensity measures \( \text{IM} \) and structural response as Engineering Demand Parameter, \( \text{EDP} \). One of PSDM method is \textit{Cload approach} by doing regression analysis between \( \text{IM} \) and \( \text{EDP} \) with uncertainty variable \( a, b \). Logarithmic corellation of \( \text{EDP} \) and \( \text{IM} \) is shown below:

\[
\text{EDP} = \ln(a) + b \ln(\text{IM})
\]

and

\[
\beta_{\text{EDP}|\text{IM}} = \sqrt{\frac{\sum_{i=1}^{N}(\ln(\text{EDP}) - \ln(a) - b \ln(\text{IM}))^2}{N-2}}
\]

where \( \text{EDP} \) is engineering demand parameter in which structural ductility is used in this study, \( \text{IM} \) is hazard intensity measure, \( a \) and \( b \) as uncertainty variable, \( N \) is simulation total and \( \beta_{\text{EDP}} \) is dispersion of demand.

In this study, there are two types of fragility curves developed; fragility curve due to earthquake only and fragility curve due to earthquake and tsunami in sequence. Both of fragility curves represent that there is percentage of damage level probability increases caused by tsunami load. The probability of damage level caused by earthquake based on development of fragility curve as shown below:

**Figure 5.** Earthquake fragility curve

**Table 7.** Probability of structural damage level due to earthquake

| Damage Level | Percentage of Probability |
|--------------|---------------------------|
| Slight       | 100%                      |
| Moderate     | 100%                      |
| Extensive    | 92%                       |
| Collapse     | 5.4%                      |
Figure 6. Earthquake and tsunami fragility curve

Table 8. Probability of structural damage level due to earthquake and tsunami in sequence

| Damage Level | Percentage of Probability |
|--------------|---------------------------|
| Slight       | 100%                      |
| Moderate     | 100%                      |
| Extensive    | 98%                       |
| Collapse     | 11%                       |

5. Conclusion
Existing reinforced concrete building Maternity and Children’s M. Djamil Hospital is subjected to earthquake and tsunami load in sequence. Based on structural analysis and fragility curve development it can be concluded that due to earthquake simulation, the probability of slight damage level is 100%, moderate 100%, extensive 92% and collapse 5.4%. The percentages increase when tsunami load applied to structure in sequence. Earthquake-Tsunami fragility curve represent that the probability of slight damage level is 100%, moderate 100%, extensive 98% and collapse 11%.

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