Sensitivity Analysis of Tall Buildings in Semarang, Indonesia Due To Fault Earthquakes With Maximum 7 Mw

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Sensitivity Analysis of Tall Buildings in Semarang, Indonesia Due to Fault Earthquakes with Maximum 7 Mw

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Abstract. Fault is one of the dangerous earthquake sources that can cause building failure. A lot of buildings were collapsed caused by Yogyakarta (2006) and Pidie (2016) fault source earthquakes with maximum magnitude 6.4 Mw. Following the research conducted by Team for Revision of Seismic Hazard Maps of Indonesia 2010 and 2016, Lasem, Demak and Semarang faults are three closest earthquake sources surrounding Semarang. The ground motion from those three earthquake sources should be taken into account for structural design and evaluation. Most of tall buildings, with minimum 40 meter high, in Semarang were designed and constructed following the 2002 and 2012 Indonesian Seismic Code. This paper presents the result of sensitivity analysis research with emphasis on the prediction of deformation and inter-story drift of existing tall building within the city against fault earthquakes. The analysis was performed by conducting dynamic structural analysis of 8 (eight) tall buildings using modified acceleration time histories. The modified acceleration time histories were calculated for three fault earthquakes with magnitude from 6 Mw to 7 Mw. The modified acceleration time histories were implemented due to inadequate time histories data caused by those three fault earthquakes. Sensitivity analysis of building against earthquake can be predicted by evaluating surface response spectra calculated using seismic code and surface response spectra calculated from acceleration time histories from a specific earthquake event. If surface response spectra calculated using seismic code is greater than surface response spectra calculated from acceleration time histories the structure will stable enough to resist the earthquake force.

INTRODUCTION

Sensitivity analysis of building structure is one of the important methods use for evaluating the stability and stiffness of structure. Sensitivity analysis is an analysis method for evaluating the stability and stiffness of buildings by conducting gradually increasing or decreasing loads or special loads of building structure. The objective of the analysis is to get the information of maximum loads that can be applied to one building. A lot of parameters can be used to evaluate the stability and stiffness of building. Stability of tall buildings (minimum 40m high) usually performs by evaluating deformation and inter-story drift and comparing it with the deformation and drift ratio values proposed by national or international codes. Design of tall buildings usually performs by conducting specific loads or combine loads to obtain the information of size and detail information of structure elements to be built. Engineers usually do not care with restrain capability of structure against improve loads. Seismic loads is one of the important loads should be taken into account for evaluating the stability and stiffness of buildings.

Design of inter-story drift and lateral stability is an issue which should be addressed in the early stages of design development. This paper presents the sensitivity analysis of tall buildings against seismic loads. The analysis was performed by conducting special seismic loads produces by specific earthquake with specific magnitude and epicenter distance between the buildings with earthquake source positions. A deterministic approach was performed to evaluate deformation and inter story drift ratio of 8 (eight) tall buildings with minimum 40 meter high. All buildings are located in Semarang and were designed and built using [1, 2].

Following the research conducted by Team for Revision of Seismic Hazard Maps of Indonesia 2010 and 2016, 5 (five) shallow crustal fault earthquake sources are located less than 50 Km distance to Semarang. Semarang Fault and

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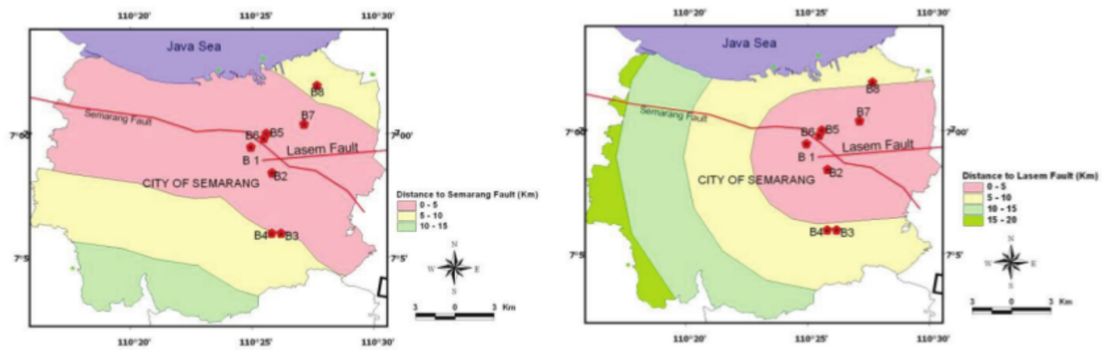
Lasem Fault are two earthquake sources which crosses the study area. Fig. 1 (a) shows the location of Semarang fault and Lasem fault and distribution of epicentre distances for the whole area of the city against Semarang fault. However Fig. 1 (b) shows the distribution of epicentre distances for the whole area of the city against Lasem Fault. The position of all (8) buildings (reinforced concrete building) can also be seen on those two figures.



(a) (b)

FIGURE 1. Contour map of epicenter distance against Semarang fault trace (a) and contour map of epicenter distance against Lasem fault trace.

GEOTECHNICAL CONDITIONS

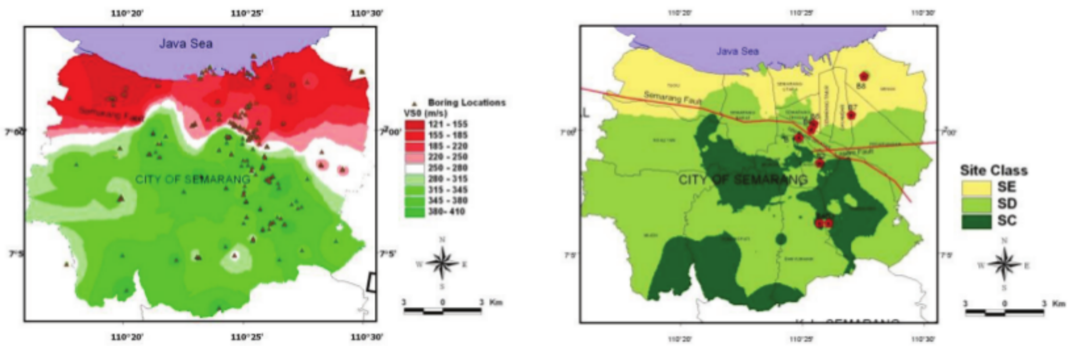
Semarang is the capital city of Central Java Province. The city has an area of about 374 square kilometres. Based to on the topographic relief, the city can be divided into two different regions, a coastal plain area in the northern part with maximum 5% slopes and the hilly area in the center and southern parts with maximum 33% slope. Site characterization (classification) of geotechnical data were carried out by [3 and 4] by interpreting the results of soil boring investigations at 288 locations with minimum 30 meter depth. In-situ standard penetration test (N-SPT) were collected for each boring locations to identified Vs30 value (average shear wave velocity at top 30 meter soil layer). Vs30 value was calculated and estimated following the same method proposed by [2] and using equation (1), where 'd_i' and 'Vs_i' represent thickness and shear wave velocity of each soil layer respectively. The Vs (shear wave velocity) values for each soil layer were estimated using N-SPT value and conducting three empirical correlation equations proposed by [5, 6 and 7].

Based on all Vs30 values calculated at 288 locations, Vs30 map of the study area was then developed. Fig. 2(a) shows the distribution of Vs30 values for the whole area of the city. The corresponding site class map was implemented using all 288 Vs30 values and following the same method proposed by [2]. Fig. 2(b) shows the distribution of site class. Based on this site class map, the positions of each building in terms of site class can be predicted. Building no B7 and B8 are located on site class SE. Building no B1, B2, B5 and B6 are located on site class SD. Hence building no B3 and B4 are located on site class SC. Based on [2] SC, SD and SE represents hard soil, medium soil and soft soil.

$$Vs\,30 = \frac{30}{\sum_{i=1}^{N} \frac{di}{VSi}} \qquad (1)$$

DEVELOPMENT OF ACCELERATION TIME HISTORIES

Based on the research proposed by Team for Revision of Seismic Hazard Maps of Indonesia 2010 and 2016, Lasem Fault is typical strike slip earthquake mechanism source hence Semarang and Demak fault are typical reverse earthquake mechanism sources. Both typical mechanism earthquake sources have different method on producing earthquake wave. Based on these two different mechanism earthquakes, acceleration time histories develop from those two earthquakes are also different.



(a) (b)

FIGURE 2. Contour map of Vs30 and boring locations (a), Site class map and building locations (b)

Following the suggestion from Team for Revision of Seismic Hazard Maps of Indonesia 2010 and 2016, 6.5 Mw seismic magnitude should be implemented for seismic mitigation of Semarang. Based on those two seismic mechanism sources, ground motion in terms of acceleration time histories were then collected from worldwide earthquake databases. Due to the limited earthquake records of Lasem Fault, Semarang Fault and Demak Fault earthquakes with magnitude 6.5 Mw, acceleration time histories used in this study were collected from worldwide ground motion databases. For Semarang and Demak faults 15 (fifteen) acceleration time histories were collected and for Lasem fault 10 (ten) acceleration time histories were collected from Pacific Earthquake Engineering Research (PEER) NGA West-2 Database. All acceleration time histories were collected based on seismic mechanism, seismic magnitude and epicenter distance. Acceleration time histories used in this study also depends on the position of each building against fault trace. Table 1 shows minimum distance of each building to fault trace where DLF, DSF and DDF within this table represent minimum distance to Lasem Fault, Semarang Fault and Demak Fault respectively. Table 2 shows acceleration time histories used for all buildings due to Lasem Fault and Semarang fault earthquakes.

TABLE 1. Minimum distance of each building to fault trace

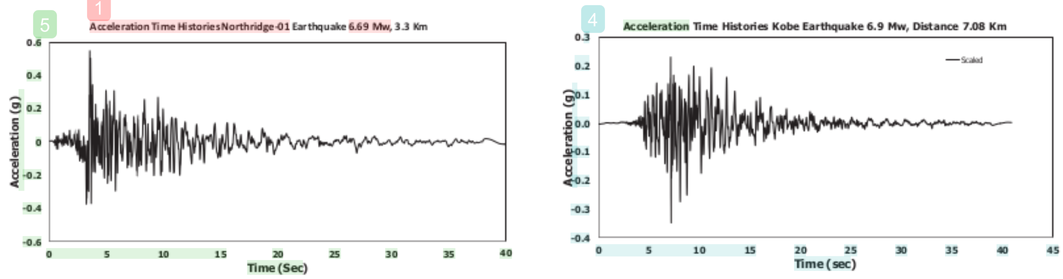
Building No.	Site Class	DLF (Km)	DSF (Km)	DDF (Km)
B1	SC	1.38	0.65	13.80
B2	SC	0.92	1.16	11.37
B3	SC	5.44	4.98	8.45
B4	SC	5.40	5.11	9.11
B5	SD	2.03	0.85	13.75
B6	SD	1.65	0.42	13.58
B7	SE	2.51	3.13	12.69
B8	SE	5.31	5.94	14.90

The acceleration time histories collected from worldwide databases could not directly be used for structural analysis. All acceleration time histories were recorded at bedrock elevation and should be checked and need matches with predicted earthquake produce by local seismic source. All acceleration time histories should be propagated to surface elevation. Surface acceleration time histories can be developed following two basic analysis such as response spectral matching and site response analysis. The first analysis related with matching analysis of time histories collected from worldwide databases with predicted spectral acceleration time histories from local earthquake source scenario. Response spectral matching analysis was conducted following the same method proposed by [8] and producing modified (matched) acceleration time histories. The second analysis related with propagation of ground motion in terms of modified acceleration time histories from bedrock position to earth surface. Surface acceleration time histories developed from those two analysis can be used for dynamic structural analysis. Figure 3(a) shows surface acceleration time histories modified from Northridge-01 earthquake with magnitude 6.69 Mw and epicenter distance 3.3 Km and Figure 3(b) shows surface acceleration time histories of Kobe earthquake with magnitude 6.9 Mw and epicenter distance 7.08 Km.

TABLE 2. Time histories for fault earthquake

Semarang Fault Source Earthquake				Lasem Fault Source Earthquake			
Earthquake Event	**Station**	**M (Mw)**	**R (km)**	**Earthquake Event**	**Station**	**M (Mw)**	**R (km)**
Northridge-02 (1994)	Arleta - Nordhoff Fire Sta	6.05	1.48	Imperial Valley (1979)	El Centro Array #8	6.53	3.86
	Newhall - Fire Sta	6.05	7.36		Chihuahua	6.53	7.29
	LA - Century City CC North	6.05	18.34		El Centro Array #11	6.53	12.56
Chi-Chi, Taiwan-03 (1999)	TCU084	6.2	3.68	Chi-Chi Taiwan (1999)	CHY074	6.2	6.02
	TCU089	6.2	5.93		CHY080	6.2	12.44
	TCU076	6.2	13.04	Kobe, Japan (1995)	Port-Island	6.9	3.31
Northridge-01 (1994)	Arleta - Nordhoff Fire Sta	6.69	3.3		Nishi-Akashi	6.9	7.08
	Beverly Hills - 14145 Mulhol	6.69	9.44		Amagasaki	6.9	11.34
	LA - Brentwood VA Hospital	6.69	12.92	Victoria Mexico (1980)	Victoria Hospital Sotano	6.33	6.07
Chuetsu-oki, Japan (2007)	Nagaoka	6.8	3.97		Cerro Prieto	6.33	13.8
	Kashiwazaki City Takayanagicho	6.8	10.38				
	Yan Sakuramachi City watershed	6.8	12.98				
Iwate, Japan (2008)	IWTH24	6.9	3.1				
	IWT011	6.9	8.41				
	Kurihara City	6.9	12.83				

M = seismic magnitude; R = Epicentral distance



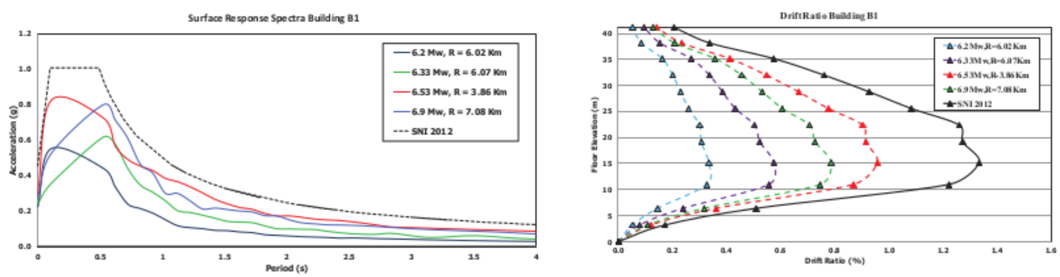
(a) (b)

FIGURE 3. Acceleration time histories Northridge-01, M = 6.69 Mw, R = 3.3 Km (a), Acceleration time histories Kobe earthquake, M = 6.9 Mw, R = 7.08 Km (b)

STRUCTURAL ANALYSIS

The structural analysis was performed by conducting 3D analysis of model structure to get the deformation and inter-story drift ratio of each floor elevation. Combine force live load, dead load and seismic force were implemented for each building. Seismic force was implemented by conducting two model earthquake forces response spectra and time histories function. Acceleration response spectra used in structural analysis developed from surface spectra obtained from online facilities prepare by [9]. Site response analysis was performed to obtain surface response spectra developed from acceleration time histories. Site response analysis was performed using the constitutive model proposed by [10 and 11] and utilizing the free software NERA [12]. The propagation analysis had been performed using Equation (2), where "ρ" is soil density, "η" is viscosity and "G" is shear modulus of soil. Figure 4(a) shows 4 (four) example surface spectra and SNI surface spectra obtained from [9] used for building B1. Figure 4(b) shows dynamic analysis result in terms of inter story drift values for building B1 using 5 (five) surface spectra.

$$\rho \frac{\partial^2 u}{\partial t^2} = G \frac{\partial^2 u}{\partial z^2} + \eta \frac{\partial^3 u}{\partial z^2 \partial t} \qquad (2)$$



(a) (b)

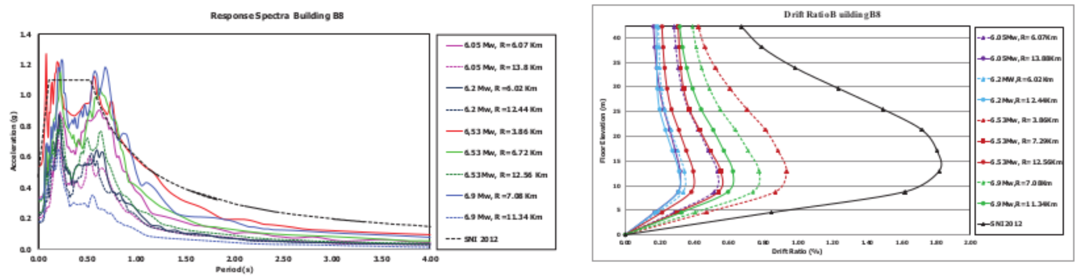
FIGURE 4. Surface response spectra of Semarang earthquake with magnitude 6.2 Mw to 6.9 Mw and epicenter distance less than 10 Km for building B1(a) and drift ratio for building B1(b)

RESULT AND DISCUSSION

Deformation and inter-story drift calculated using surface spectra acceleration from [9] can be compared with the same value calculated using surface acceleration time histories. Drift ratio and deformation of building calculated using acceleration time histories is less than the same value calculated using [9] when surface response spectra calculated using acceleration histories is less than surface response spectra calculated using [9]. Fig. 5(a) shows surface response spectra calculated using [9] and 9 (nine) surface spectra calculated from acceleration time histories for building B8. Fig. 5(b) shows corresponding drift ratio result calculated using response spectra from [9] and acceleration time histories. As can be seen on Figure 5(a) no surface response spectra calculated from acceleration time histories greater than surface response spectra calculated from [9]. The corresponding drift ratio analysis as can be seen on Figure 5(b) calculated using all 9 (nine) surface spectra are less than the drift ratio value calculated using [9]. Stability of building structure B8 has a correlation with predicted surface spectra calculated using all 9 seismic spectra and spectra from [9]. Figure 6(a) shows the correlation of 4 (four) examples response spectra calculated from seismic acceleration time histories and response spectra using [9] for building B3. The response spectra produce by Imperial Valley earthquake with magnitude 6.53 Mw and epicentre distance 3.86 Km is greater than the response spectra calculated from [9]. It can be seen on Figure 6(b) that the deformation of building B3 and Figure 6(c) the drift ratio values of building B3 calculated using Imperial Valley earthquake with magnitude 6.53 Mw and epicentre distance 3.86 is greater than the deformation and drift ratio calculated from [9]. If surface spectra calculated using [9] is less than surface spectra calculated using acceleration time histories, the structure will not strong enough to resist the deformation from specific earthquake. In terms of drift ratio and deformation values building B3 is not strong enough to resist earthquake force produced by an earthquake with magnitude 6.53 Mw and epicentre distance 3.86 Km.

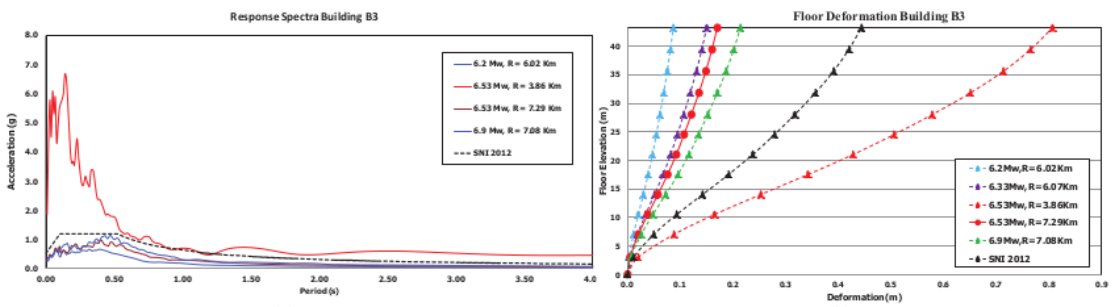
CONCLUSION

Sensitivity analysis of building against earthquake can be predicted by evaluating surface response spectra calculated using seismic code and surface response spectra calculated from acceleration time histories from a specific earthquake event. If surface response spectra calculated using seismic code is greater than surface response spectra calculated from acceleration time histories the structure will stable enough to resist the earthquake force. Based on the evaluation of 8 building in Semarang, building B3 will not strong enough to resist earthquake force produced by earthquake with magnitude more than 6.5 Mw and epicentre distance to building position less than 5 Km. Building B1 and B8 is strong enough to resist an earthquake with magnitude in between 6 to 6.9 Mw and epicentre distance to fault trace in between 3 Km to 15 Km.

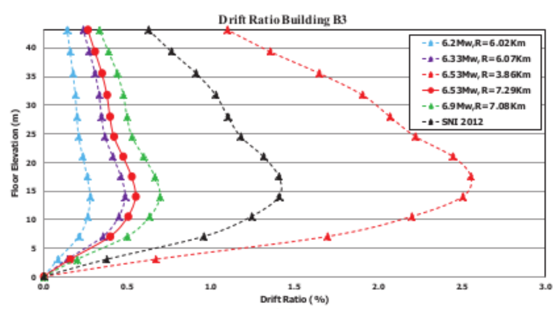


(a) (b)

FIGURE 5. Surface spectra for building B8 (a) and drift ratio of building B8.



(a) (b)



(c)

FIGURE 6. Surface spectra for building B3 (a), floor deformation building B3 (b) and drift ratio building B3 (c).

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