Development of Acceleration Time Histories for Semarang, Indonesia, Due to Shallow Crustal Fault Earthquakes

by Sri Prabandiyani R. W.

Development of Acceleration Time Histories for Semarang, Indonesia, Due to Shallow Crustal Fault Earthquakes

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1. INTRODUCTION

Research on seismic microzonation of Semarang is still ongoing. Following the research conducted by Team for Revision of Seismic Hazard Maps of Indonesia 2010, Lasem Fault is one of the most interesting seismic sources which should be taken into account for seismic mitigation of this city. Based on final research conducting by Team for Revision of Seismic Hazard Maps of Indonesia 2016 there are another 5 (five) shallow crustal fault sources (Rawapening, Ungaran, Semarang, Demak and Welerei faults) which take the advantage for seismic mitigation for this city. Fig.1. shows the trace line of all faults located surrounding and crossing the city. Semarang Fault and Lasem Fault are two shallow crustal faults crossing the city and will take the important earthquake sources to be taken into account for seismic hazard and seismic mitigation for this area.

Seismic microzonation for Semarang has already been performed on 2015 by conducting Lasem Fault as an active earthquake source for seismic hazard analysis [1]. Site response analysis for seismic microzonation was performed using 17 different time histories from five strike-slip mechanism shallow crustal faults earthquake with average magnitude 6.5 Mw. Site response analysis was performed at 190 soil boring locations with maximum 20 km distance from Lasem fault trace. This paper presents the development of surface acceleration time histories due to shallow crustal faults for the whole area of Semarang. Surface acceleration time histories were developed and calculated at 288 boring locations and conducting Semarang Fault, reverse fault mechanism earthquake source, as the main and dangerous seismic source for this study are. Fig.2. shows distribution of all soil investigations and its position against Semarang Fault trace. Most of all soil boring locations (249 points) are distributed less than 5 Km, 32 locations are distributed in between 5 to 10 Km and the rest 7 locations are distributed more than 10 Km from Semarang Fault trace. Surface time histories, acceleration time histories, were developed following the same method used by [1 and 2]. Surface time histories developed form this study can be used for dynamic structure design and evaluation and also as part of the second seismic microzonation scenario for this city.

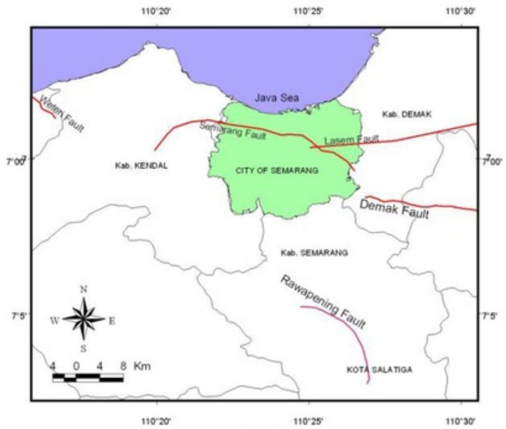

Fig. 1. Fault traces

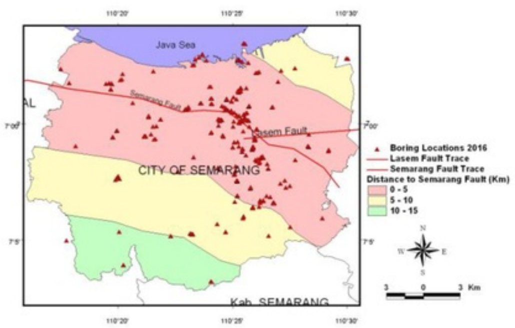

Fig. 2. Soil boring locations and its distance against Semarang fault trace

Due to inadequate accelerations time histories data produced by Semarang Fault earthquake, the modified acceleration time histories were developed using another similar seismicity reverse fault earthquake data. The time histories for reverse fault earthquake were collected from worldwide historical earthquake databases using three equal parameters such as magnitude, distance and seismic mechanism. The modified time histories, from another earthquake or past earthquakes, needs to match with earthquake scenario produced by Semarang Fault. Response spectral matching analysis between specific time histories (from worldwide earthquake data) and spectral acceleration (predicted spectral target from Semarang Fault earthquake) should be performed to get modified time histories.

The development of surface time histories for Semarang was performed following the procedures:

1. Conducting geological, geophysical and soil investigation and analysis for developing soil profile, bedrock elevation and site class maps of Semarang.
2. Conducting seismic hazard analysis and seismic hazard de-aggregation for estimating magnitude and distance for shallow crustal fault earthquake and developing spectral target acceleration using deterministic hazard analysis.
3. Collecting acceleration time histories from worldwide historical earthquake records due to shallow crustal fault sources with magnitude 6.5 Mw and maximum distance 15 km.
4. Developing modified acceleration time histories by conducting response spectral matching analysis.
5. Conducting shear wave propagation analysis using modified time histories calculated from response spectral matching analysis for obtaining surface acceleration time histories.

2. GEOLOGICAL AND GEOTECHNICAL CONDITIONS

Depth of engineering bedrock is one of the important parameters used to perform site response analysis. Identification of bedrock elevation for the study area was performed using single station feedback Microtremor and implementing three component ambient vibrations [2, 3 and 4]. Bedrock elevation measurement was performed at 218 locations. Using three component ambient vibrations, the depth of engineering bedrock can be predicted using two empirical formulas proposed by [5] and [6]. Fig.3. shows the distribution of bedrock depth of the study area. As can be seen in this figure the depth of engineering bedrock or the thickness of soil deposit is increase from Southern part to the Northern part of the study area.

Site characterization (classification) of geotechnical data was carried out by interpreting the results of field investigations such as in-situ standard penetration test (SPT) and laboratory tests. To develop site response analysis, 288 boring investigations with a minimum 30 m depth was performed in all part of Semarang city. The dynamic soil property was also conducted to encounter limited data of shear wave velocity profiles in Semarang. The shear wave velocity profile was estimated using SPT-N data and calculated using three empirical equations proposed by [7, 8 and 9]. Figure 3 shows the distribution of Vs30 (average shear wave velocity at top 30 meter soil layer) calculated from 288 boring locations.

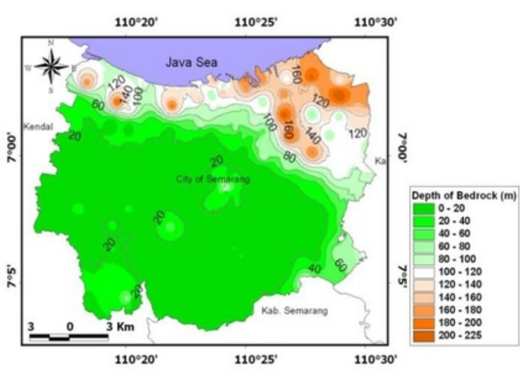

Fig. 3. Depth of engineering bedrock identified by single station feedback seismometer [2]

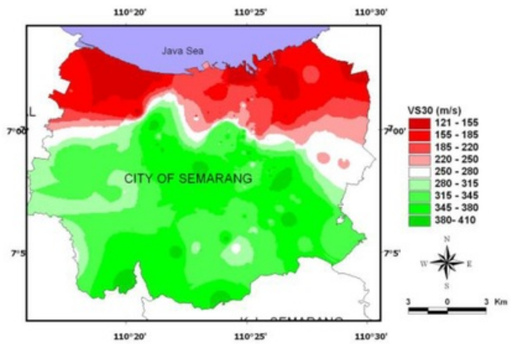

Fig. 3. Distribution of Vs30

3. DEVELOPMENT OF ACCELERATION TIME HISTORIES

Acceleration time-history for shallow crustal fault source was developed through three steps de-aggregation seismic hazard analysis, deterministic seismic hazard analysis and response spectral matching. De-aggregation seismic hazard analysis was performed to obtain controlling earthquake in terms of magnitude and distance which probably can gives maximum spectral acceleration for the whole area of the city. De-aggregation seismic hazard for Semarang was performed for shallow crustal fault with three different periods PGA, T=0.2s and T=1s and following the procedure propose by [10 and 11]. Fig.4. shows one example de-aggregation results for PGA with return period 2500 years. It seems in this figure that earthquake with magnitude 6.5 Mw until 6.7 Mw and maximum distance 20 km controlling the earthquake of this area.

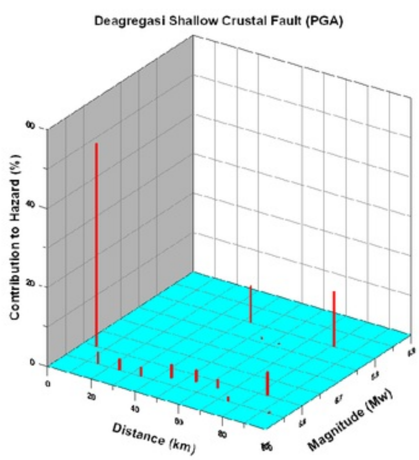

Fig. 4. De-aggregation PGA for shallow crustal fault

Based on de-aggregation seismic hazard analysis results the scenario for shallow crustal fault earthquake was implemented using average magnitude 6.5 Mw and maximum distance 15 Km. Due to the limited earthquake records of Semarang Fault earthquake with magnitude 6.5 Mw, historical earthquake records with magnitude ranging from 6 to 7 Mw and maximum distance 15 km were then collected for shallow crustal fault. Table 1 shows 15 acceleration time histories from 5 different earthquake events used in this study. All acceleration time histories data were collected from PEER NGA-West 2 Databases.

Table 1. Earthquake sources used in this study

Event	Station	M (Mw)	R (km)
Northridge-02 (1994)	Arleta - Nordhoff Fire Sta	6.05	1.48
	Newhall - Fire Sta	6.05	7.36
	LA - Century City CC North	6.05	18.34
Chi-Chi, Taiwan-03 (1999)	TCU084	6.2	3.68
	TCU089	6.2	5.93
	TCU076	6.2	13.04
Northridge-01 (1994)	Arleta - Nordhoff Fire Sta	6.69	3.3
	Beverly Hills - 14145 Mulhol	6.69	9.44
	LA - Brentwood VA Hospital	6.69	12.92
Chuetsu-oki, Japan (2007)	Nagaoka	6.8	3.97
	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

The target spectrum used for spectral matching analysis was predicted at bedrock elevation using deterministic hazard analysis by conducting three different attenuation functions proposed by [12, 13 and 14]. All target spectrums were calculated for reverse mechanism shallow crustal fault sources. Fig. 5 shows all target spectrums implemented in this study.

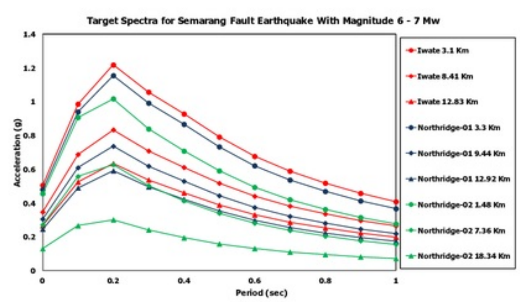

Fig. 5. Target spectrum used for spectral matching analysis

The modified acceleration time histories were predicted using response spectral matching analysis and following the same method proposed by [15]. The modified time histories was predicted using all 15 acceleration time histories and should be matched with target spectrum as mentioned in Fig. 5. Initial time histories must have similar shape with matched time histories (time histories calculated from response spectral matching). Care must be taken into account to evaluate both time histories. Fig. 7 shows an example result of spectral matching calculated for Northridge-01 earthquake with maximum distance 5 Km. Fig. 7 shows its corresponding two time histories (initial and matched time histories) results calculated from spectral matching analysis..

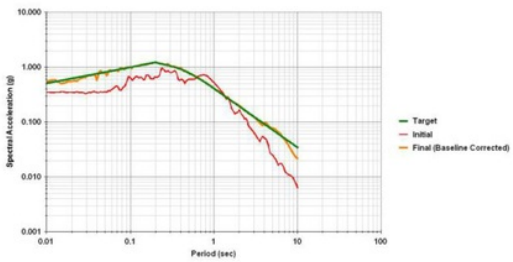

Fig. 6. Spectral matching result for Northridege-01 earthquake

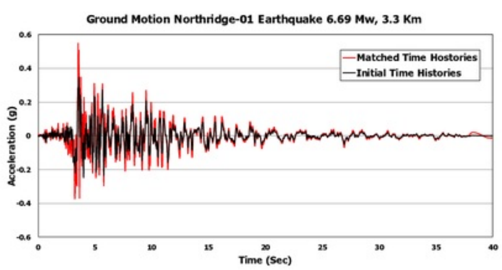

Fig. 7. Initial and matched time histories for Northridge-01 earthquake with magnitude 6.69 Mw and distance 3.3 Km

4. SITE RESPONSE ANALYSIS

Site response analysis was performed at 288 positions of soil boring for obtaining surface time histories. Site response analysis was performed using matched time histories calculated from spectral matching analysis. All 288 soil investigation points are distributed into three different distance categories (0-5 Km, 5-10 Km and 10-15 Km) to Semarang fault as already mentioned on Fig. 2. Site response analysis was implemented based on the assumption that all boundaries are horizontal and the response of a soil layer is predominantly caused by shear wave propagating vertically from the underlying bedrock. In this study the general response analysis was performed using equivalent linear approach and performed using the model proposed by [16 and 17] and utilizing free software NERA [18].

Due to inadequate data related with soil properties from end boring level until bedrock elevation, site response analysis was performed using soil deposit model proposed by [2]. Fig. 8 shows the corresponding soil deposit model for site response analysis. Bedrock elevation for each boring locations is predicted using bedrock elevation map as mentioned in Fig. 3. Fig. 9 shows an example of two time histories, initial time histories at bedrock elevation and surface time histories, calculated from site response analysis at BH-44. Site response analysis was performed using modified time histories from Northridge-01 earthquake with magnitude 6.69 Mw and 7.36 Km distance from Semarang Fault. Site response analysis was performed at medium (SD) soil class [19]. Peak ground acceleration (PGA) increases from 0.26 g at bedrock elevation to 0.52 g at surface elevation. Predicted PGA amplification factor calculated at this location is 2.07.

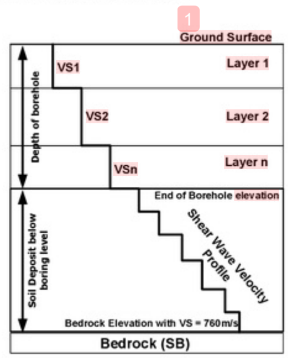

Fig. 8. Soil profile model for site response analysis

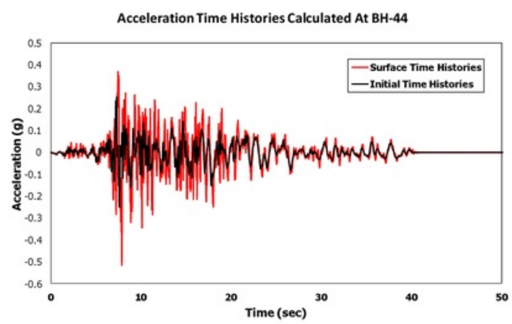

Fig. 9. Example time histories calculated using site response analysis

5. RESULTS AND DISCUSSION

Based on de-aggregation analysis for shallow crustal fault source conducted in this study identify controlling magnitude and distance of the earthquake sources for PGA, T=0.2s and T=1s. Earthquake with magnitude in-between 6-7 Mw and maximum distance 15 Km are controlling the seismic hazard for the study area. Spectral acceleration calculated at 288 boring locations using 15 time histories from 5 earthquake event seems that the maximum value were identified within the closest area to Semarang Fault trace. Fig. 10 shows an example of contour map of PGA at surface due to earthquake with magnitude 6.9 Mw. This PGA map was developed using time histories of Iwate earthquake (2008) with magnitude 6.9 Mw. Spectra acceleration developed from surface time histories must be verified and compared with spectra acceleration proposed by [19]. Fig. 10 shows an example of spectra verification at boring no Lok64Bh1. Average spectra modified from 5 (five) time histories (dash line) match with the surface spectra proposed by [19].

Table 2 - 4 shows distribution of spectra accelerations (PGA, T=0.2s and T=1s) for site class SC, SD and SE respectively. Site class SC, SD and SE was predicted using Vs30 values from 288 locations and following the same method proposed by [19]. Surface PGA for site SC is distributed between 0.17g until 0.7g where "g" is represents gravitational acceleration. Spectra 0.2s are distributed between 0.47g until 1.72g. However spectra 1s are distributed between 0.09g until 0.66g. PGA for site SD is distributed between 0.12g until 0.7g. Spectra 0.2s are distributed between 0.67g until 1.43g. Spectra 1s are distributed between 0.14g until 0.97g. As can be seen on Table 4 surface PGA for site SE are distributed between 0.21g until 0.48g. Spectra 0.2s are distributed between 0.17g until 1.26g. and spectra 1s are distributed between 0.33g until 0.97g. Refer to Fig. 10 minimum surface PGA values are identified at the northern part of the study area.

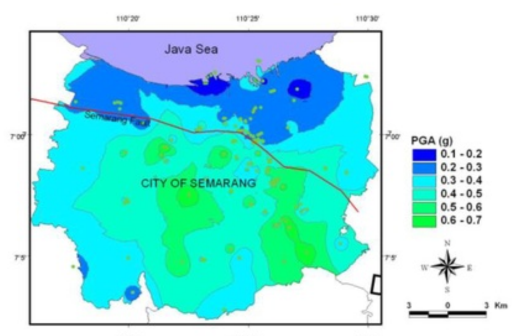

Fig. 10. Contour map of peak ground acceleration at surface due to Semarang fault scenario with magnitude 6.9 Mw.

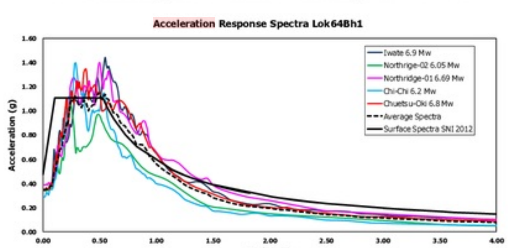

Fig. 11. Comparison result of surface spectra accelerations from five earthquake with surface spectra SNI 1726:2012

Table 2. Minimum and maximum spectral acceleration for site class SC

	PGA(g)	T02(g)	T1(g)	M (Mw)
Min	0.12	0.47	0.09	6.05
Max	0.66	1.33	0.46	
Min	0.23	0.78	0.14	6.2
Max	0.55	1.50	0.36	
Min	0.35	0.76	0.18	6.69
Max	0.66	1.40	0.66	
Min	0.35	1.00	0.23	6.8
Max	0.70	1.72	0.65	
Min	0.35	0.74	0.21	6.9
Max	0.63	1.59	0.65	

Table 3. Minimum and maximum spectral acceleration for site class SD

	PGA(g)	T02(g)	T1(g)	M (Mw)
Min	0.17	0.69	0.14	6.05
Max	0.51	1.11	0.82	
Min	0.20	0.76	0.40	6.2
Max	0.66	1.35	0.88	
Min	0.20	0.69	0.36	6.69
Max	0.69	1.43	0.52	
Min	0.22	0.67	0.51	6.8
Max	0.70	1.28	0.97	
Min	0.24	0.88	0.55	6.9
Max	0.70	1.34	0.88	

Table 4. Minimum and maximum spectral acceleration for site class SE

	PGA(g)	T02(g)	T1(g)	M (Mw)
Min	0.38	0.17	0.37	6.05
Max	0.48	0.29	1.01	
Min	0.23	0.20	0.33	6.2
Max	0.35	0.28	1.21	
Min	0.21	0.46	0.38	6.69
Max	0.35	0.84	1.47	
Min	0.21	0.42	0.41	6.8
Max	0.38	1.26	1.00	
Min	0.22	0.48	0.41	6.9
Max	0.38	0.94	0.92	

6. CONCLUSIONS

Surface time histories for Semarang, 15 time histories, were already implemented and developed based on three major steps de-aggregation, response spectral matching and site response analysis. These time histories were developed for Semarang fault earthquake source, reverse fault source. Comparison analysis was also performed in this study for comparing surface spectral acceleration, calculated from surface time histories, with surface spectral acceleration prepared by SNI 1726:2012. Based on previous study proposed by [2] total 17 acceleration time histories were also developed from strike-slip mechanism earthquake (Lasem Fault source). For seismic mitigation a total of 32 surface time histories must be taken into account for structural design and evaluation.

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