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GENERATION OF A PAIR OF SURFACE TIME HISTORIES FOR JAKARTA USED FOR EARTHQUAKE RESISTANCE DESIGN OF INFRASTRUCTURES

B.M. Hutapea*, M. Asrurifak, Hendriyawan, Masyhur Irsyam

Himpunan Ahli Teknik Tanah Indonesia (HATTI)
Jl. Warung Jati Barat Raya No.75 Jakarta, Indonesia 12740

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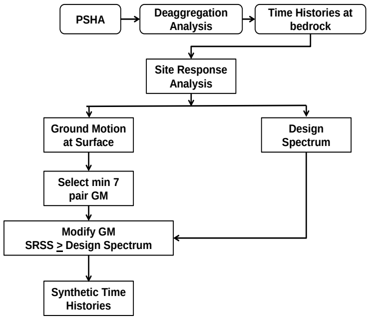
*Corresponding author
bigmanhtp@gmail.com

Graphical abstract



Abstract

It is not the earthquake but the collapse of the building and infrastructure that will cause the damage and the loss of human lives. To mitigate these hazards, the building and infrastructure need to be designed such that will not collapse due to earthquake. This paper presents the procedure for generating time histories at ground surface for Jakarta area. Required data to generate these modified time histories were extracted from the Team for Revision of Seismic Hazard Maps of Indonesia 2010. The results are used as input motions in dynamic time history analysis for predicting earthquake design loads for infrastructures, such as bridges such that those structures can be designed to bear the impact of an earthquake and prevent collapse.

Keywords: Time histories, hazard de-aggregation, ground surface

Abstrak

Bukan disebabkan gempa bumi tetapi keruntuhan bangunan dan infrastruktur yang menyebabkan kerosakan dan kehilangan nyawa manusia. Bagi mengurangkan bahaya sebegini, bangunan dan infrastruktur perlu direkabentuk supaya tidak runtuh disebabkan oleh gempa bumi. Kertas kerja ini membentangkan prosedur bagi menjana *modified time histories* di permukaan tanah untuk kawasan Jakarta. Data yang diperlukan untuk menghasilkan *modified time histories* diambil daripada Kumpulan Penyemakan Peta Bahaya Seismik Indonesia 2010. Keputusan digunakan sebagai input gerakan dalam analisis *dynamic time history* bagi meramal beban rekabentuk gempa bumi untuk infrastruktur, seperti jambatan agar struktur sebegini boleh direkabentuk bagi menanggung kesan gempa bumi dan mencegah keruntuhan.

Kata kunci: Time histories, hazard de-aggregation, permukaan tanah

1.0 INTRODUCTION

According to the current Indonesian Seismic Hazard Map published in 2010 by the Indonesian Public Work Department, Jakarta is considered as a high seismicity area which means that Jakarta is potentially affected by earthquake hazards. Dense populated and many man-made structures and infrastructures in Jakarta area can significantly increase the hazards. The collapse of the infrastructures will cause the damage and loss of human lives. In order to alleviate hazards and losses due to earthquake, seismic design loads need to be applied in design practice in Jakarta area. To predict that loads requires ground surface time histories such that the infrastructures can be designed to bear that loads and prevent collapse.

This paper presents procedure for generating time histories at ground surface for Jakarta area. This was conducted by modifying time histories given in Indonesian Earthquake Hazard Map prepared by Team for Revision of Indonesian Seismic Hazard Maps of Indonesia 2010 [1]. The procedure was started by conducting Probabilistic Seismic Hazard Analysis (PSHA) for 1000 years return period. De-aggregation was then carried out on the PSHA results in order to decide controlling earthquakes that is expressed in terms of magnitude M and hypocenter distance R at PGA, 0.2 second, and 1.0 second periods. Next the actual motions of the controlling earthquakes were spectral matched to PSHA target spectrum. This was followed by propagating the ground motions, which is obtained due to spectral matching, from bedrock to ground surface. Finally after developing design spectra at the ground surface, the modified time histories, i.e. the time histories at the ground surface, was generated. The generated time histories at ground surface can then be used to predict earthquake design loads for infrastructures, such as bridges.

2.0 SEISMIC HAZARD ANALYSIS

Seismic hazard analysis (SHA) is a process to evaluate quantitatively the design parameters of earthquake ground motion at a particular site. Deterministic and probabilistic methods have been widely used in conducting SHA [2-4]. In this paper however, seismic hazard analysis was carried out following the PSHA method. The method is based on the total probability theorem that has been implemented in EZ-Frisk computer program [5]. The theorem is expressed as:

$$P[I \geq i] = \int_r \int_m P[I \geq i \,|\, m \text{ and } r] f_M(m).f_R(r)\, dm\, dr \qquad (1)$$

where P indicates probability, $P[I \geq i \,|\, m \text{ and } r]$ is the probability that an intensity I is greater than i due to an earthquake of magnitude m at hypocenter distance r, $f_M(m)$ and $f_R(r)$ are probability density functions on magnitude and distance respectively.

The PSHA has contemplated the tectonic setting, regional geology, and seismicity of the site interest. Seismic sources characterization within radius of 500 km from the city of Jakarta has been considered. Those seismic sources are designated by subduction zones, fault, and background zones. Earthquake parameters, such as: slip rate, dip, geometry, and magnitude are extracted from the results obtained by Team for Revision of Indonesian Seismic Hazard Maps of Indonesia 2010 [1].

3.0 PSHA, DE-AGGREGATION, AND TARGET SPECTRUM

The PSHA produce the level of peak ground acceleration (PGA) and spectral acceleration at base rock as a function of probability earthquake hazard level. De-aggregation of the PSHA results were then conducted to determine controlling earthquake, as a function of magnitude M and hypocenter distance R, which gives the largest contribution on the maximum spectral acceleration. Thus, de-aggregation will give controlling earthquake with magnitude M and mean distance R of any exceeding probability and spectral period. Target spectrums for infrastructure design were generated based on performed-base concept. The purpose is to obtain levels of ground motion, and to develop design response spectra at base rock for two design levels, which are 100 years and 1000 years return periods of earthquake.

Uniform Hazard Spectrum (UHS) curves obtained from PSHA gives geometric mean values of the spectral acceleration. To obtain the maximum rotated component of the spectrum as required by ASCE/SEI 7-10 [6], the geometric mean values of the spectral acceleration need to be multiplied by directivity factors (DF). These directivity factors, which are defined as the ratio of the maximum to geometric mean spectral, are 1.1 and 1.3 for 0.2 second and 1.0 second periods, respectively. The DF for PGA however, is 1.0, which means no multiplication is required, and for periods above 1.0 second is 1.3. For periods between PGA and 0.2 second, the DF was obtained by linearly interpolated between 1.0 and 1.1; while for periods between 0.2 and 1.0 second the DF was obtained by linearly interpolated between 1.1 and 1.3. Table 1 show the DF and the resulting maximum rotated components for the range of periods from PGA to 10 seconds, while Figure shows maximum spectral acceleration for 100 and 1000 years cases.

Table 1 Mean spectral acceleration values at bedrock of Jakarta

Spectral Period (sec)	Geometric Mean Spectrum (gal)		DF	SA Maximum Direction (gal)	
	100y	1000y		100y	1000y
PGA	104.87	258.59	1.000	104.87	258.59
0.05	150.98	386.12	1.027	155.03	396.50
0.10	185.31	466.66	1.053	195.04	491.16
0.20	198.46	484.52	1.100	218.30	532.97
0.30	167.65	415.85	1.143	191.54	475.10
0.40	144.60	368.76	1.180	170.63	435.13
0.50	127.53	330.30	1.213	154.63	400.49
0.75	86.24	226.71	1.272	109.69	288.35
1.00	64.77	174.81	1.300	84.20	227.26
2.00	29.22	89.85	1.300	37.99	116.80
3.00	16.52	52.84	1.300	21.48	68.69
4.00	12.09	38.10	1.300	15.71	49.53
5.00	9.70	29.49	1.300	12.61	38.34
6.00	6.34	21.28	1.300	8.24	27.66
8.00	3.44	12.40	1.300	4.47	16.12
10.00	2.25	7.88	1.300	2.92	10.25

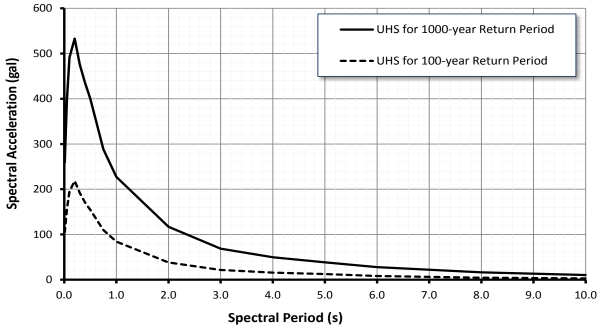
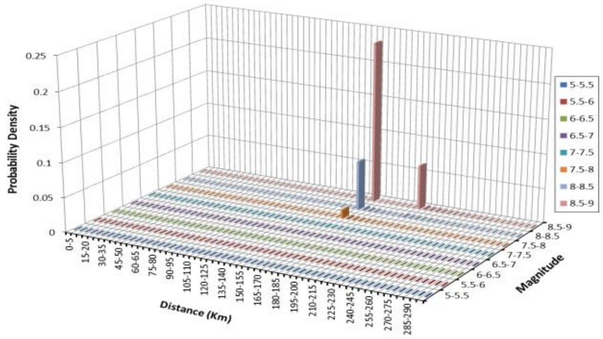


Figure 1 Probabilistic spectra with maximum direction at bedrock of Jakarta

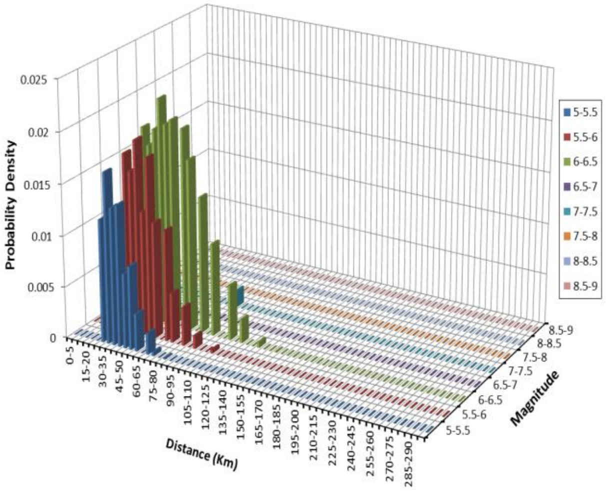
Examples of de-aggregation results for PGA with 1000 years return period due to Megathrust, Shallow Crustal and Benioff seismic sources are presented in Figure 2, respectively. The results can be used to developed mean estimates of magnitude and distance for varies periods and seismic sources in order to select recorded ground motion corresponding to specified condition. Table 2 presents the summary of hazard de-aggregation for Jakarta.

Table 2 Summary hazard de-aggregation for Jakarta

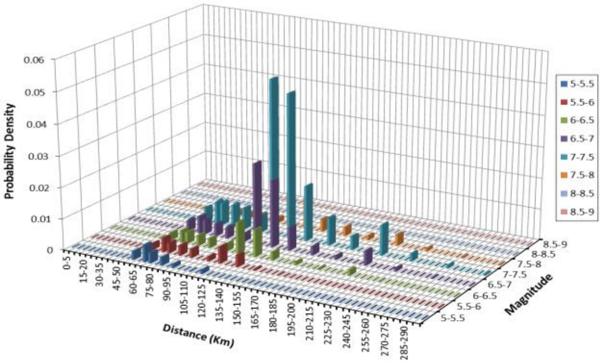
Return Period (year)	Spectrum Period (sec)	Megathrust		Shallow crustal		Benioff	
		Magnitude (Mw)	Distance (km)	Magnitude (Mw)	Distance (km)	Magnitude (Mw)	Distance (km)
100	PGA	8.5	179	5.9	71	6.5	139
	0.2	8.4	179	5.9	71	6.5	139
	1.0	8.4	203	6.5	101	6.7	150
1000	PGA	8.7	171	5.9	51	6.9	122
	0.2	8.7	172	6.0	51	6.8	121
	1.0	8.6	188	6.5	56	7.1	129



(a) Megathrust sources



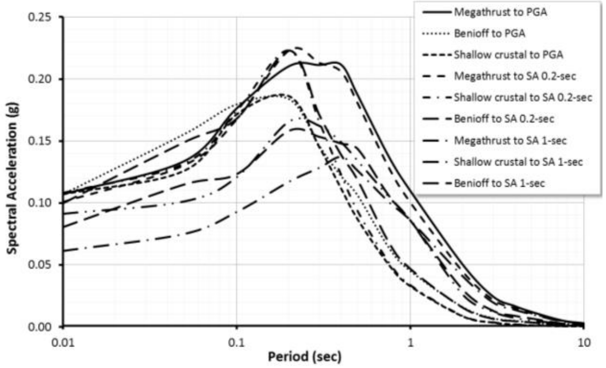
(b) Shallow Crustal Sources



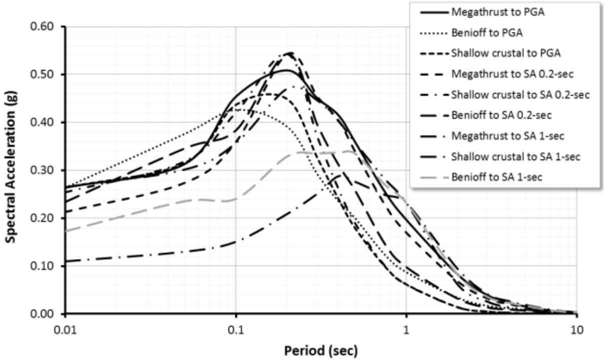
(c) Benioff sources

Figure 2 De-aggregation hazard result of PGA for 1000 year return period

The target response spectra were developed based on combination of mean magnitude and distance from hazard de-aggregation analysis. Following the ASCE/SEI 7-10 requirement, the Site Specific Response Spectra Analysis (SSRSA) has to be conducted based on input ground motion that are scaled to target spectral. To accommodate this requirement, nine (9) target spectrum scaled to UHS at three (3) periods of interest, which are T = 0.01 (PGA), T=0.2 second and T=1.0 second, were generated. The target spectral accepts Conditional Mean Spectrum (CMS) method proposed by Baker [7]. The method has been implemented into the EZ-Frisk computer program [5]. Figure 3 shows the generated target spectra that have been scaled at those periods of interest for 100 and 1000 years cases respectively.



(a) UHS for 100 years



(b) UHS for 1000 years

Figure 3 Scaled target spectra

4.0 INPUT GROUND MOTION

Shear wave propagation analysis in soil deposits require time histories as an input motion. At the present time unfortunately, there are no recorded time histories from Jakarta to conduct the analysis. The design time histories therefore, were selected from the worldwide appropriate recording station of historical earthquakes scaled to spectral target for 1000 years case. The selection were conducted based on the magnitude M and distance R obtained by de-aggregation analyses as shown in Table 2. Nine (9) selected time histories for different types of seismic sources such as subduction (Megathrust and Benioff) and shallow crustal fault are presented in Table 3.

Typically, the spectral amplitudes of the selected records do not match the target spectrum within the band of engineering interest. Scaling of these empirical records to match the target spectrum therefore, is required. The matching process follows the Spectral-Matching method proposed by Al Atik and Abrahamson [8], which has been implemented in the EZ-Frisk computer program [5]. Figure 4 shows illustration of the matching process to obtain modified ground motion.

Table 3 De-aggregation resume and characteristic of the recommended earthquake motions with 1000 years return period

NO	DEAG	SOURCE	M	R (km)	Record Ground Motion	M	R (km)
1	PGA 1000y	Megathrust	8.7	171	Chile, 27 Feb 2010	8.8	179
2		Shallow crustal	5.9	51	Livermore-01, PEER, 1980	5.8	54
3		Benioff	6.9	122	Miyagi Oki, 2003	7.0	152
4	SA 0.2-sec 1000y	Megathrust	8.7	172	Chile, 27 Feb 2010	8.8	178
5		Shallow crustal	6.0	51	Livermore-01, 1980	5.8	54
6		Benioff	6.8	121	Michoacán Earthquake, 22 Mar 1997	6.6	138
7	SA 1-sec 1000y	Megathrust	8.6	187.5	Chile, , 27 Feb 2010	8.8	178
8		Shallow crustal	6.5	56	Big Bear-01, PEER, 1992	6.5	64
9		Benioff	7.1	129	Miyagi Oki, 2003	7.0	152

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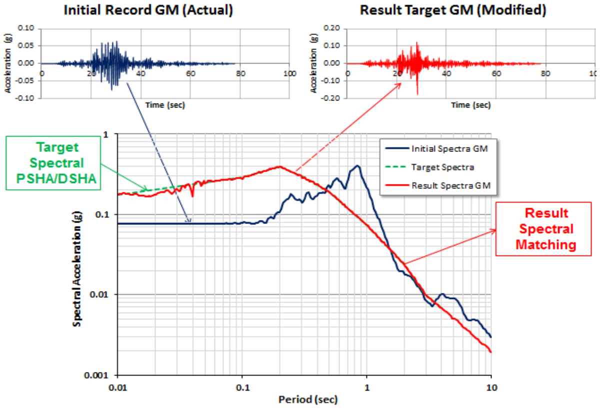


Figure 4 Illustration spectral match process to obtain modified ground motion

5.0 SITE SPECIFIC RESPONSE SPECTRA ANALYSIS (SSRSA)

SSRSA was conducted in order to obtain spectral acceleration at the ground surface for different soil conditions. The analyses were performed using 1-D shear wave propagation theory that has been implemented in a Computer Program NERA [9]. The dynamic soil parameters that are required to conduct the analysis are: a) the dynamic shear modulus, b) dynamic material damping (e.g. damping ratio-%), and c) variation of shear modulus and/damping ratio with shear strain.

In this paper, the soil shear wave velocity on the upper 30m that are required for conducting SSRSA was derived from Standard Penetration Test (SPT) data, NSPT, using empirical correlations proposed by Ohta and Goto [10] and Imai and Tonouchi [11]. These two correlations are valid for all soil. Figure 5 shows the plot of the correlations with more than two hundred soil borings data (shear wave velocity Vs and NSPT) representing site class SE (soft soil). Figure 6 shows the locations of the soil borings site. It can be seen from Figure 6 that the two correlations are fit quite well with the soil borings data. In this paper therefore, the shear wave velocity profiles are developed based on the average of these two correlations. The results are presented in Figure 7. Referenced bedrock (S_B with Vs = 760 m/s) is assumed at depth of 550m with extrapolation.

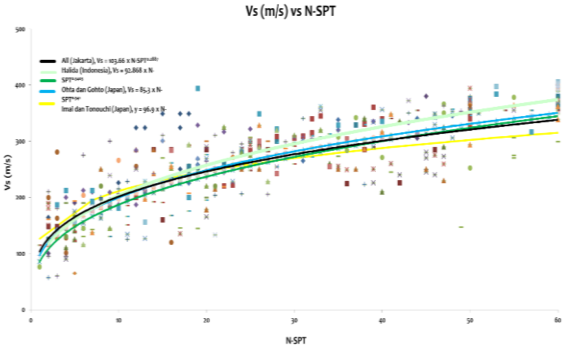


Figure 5 Correlation of Vs and NSPT

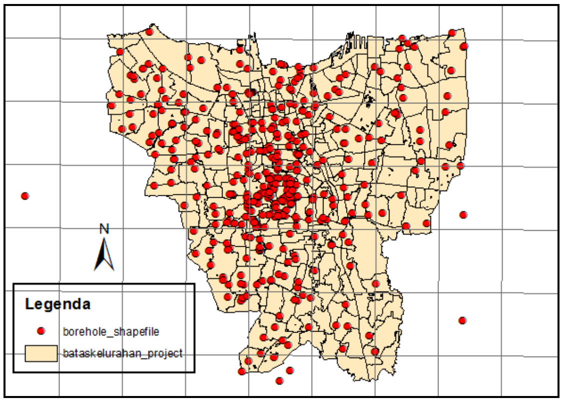


Figure 6 Location of soil boring

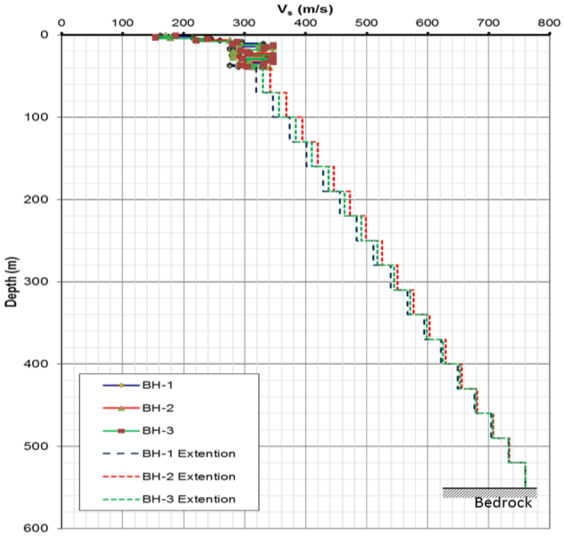


Figure 7 Shear wave velocity data as a function of depth for site response analysis

The wave propagation analyses were conducted considering nine (9) time histories for each return period of earthquake. The summary of the results are shown in Figure 8.

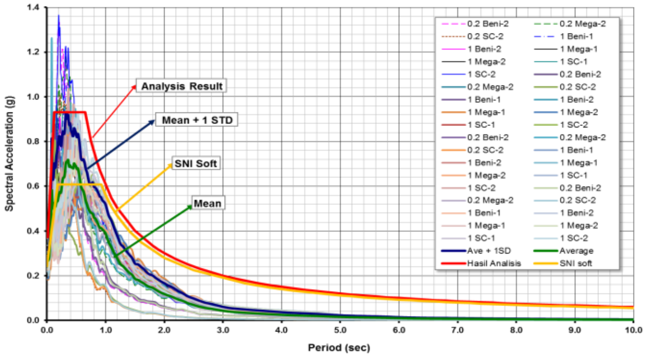


Figure 8 Response spectra on ground surface for 1000 years

6.0 GENERATE MODIFIED TIME HISTORIES AT GROUND SURFACE

According to ASCE/SEI 7-10, there are two methods in generating time histories at ground surface based on the requirement in structural analysis. For 2-dimensional structural analysis, the ground motion (GM) shall be scaled such that the avarage value of the 5% dampet response spectra for suite of motion is not less than the design response spectrum for the site for periods ranging from 0.2T to 1.5T, where T is the natural period of the structure in the fundamental mode for direction of response being analyzed.

For 3-dimensional analysis, the GM shall consist of at least seven (7) pairs of appropriated GM accelaration component. The appropriate GMs shall be selected from event having magnitude, fault distance and sources mechanisms that are consistent with those that control the maximum considered earthquake. For each pair of horizontal ground motion components, a square root of the sum of the squares (SRSS) spectrum shall be constructed by taking the SRSS of the 5 percent-damped response spectra for the scaled components (where an identical scale factor is applied to both components of a pair). Each pair of motions shall be scaled such that in the period range from 0.2T to 1.5T, the average of the SRSS spectra from all horizontal component pairs does not fall below the corresponding ordinate of the response spectrum used in the design. The procedure used in generating time histories at ground surface can be seen in Figure 9.

The authors propose 7 (seven) pairs of selected GMs that can be used for spectral matched for surface of Jakarta (Table 4). The calculated SRSS response spectra from a pair of Ground Motion Megathrust earthquakes are shown in Figure 10. Finally, SRSS of matched time histories/input motion for 1000 years return period can be seen in Figure 11.

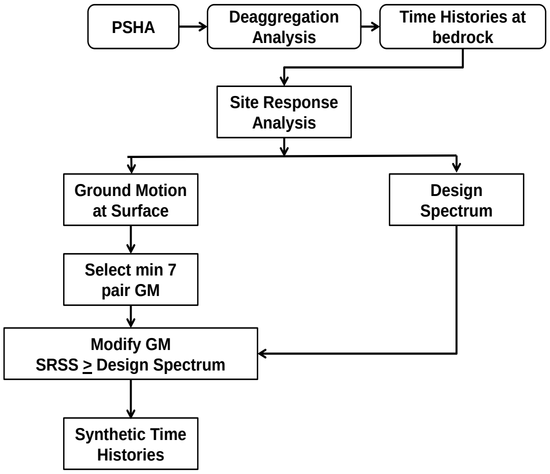


Figure 9 Procedure for generating synthetic time histories

Table 4 Seven pairs of ground motions proposed for spectral matching for Jakarta for 1000 years return period

Earthquake sources	Record ground motion	Direct	M	R (km)	Data Source
Subduction Interface (Megathrust)	Chile, 27 Feb 2010	90 360	8.8	178	SSN/USGS, CESMD
	Tohoku, Japan, 3 Mar 2011	EW1 NS1	9.0	201	CESMD
	Southern Sumatra, 12 Sep 2007	90 360	8.4	392	CTO/USGS
Deep Subduction Intraslab (Benioff)	Michoacán Earthquake, 22 Mar 1997	N00W N90W	6.6	138	CESMD
	Miyagi Oki, 2003	EW1 NS1	7.0	152	CESMD
Shallow Crustal fault & Background	Livermore-01, 1980	STP093 STP183	5.8	54	PEER
	Big Bear-01, 1992	SAF090 SAF180	6.4	64	PEER

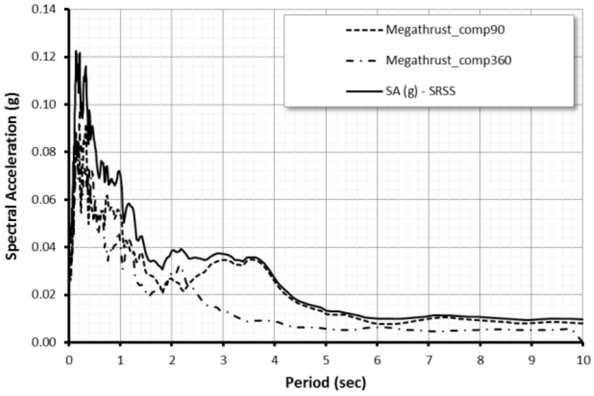


Figure 10 Spectra from a pair of ground motions Megathrust and result of compute Square Root of the Sum of the Square (SRSS) of the response spectra

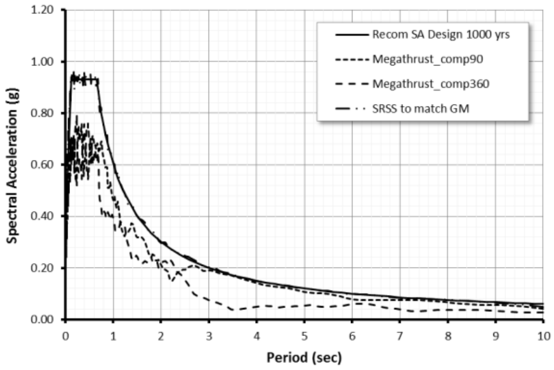
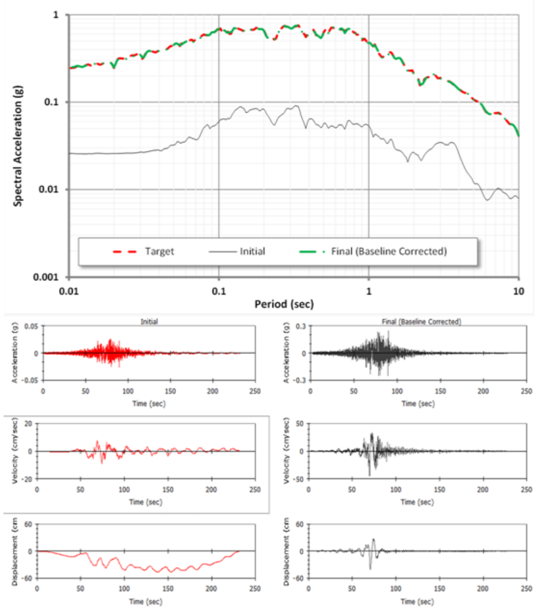


Figure 11 SRSS of matched time histories/input motion for 1000 years return period

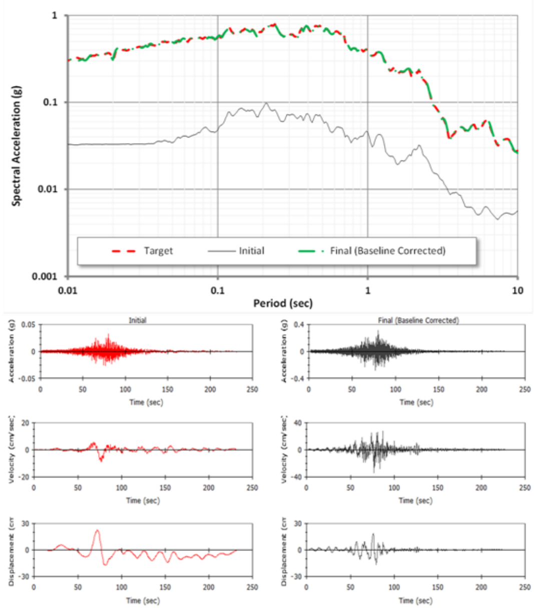
7.0 RESULTS OF MATCHING PROCEDURE FOR 1000 YEARS RETURN PERIOD

The selected time histories, which were used in spectral matching procedure in order to obtain modified time histories with the average of the SRSS equal to the corresponding ordinate of the response spectrum used in the design, is listed in Table 4.

Figure 12 to Figure 14 show the modified time histories of a pair of Megathrust, Shallow crustal and Benioff earthquakes that have been developed following the procedures mentioned previously. These generated time histories at ground surface can then be used in seismic analysis for infrastructures at Jakarta area.

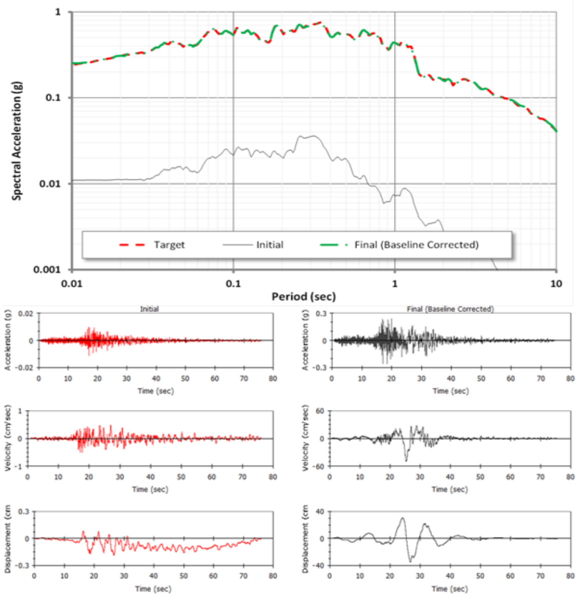


a) Megathrust_Comp90

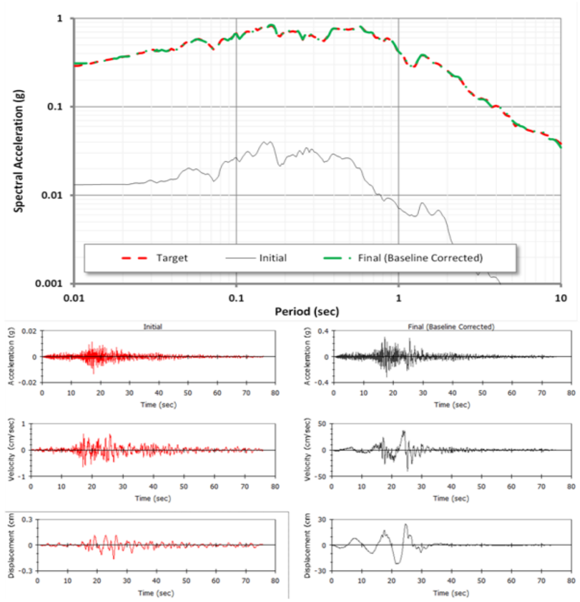


b) Megathrust_Comp360

Figure 12 A pair of Megathrust modified time histories and matched time histories/input motion

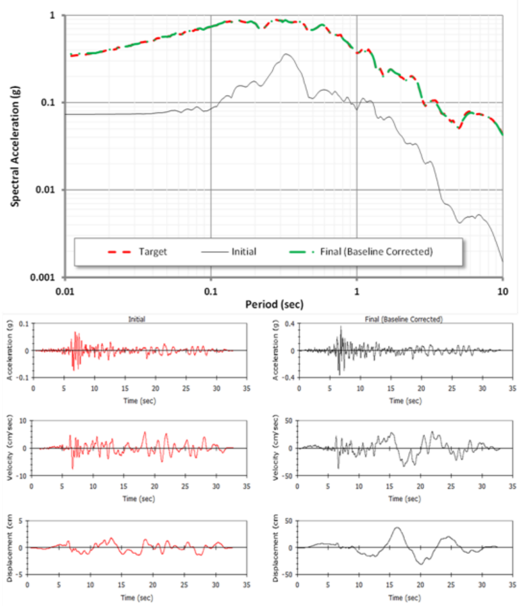


a) Benioff_CompN00W

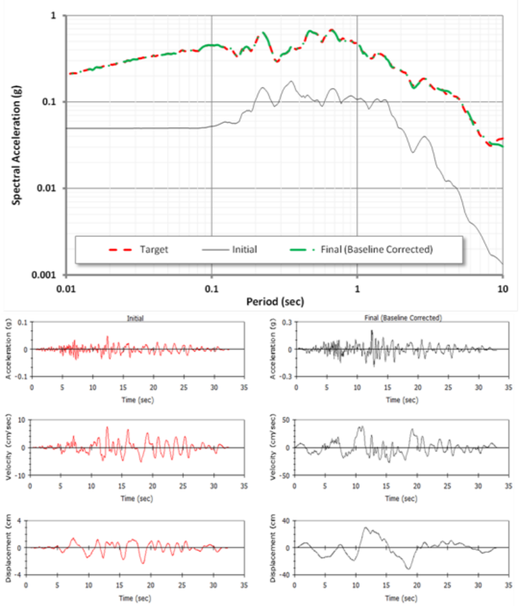


b) Benioff_CompN90W

Figure 13 A pair of Benioff modified time histories and matched time histories/input motion



a) Shallow_crustal_compSTP093



b) Shallow_crustal_compSTP183

Figure 14 A pair of Shallow crustal fault modified time histories and matched time histories/input

8.0 CONCLUSION

Seven (7) pairs of time histories at the ground surface are required for dynamic analysis of infrastructure. This paper presents, examples of ground surface time histories representing Megathrust, Benioff, and shallow crustal faults. The generation of the ground surface time histories was conducted for 1000 years return period following the ASCE/SEI 7-10 recommendations. The process of spectral hazard analysis on this study used shallow background, deep background, fault and subduction seismic source models that have been recently developed by Team for Revision of Seismic Hazard Maps of Indonesia 2010.

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References

[1] Irsyam, M., Sengara, I.W., Asrurifak, M., Ridwan, M., Aldiamar, F., Widiyantoro, S., Triyoso, W., Natawijaya, D.H., Kertapati, E., Meilano, I. and Suhardjono (Team for Revision of Seismic Hazard Maps of Indonesia 2010). 2010. Summary: Development of Seismic Hazard Maps of Indonesia for Revision of Seismic Hazard Map in SNI 03-1726-2002. Reseach report submited to the Ministry of Public Works by Team for Revision of Seismic Hazard Maps of Indonesia. July.

[2] Cornel, C.A. 1968. Engineering Seismic Risk Analysis. *Bulletin of the Seismological Society of America*. 58(5): 1583-1606.

[3] Kramer, S. L. 1996. *Geotechnical Earthquake Engineering*. Prentice-Hall, New Jersey.

[4] McGuire, R.K. 1976. EQRISK (Evaluation of Site for Earthquake Risk) User's Manual. United State Department of Interior Geological Survey.

[5] Risk Engineering. 2005. EZ-FRISK, *Software for Earthquake Ground Motion: User's Manual*. Risk Engineering Inc.

[6] ASCE/SEI-7-10. 2010. *America Society of Civil Engineers Minimum Design Loads for Buildings and Other Structures*. Structural Engineering Institute ASCE, Virginia, USA.

[7] Baker, J.W. 2011. Conditional Mean Spectrum: Tool For Ground Motion Selection. *Journal of Structural Engineering*. 137(3): 322-331.

[8] Al Attic, L and Abrahamson, N. 2010. An Improved Method for No stationary Spectral Matching. *Earthquake Spectra*. 26(3): 601-617.

[9] Bardet, J.P and Tobita, T. 2001. NERA - A Computer Program for Nonlinear Earthquake site Response Analyses of Layered Soil Deposits. Department of Civil Engineering University of Southern California.

[10] Ohta, Y and Goto, N. 1978. Empirical Shear Wave Velocity Equation in Terms of Characteristic Soil Indexes. *Earthquake Engineering Structural Dynamics.* 6(2): 167-187.

[11] Imai, T and Tonouchi, K. 1982. Correlation of N-value with S-wave Velocity and Shear Modulus. *Proceeding of The 2nd European Symposium on Penetration Testing*, Amsterdam. 57-72.