3-DIMENSIONAL SOURCE ZONES PROBABILISTIC SEISMIC HAZARD ANALYSIS FOR JAKARTA AND SITE-SPECIFIC RESPONSE ANALYSIS FOR SEISMIC DESIGN CRITERIA OF 45-STOREY PLAZA INDONESIA II BUILDING

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1. Introduction

Seismic design criteria for high-rise building can be simply referred from applicable building codes based on its level of seismic hazard or peak acceleration at referenced baserock (PBA). The other parameter that is needed is site classification. With this PBA and site-class, design response spectra representing seismic load to the building can be defined. PBA for city of Jakarta according to the current Indonesian building codes (SNI-03-1726-2002) is 0.15g. This level of PBA is specified for 475 years return period earthquake.

Seismic design criteria for 45-storey Plaza Indonesia II building was needed for structural and foundation detailed engineering design. Site classification analysis suggests that the site fall into the S_E (soft). This is due to the fact that the site consist more than 3 m soil layer having undrained shear strength (s_u) less than 25 kPa, Plasticity Index (PI) > 20 and water content (wn) > 40, or it fall in the border of S_E and S_D (medium) site class.

To provide representative seismic design criteria for the building, level of PBA is first verified through probabilistic seismic hazard analysis (PSHA) for city of Jakarta. Further site-specific response analysis (SSRA) was conducted and presented in this paper to more accurately represent seismic design criteria in term of design response spectra.

2. Probabilistic Seismic Hazard Analysis

PSHA for city of Jakarta was conducted to estimate PBA. This analysis is an update of previous analysis conducted by Sengara et. al. (1999). The analysis is based on total probability theorem assuming earthquake magnitude (M), hypocenter distance (r) as continuous independent random variable that affected the intensity (I). This theorem can be expressed as:

$$P[I \geq i] = \int_r \int_m P[I \geq i \ | m \text{ and } r|] f_M(m) f_R(r) dmdr$$

where:

- P [I ≥ i | m and r] is conditional probability for earthquake occurrence that cause local ground movement of intensity I ≥ i provided any point in the seismic source with a known magnitude (M) and a source distance (r).
- $f_M(m)$ is magnitude probability density function for the source area.

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- $f_R(r)$ is source distance probability density function for the source area.

The current analysis is conducted by using EZ-FRISK computer program (Risk Engineering, 2004). This program considers 3-D seismic source zones (Figure 1) that has considered the tectonic setting, regional geology, seismicity around City of Jakarta. In this analysis, seismic source characterization of both subduction sources in the south and shallow crustal faults within radius of 500 km from city of Jakarta has been made. In this analysis, the subduction earthquake sources characterization consist of separate identification of megathrust and benioff seismic source zone.

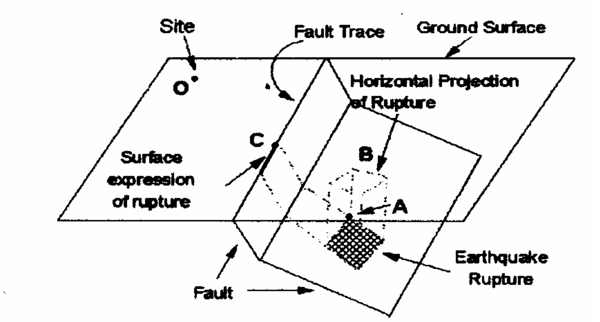

Figure 1. Illustration of 3-D seismic source zoning as input for the PSHA using EZ-FRISK

Tectonic Setting and Earthquake History

Tectonic setting and earthquake history around city of Jakarta has been elaborated in many similar study previously conducted (Seed et al., 1996; Sengara et al., 1999; Firmansjah and Irsyam, 1999). Based on geological and historical condition, seismic source zones of Jakarta can be divided into subduction and shallow crustal source zones. Subduction type source zone is Australian plate subducting under the Eurasian plate, which is called the Indonesian arc. This arc is located south of Java Island with the subduction starting from Indian Ocean. From hypocenter profile plots it can be seen that the earthquake hypocenter subducts from south to north. This is marked by the trends of epicenter depth increasing from south to north. Based on these facts, it is estimated that Jakarta earthquake with subduction mechanisms is caused by these Indonesian arc activities.

Shallow crustal source zones that contribute to Jakarta seismicity consist of Semangko fault passing Sunda Strait, Merak-Ujungkulon, Bogor-Puncak-Cianjur,Sukabumi-Padalarang-Bandung, Purwakarta-Subang-Majalengka-Kuningan, Garut-Tasik Malaya-Ciamis faults. All of these earthquake faults are responsible for most of the earthquake occurrences felt in Jakarta. Figure 2 shows the shallow crustal faults around Jakarta area.

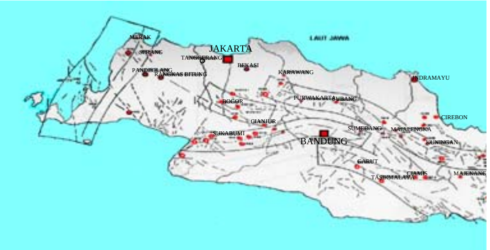

Figure 2. Shallow crustal faults around Jakarta area

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Earthquake Source Model

Based on the fact that earthquake intensity decays significantly at distances about 500 km and greater, the seismic sources zone that contribute to the site are limited those within a radius of 500 km, therefore Java subduction zone in the south of Java, southern part of Sumatera Subduction zone (Bengkulu and Sunda Zone) and several shallow crustal sources on Java and Sunda Strait will be analyzed in this seismic hazard analysis within this radius. The seismic sources located outside of this radius may not significantly influence to the probabilistic peak acceleration. Seismic source associated with subduction zone of Sunda Arc is divided into megathrust and benioff zone.

The events occurred at depth greater than 200 km are excluded in the analysis due to their paucity and great distance from the sites. Figure 3 illustrates the general seismic sources zones that used to predict subduction fault geometry such as dip and depth value. The hypocentral for Sunda Arc are shown in Figure 4 to Figure 8 for Java-1, Java-2, Java-3, Bengkulu and Sunda Zone respectively. Dip and depth value that obtained will be used in the seismic hazard analysis (noted as dip and depth model no. #1). We also reconsider subduction dip and depth value (noted as dip and depth model no. #2) from geological references and previous study of seismic hazard analysis for Jakarta city to cover uncertainties in the subduction fault geometry.

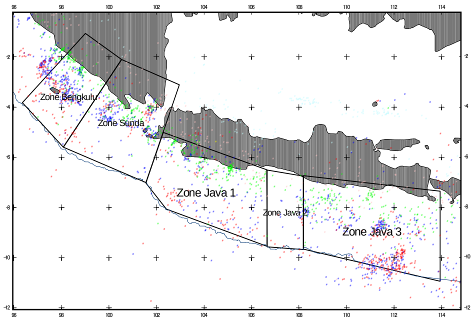

Figure 3. General Subduction seismic source zones Model

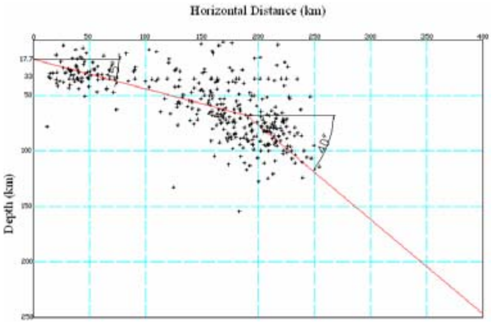

Figure 4. Hypocentral distribution at Java-1 Zone

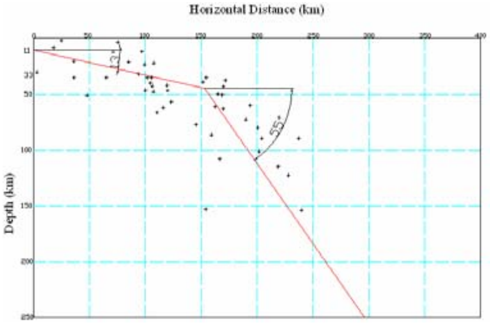

Figure 5. Hypocentral distribution at Java-2 Zone

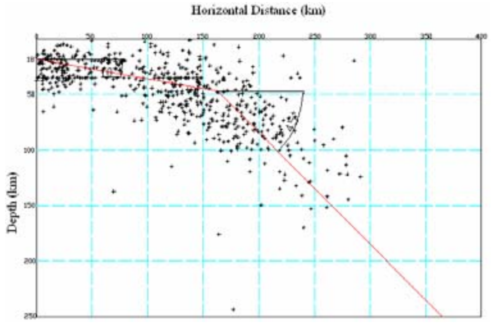

Figure 6. Hypocentral distribution at 2-3 Zone

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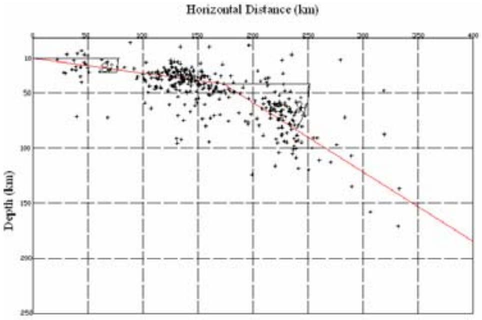

Figure 7. Hypocentral distribution at Bengkulu Zone

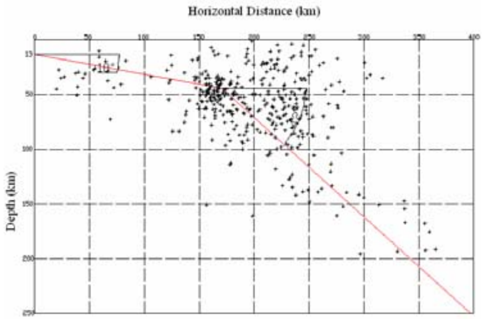

Figure 8. Hypocentral distribution at Sunda Zone

Earthquake occurrence parameters describe earthquake activity within the earth crust in a certain region. An earthquake occurrence model provides a description of potential future earthquake in term of their spatial variation, rupture size and frequency of occurrence. In this study, a-b parameters are obtained using Least Square Method, Weichert (1980) and Kijko & Sellevol (1989). We have calculated the b value from each of these zones separately, however we assume a b-value of 1.0 for all of these source zones.

The probability computations described in the preceeding section allow systematic consideration of uncertainty in values of the parameters of a particular seismic hazard model through a logic tree methodology. The use of logic trees (Power et.al., 1981; Kulkarni et.al., 1984; Coppersmith and Youngs, 1986) provides a convenient framework for the explicit treatment of model uncertainty. In this study, characteristic recurrence model is applied with the combination of two various dip which has the same weight factor. Attenuation functions of Boore et.al. (1997), Sadigh (1997), and Idriss (2004) for shallow crustal faults are assigned a relative likelihood of 0.33, respectively. These attenuation functions are considered appropriate for shallow crustals earthquakes. For subduction earthquakes, attenuation function of Youngs (1997) at rock is adopted since this function is considered to be appropriate to represent subduction earthquake source in this study.

Recurrence parameters are calculated by using three methods, least square method which has weight factor of 0.2, Weichert method 0.3 and the highest weight factor (0.5) is Kijko & Sellevol method. Different relative likelihoods are assigned to the maximum magnitude.

To use the logic tree, a seismic hazard analysis is carried out for the combination of model and/or parameters associated with each terminal branch. The logic tree approach allows the use of alternative models, each of which is assigned a weighting factor that is interpreted as the relative likelihood of that model being correct.

3. RESULT OF PSHA

The PSHA for city of Jakarta resulted in hazard curve shown in Figure 9. The hazard curve shows contribution of each seismic source to total probability. Since the seismic design criteria according to the Indonesian seismic building codes (SNI-03-1726-2002) is for 475 years earthquake return period, it is indicated that the PBA resulted from our PSHA is 0.19g. This value is slightly higher compared to the previous PSHA using 2-D seismic source zones approach reported in Sengara et al., 1999 (PBA=0.17g). Note also that the current PBA in the SNI-03-1726-2002 for city of Jakarta is 0.15g.

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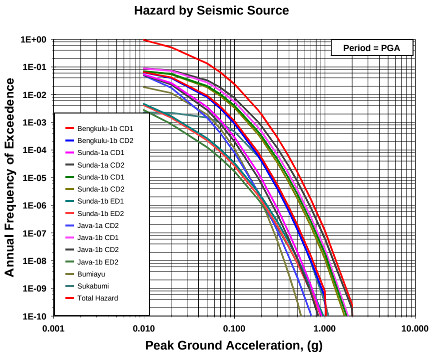

Figure 9. Hazard by Seismic Curve at T=PGA

It is essential to understand characteristics of ground motions as input to the SSRA. The essential output in the PSHA is the Uniform Hazard Spectra (UHS) for the level of probability of interest. Our PSHA resulted in UHS as shown in Figure 10. Further, we need to identity what is dominant earthquake events that could provide critical seismic hazard to the structure, considering the natural period of the structure. Based on structural analysis, the natural period of Plaza Indonesia II building is about 5 – 6 seconds. Hence, long period ground motions are considered to give critical influence on dynamic response of the structure. Therefore, to develop and recommend design response spectra for dynamic structural analysis, we need target response spectra that correspond to this critical conditon.

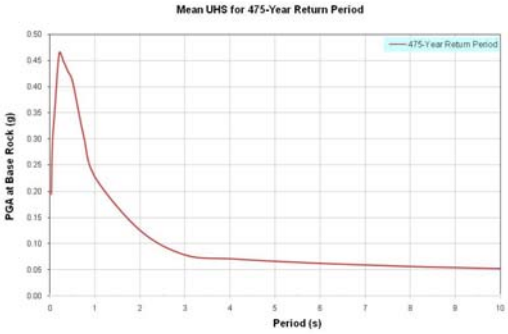

Figure 10. Mean UHS for 475-Year Return Period

Potential incoming earthquake to the site could be originated from megathrust, benioff, and shallow crustal events. In order to develop target response spectra from each earthquake source, we have conducted magnitude-distance de-aggregaton analysis to identify earthquake sources that have dominant contribution to the hazard value for long period motions. In this case, long period ground motions of our concern are represented by those of having oscilatory period T around 2 seconds. Therefore, we perform magnitude-distance de-aggregation analysis for T=2 seconds. De-aggregation in the PSHA determines the controlling earthquake magnitudes and distances. It is indicated in the de-aggregation curve that the dominant event is Megathrust earthquake with Mw=8.2 with the rupture length from the site is around 150 km (Figure 11).

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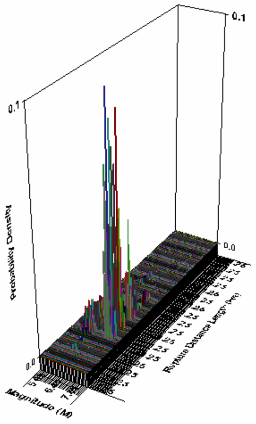

Figure 11. Magnitude-distance De-aggregation for level of hazard at T = 2 sec

3.1. Rock Target Spectra

Site response analysis need to be performed by considering appropriate input motion and dynamic soil properties of the site. There have been difficulties faced in SSRA since there are no strong-motion earthquake records available for Jakarta. Therefore, synthetic input motion generation has been conducted in this process. There are two steps in developing synthetic input motion. First step is to develop baserock target spectra. Baserock target spectra of particular dominant event could be developed based on the magnitude and distance parameters using appropriate attenuation functions. The second step is to use available strong-motion records having similar characteristics to the seismic source that its response spectra match the target spectra. In this process, spectral matching techniques proposed by Abrahamson that is built in the EZ-FRISK Computer Program (Risk Engineering, 2004).

To recommend spectral acceleration for long period, we scale dominant earthquake events rock target spectra to T = 2 second of the UHS. From scaled target response spectra, it is indicated that Megathrust event is dominating earthquake hazard for period greater than T = 2 second, as shown in Figure 13. Since spectral acceleration for whole range of period is also needed, then to recommend spectral acceleration for shorter periods, we also scale rock target spectra of short period motions to T = 0.2 second of that of the UHS. This scaled rock target spectra is presented in Figure 12.

Five input motions, that are scaled benioff, scaled megathrust and two scaled shallow crustals fault have been generated from existing strong-motion records of appropriate earthquake mechanisms. These input motions were used as input in the SSRA.

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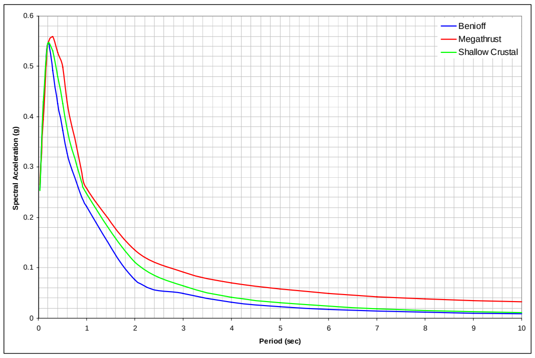

Figure 12. Target Spectra of Dominant Events Scaled to T = 0.2 Second

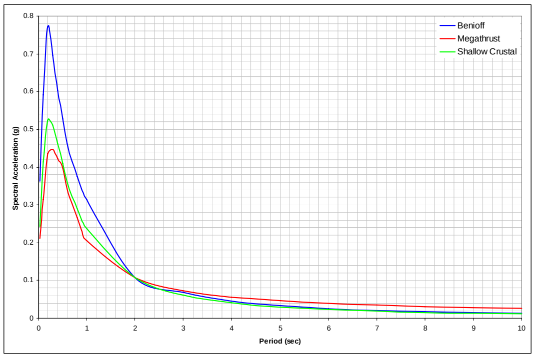

Figure 13. Target Spectra of Dominant Events Scaled to T = 2.0 Sec

4. SITE SPECIFIC RESPONSE ANALYSIS

4.1. Base-rock Condition

Geological survey and geotechnical investigation data was collected to know the subsurface conditions of Jakarta. There is limited information on geological information at the site. Geotechnical South-North profile was generated from this limited subsurface information. Based on the interpolation on base-rock South-North profile for Jakarta (Geological Research and Development Center, 1997), the depth of base-rock at Plaza Indonesia is estimated about 300 meter, and this is the basis of subsurface geometry used as an input in the SSRA.

4.2. Dynamic Soil Properties

Shear wave velocity data from field measurement for Plaza Indonesia site was obtained from two set of seismic down-hole test to a depth of 30 meter and 50 meter from the ground surface, respectively. Shear wave velocity data below this depth is approximated by using available formula that is correlated to N-SPT data and other soil properties. Referenced baserock (S_B with Vs = 720 m/s) is assumed at q depth of 300m. Figure 14 shows shear wave velocity data as a function of depths. This profile was used as input to the SSRA.

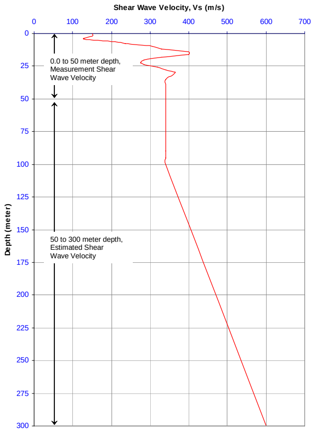

Figure 14. Shear wave velocity profile for site response analysis for Plaza Indonesia site.

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4.3. Seismic Wave Propagation Analysis

Seismic wave propagation analysis was conducted using NERA computer program. This program applies frequency-domain approach and non-linear soil properties where its shear modulus decreases as a function of increasing strain, while damping increases as a function of increasing strain. The wave propagation analysis using NERA computer program indicated that the peak acceleration for return period 475 years is amplified from 0.19g at the base-rock to values that vary from 0.23 g to 0.31 g at ground surface. The PGA is influenced by the shear wave velocity profile, frequency content and duration of input motions that have resulted in variations in the PGA.

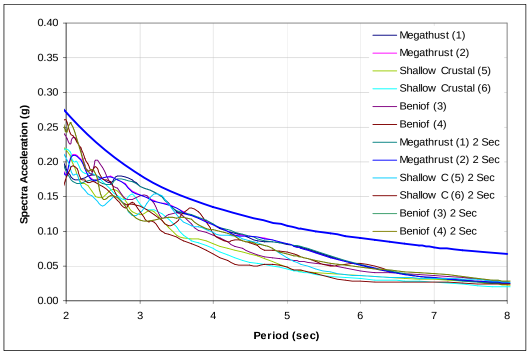

Figure 15. Ground surface response spectra based on frequency domain analysis for the range of the period of interest of the proposed tower (5-6 seconds), 475 years return period

4.4. Ground Surface Response Spectra

Based on result of seismic wave propagation analysis, recommendation of 5% damped spectral acceleration at ground surface for long periods has been developed as shown in Figure 15. Design response spectra of periods higher than 2 seconds is recommended by enveloping the spectral responses resulted form all the potential earthquakes input motions. The recommended design spectra resulted from this study is compared to that of SNI-03-1726-2002 and UBC97 for the range of the period of interest of the proposed tower (5-6 seconds) as shown in Figure 16 and Figure 17**,** for PBA of 0.15g and 0.19g, respectively. It is indicated that response spectra resulted from this analysis fall within the range of S_D and S_E site class of both SNI-03-1726-2002 and UBC97.

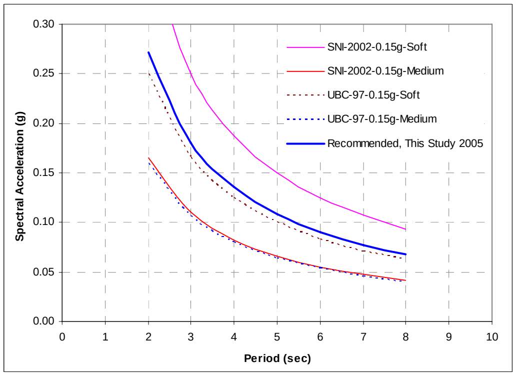

Figure 16. Comparison design spectra of 475 years return period resulted from this study, SNI-1726-2002 and UBC97 for the range of the period of interest of the proposed tower (5-6 seconds), PBA=0.15g

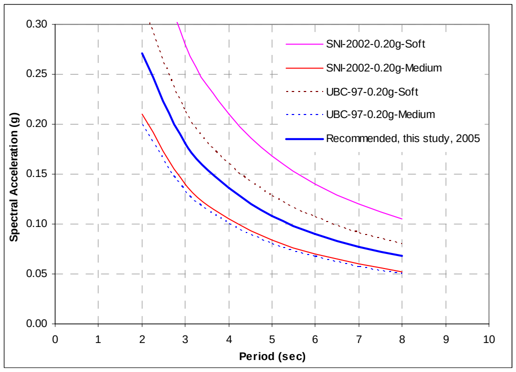

Figure 17. Comparison design spectra of 475 years return period resulted from this study, SNI-1726-2002 and UBC97 for the range of the period of interest of the proposed tower (5-6 seconds), PBA=0.19g

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Since peak accelerations for whole range of periods are required in the dynamic structural analysis, then wave propagation analysis using input motion scaled to T=0.2 second was also conducted and response spectra resulted from this analysis representing short period motions is presented. Entire response spectra resulted from both short and long period input motions are plotted and an envelope of design response spectra is recommended as presented in Figure 18. The recommended design response spectra was not averaged from series of response spectra as resulted from wave propagation analysis, since the input motions are scenario earthquakes, each of them with its different characteristics looks to provide different response as shown in Figure 18.

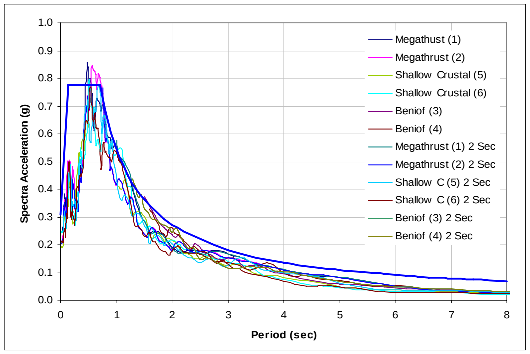

Figure 18. Recommended ground surface design response spectra for 475-years return period

5. CONCLUSIONS AND RECOMMENDATIONS

Probabilistic Seismic Hazard Analysis (PSHA) and site-specific response analysis (SSRA) for developing design response spectra for Plaza Indonesia II building have been conducted. The PSHA considers 3-D seismic source zones and adopts Young's attenuation function for subduction source zones and combination of Sadigh et al., Idriss, and Boore et al. attenuation functions for shallow crustal source zones. In addition, both exponential and characteristic recurrence models have been adopted. The PSHA for 475 years return period earthquake resulted in peak ground acceleration at baserock is 0.19g. This results is higher compared to the currently adopted for city of Jakarta (according to SNI-03-1726-2002) which is only 0.15g.

De-aggregation within the PSHA indicates that seismic source originated from the megathrust of the subduction provides the highet contribution to the probability. Uniform hazard spectra was developed and is used as the basis for generating seismic input motions for SSRA. Several input motions simulating both subduction and shallow crustal earthquakes have been used in the SSRA. Some of the input motions are scaled to both short and long period motions. Shear wave velocity profile was obtained from combination of existing soil investigation data and 2 seismic downhole testing.

Results of the SSRA provide response spectra that represent several earthquake scenario that are the basis for recommendation of the design response spectra. The recommended response spectra fall within the S_D (medium) and S_E (soft) site class of either SNI-1726-2002 or UBC97.

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PSHA and SSRA are essential to identify and verify the critical earthquake events and to recommend spectral acceleration associated with dynamic properties of the site as well as natural period of the building.

6. ACKNOWLEDGEMENTS

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