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Seismic Risk and Site Response Analysis for City of Bandung-Indonesia

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ABSTRACT

Bandung is considered as a relatively earthquake prone region. Seismic risk analysis considering subduction zone and surrounding active strike-slip faults in the area was performed. Crouse and Joyner & Boore attenuation functions were adopted for the subduction and strike-slip faults, respectively. The analysis was performed employing total probability theorem using EQRISK program with modification on the attenuation functions. The analysis indicated that peak base-rock acceleration is 147 gal and 200 gal for 200 and 500 years return period, respectively. Local site effects were considered by performing site response analyses in the form of wave propagation analysis from base-rock to ground surface. The analyses were performed by considering variations in dynamic soil properties. Properties of the local ground are obtained from collected soil investigation report covering Bandung area especially for northward and southward area. The wave propagation analysis was performed by using SHAKE91 computer program. Various input motions consisting of scaled available strong motion records as well as synthetic time history that are considered reasonable for Bandung, it were employed in this analysis. Target spectra for Bandung considering subduction and strike-slip mechanism were developed and then it is used to generate synthetic time histories using SIMQKE program. Result of the analysis is presented in the form of peak ground surface acceleration and amplification factor contours at ground surface. In addition, site classification of southern and northern part of Bandung based on average shear wave velocity criteria was generated. The shear wave velocity for the sites was correlated from N-SPT obtained from soil boring data. Finally, response spectra for each site class covering important sites of Bandung area are presented along with recommendations on amplification factor and design response spectra. Result of the analysis was used as an input for damage estimates of buildings and lifelines for earthquake scenario as part of Risk Assessment Tools for Diagnostic of Urban Areas against Seismic Disaster (RADIUS) Project for earthquake disaster mitigation of the city. The design response spectra from this analysis are recommended for the new building codes of the city.

INTRODUCTION

City of Bandung is considered one of the most densely populated cities in the world. Based on geological and historical conditions, seismic source zones of Bandung 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 north to south. Based on these conditions, it is estimated that Bandung earthquake with subduction mechanisms is caused by these Indonesian arc activities.
Shallow crustal source zones that contribute to Bandung 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 Bandung.

There is very limited study on seismic hazard for Bandung. It is considered necessary to evaluate seismic hazard for Bandung considering recent advances in earthquake engineering. This paper presents seismic risk analysis, microzonation, and site response analysis for Bandung. Results of the study would be useful for seismic hazard assessment for buildings and lifelines, as well as disaster management for city of Bandung. Furthermore, site response analysis would be expected to provide input to the design response spectra for the city.

EARTHQUAKE HISTORY

Based on seismicity around Bandung, earthquake sources and their mechanisms are mapped. The seismic events considered are within radius of 500 km and with magnitude of higher than 5. One large earthquake event (Ms = 8.3) was occurred in 1943 at India Ocean with epicenter distance of 500 km from Bandung. The largest shallow event within 500 km from Bandung occurred in 1933. This earthquake is one of the many earthquakes that occurred in Semangko fault. The reliable collected data is limited to earthquake after 1900 since there is no quantitative information available for earthquake before 1900.

SEISMIC RISK ANALYSIS

The first step in the analysis was to collect earthquake data dominant to affect the city. From the collected earthquake data, the earthquake sources were classified according to their fault mechanism. The source mechanisms are divided into the subduction mechanism and the strike-slip mechanism. After adopting appropriate attenuation function for each type of mechanism, seismic risk analysis was then performed to estimate peak acceleration at the base rock for various risks or return periods.

Attenuation Function

Since there is no attenuation function available, which is derived from earthquake recording in Bandung region, attenuation function considered appropriate according to the mechanism causing the earthquake was adopted. For the strike-slip mechanism, Joyner & Boore (1988) attenuation function was employed. Furthermore, for the subduction mechanism, Crouse (1991) attenuation function derived from earthquake data in North Pacific Cascadia was employed.

Joyner & Boore Attenuation Function (1988). Joyner & Boore attenuation function was published in 1988. The equation set forth by Joyner & Boore is:

$$\text{Log}(Y) = a + b(M-6) + c(M-6)^2 + d(\log(r)) + k\ r + s + \sigma \quad (1)$$

$$r^2 = ro^2 + h^2$$

Where Y is the earthquake parameters (maximum acceleration or velocity), M is the earthquake magnitude, r_o is the closest distance from the location to the vertical projection of the earthquake caused by the faults' activities on the soil surface, in km, s is the correction parameter for the local soil condition; for rocks s = 0, σ is the standard error (with a base number of 10), and a, b, c, d, k, s, and h coefficient are attained by Joyner & Boore from regression analysis.

Crouse Attenuation Function (1991). The attenuation function for rock site from Crouse is expressed as:

$$\text{Ln}(Y) = 6.36 + 1.76M - 2.73\ \text{Ln}(R + 1.58\exp(0.60M)) + 0.0091 * h \quad (2)$$

$$\sigma = 0.773$$

Where M is the earthquake magnitude moment, R is the distance in km, h is the focus depth in km, and σ is the standard deviation of ln a

Based on the regression analysis, Equation (2) has been modified for PGA as follows:

$$\ln(\text{PGA}) = p_1 + p_2 * M + p_3 * M^2 + p_4 \ln(R + p_5 \exp(p_6 (M)) + p_7 * h \quad (3)$$

where h is the focal depth and p_i is the regression coefficient.

EQRISK computer program (McGuire, 1976) that is based on total probability theorem was utilized to estimate peak ground acceleration for various return periods. The program was modified to update the attenuation functions appropriate for the region as has been described above. In this analysis, earthquake sources were divided into area and point sources based on their characteristics as shown in Fig 1.

Fig 2 presents result of seismic risk analysis that shows the variation of earthquake acceleration for various return periods. Table 1 shows the estimated acceleration in gal for 200 and 500 years return periods.

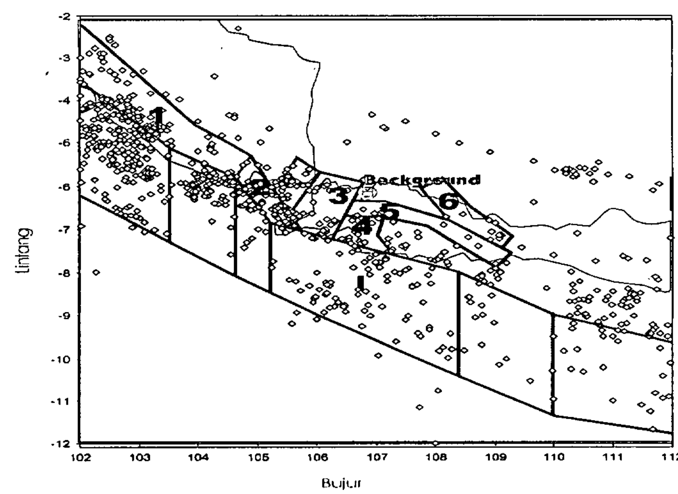

Fig. 1. Earthquake sources area model for seismic risk analyses

INPUT MOTION

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 site response analysis since there are no strong motion earthquake records available for Bandung. The simplest and conventional method to perform site-specific response analysis is by scaling available strong motion record as proposed by Seed, Idris, and Kiefer (1969). There are many uncertainties involved in to the result of site response analysis when scaling method is applied. For this reason, development of synthetic time histories to match target parameters such as peak base-rock acceleration, velocities, or spectral ordinates were pursued.

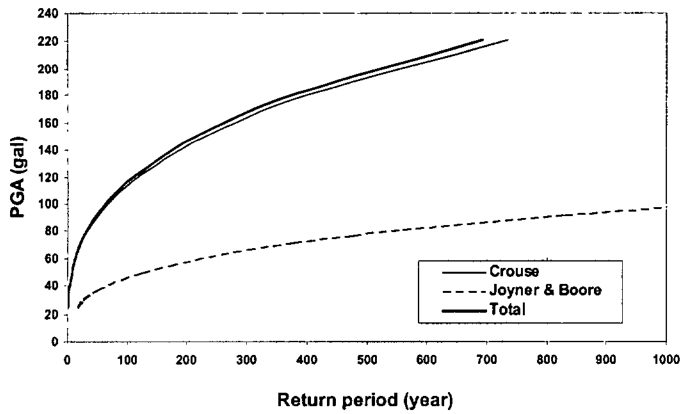

Fig. 2. Contribution of faulting and subduction sources to the total acceleration for various return periods

Table 1 Result of seismic risk analysis

Earthquake Return Period (years)	Peak Base-rock Acceleration (gal)
200	147
500	200

In this study, 10 strong motion records that include two synthetics strong motions were used to analyze effect of local ground condition as well as anticipated earthquake motion characteristics. The available strong motion records that are scaled for the city employed in this analysis consist of Cape Mendocino (0^0 and 90^0 component), Imperial Valley Earthquake-El Centro (S90W and S00E), Kobe Earthquake (NS and EW) and Loma Prieta Earthquake-Los Gatos (0^0 and 90 component). In addition, two synthetic time histories were generated, one for strike-slip and the other for subduction type earthquake motions.

<u>Synthetic Time History.</u>

Synthetic time history was generated for input motion in site response analysis since no satisfactory real motion records are available. In generating synthetic time histories, SIMQKE computer program (Ghasparini and Vanmarcke, 1976) was used.

SIMQKE computer program has the following major capabilities: computes a power spectral density function from a specified smooth response spectrum, generated statistically independent artificial acceleration time histories which match a specified response spectrum, refines the spectral match through an iterative procedure, perform a base line correction on the generated motion to ensure zero final ground velocity, and calculates response spectra with time history as input. Input parameters used in the program include target response spectrum, intensity envelope function being used, peak ground acceleration, time interval time history would be generated, and damping ratio.

In this case, time histories for 500 years return period were generated. The generated synthetics time histories for strike-slip and subduction faults are shown in Figs 3 and 4, respectively.

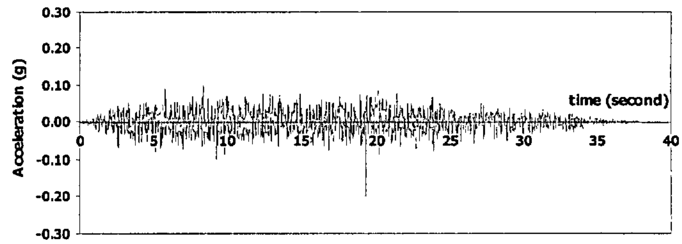

Fig. 3. Synthetic time history of strike slip earthquake mechanism

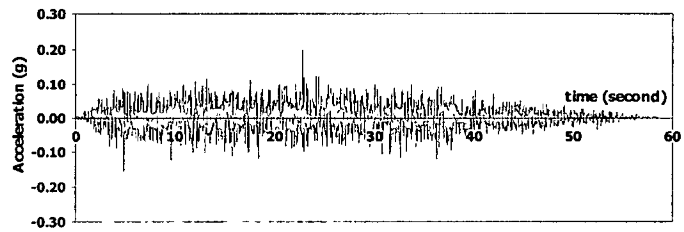

Fig. 4. Synthetic time history of subduction earthquake mechanism

BASEROCK AND SOIL CONDITION

Geological survey and geotechnical investigation data was collected to know the subsurface conditions of the city. Geotechnical south-north and east-west profiles were generated from the subsurface information. North-south cross-section indicates that depth of base-rock (tertiary rock) is approximately 70 m from the ground surface and increases about linearly to 100 m at Padalarang Cileunyi highway (southward of the city). Geological information on east-west cross-section suggests that the depth of base-rock is approximately 100 m at westward part increases about linearly to 120 m eastward of the city.

Based on both cross sections, soil condition of the city can be classified into two general soil layers. In southern part of the city, the upper layer is dominated by sandy clay to organic clay, with consistency soft to stiff. In northern part, the upper layer is dominated by coarse-grained sand, medium dense to dense. Second layer is dominated by silty sand to conglomerate and breccia with sandy matrix and consistency is very dense. In general, the thickness of the soft clay layer at southern part is higher compared to that of northern part of the city. The depth of base-rock is also increasing from north to south. This variation in the local soil condition was considered in the analysis to obtain response of the earthquake at ground surface.

SITE RESPONSE ANALYSIS

Site response analyses in the form of wave propagation from base-rock to ground surface were performed using SHAKE91 computer program (Idriss and Sun, 1991). This analysis was performed to estimate amplification factor and develop microzonation map for the city. The analysis was performed for typical 500 years design level as commonly be stipulated in most building codes. In this case, for 500 years design level, the peak base-rock acceleration as result of the seismic risk analysis is 200 gal. Wave propagation analyses were performed for approximately 20 sites covering the city area, representing variations in dynamic soil properties as well as depth of base-rock.

Dynamic properties of soil layers were estimated by using empirical correlation from available N-SPT (Seed et al., 1986) and other soil property information. Since there is no strong motion record available for Bandung, eight scaled earthquake records was employed. In addition, two synthetic time histories that have been generated for Bandung base-rock were also employed.

Results of wave propagation analysis at some locations in the city area indicated that peak ground acceleration at ground surface in southern part of the city is relatively higher than those of northern part. This trend is due to the fact that the thickness of the soft soil layer in southern part of the city is greater than that of northern part. Maximum amplification factor of 1.65 was predicted for southern part and around 1.35 for northern part of the city. A microzonation map was generated from result of the site response analyses, as shown in Fig. 5. In addition, amplification factor contour map is also developed and it is presented in Fig. 6. Note that these maps were developed based on only limited soil information. Therefore, some discrepancies may still be anticipated if additional soil data was used. As shown in Fig. 6, result of wave propagation analyses considering various input motions indicate that in general, peak base-rock acceleration is amplified.

Table 2 Amplification factors for Bandung

Site Class	Amplification Factors	
	this study	UBC97
S_2	1.25	1.20
S_3	1.50	1.40

SITE CLASSIFICATION FOR BANDUNG

Site classification for Bandung area representing variation in soil stiffness or dynamic soil properties was developed as a measure on the amount of amplification of peak acceleration from base-rock to ground surface. Site classification is based on the average shear wave velocities ($\overline{v}_s$) and average NSPT for soil layers at particular site.

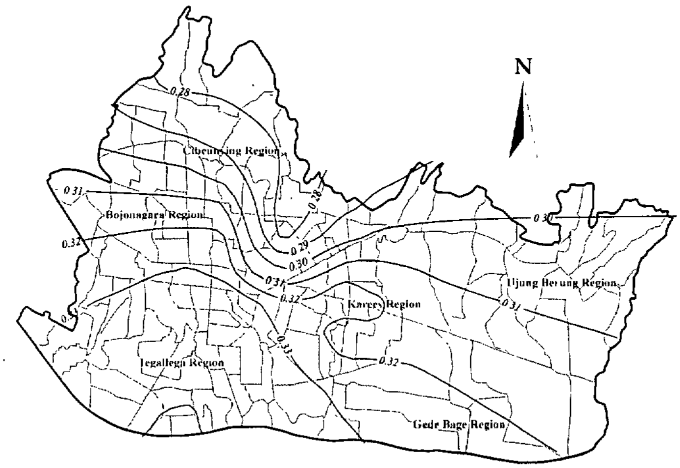

Fig. 5. Peak ground surface acceleration microzonation map of Bandung

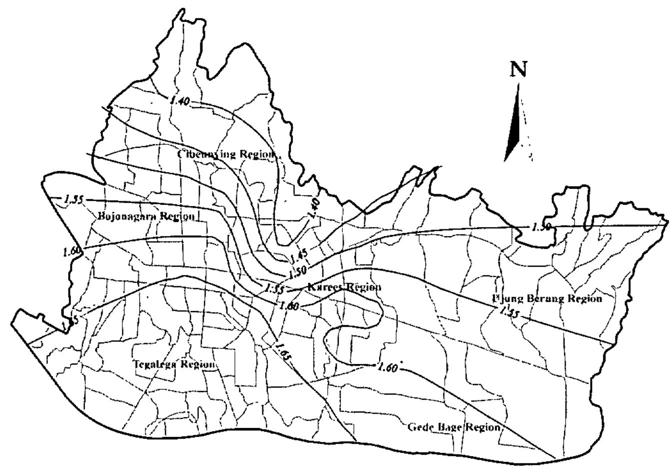

Fig. 6. Amplification factor contour map for Bandung

Based on the collected soil information, considering $\overline{v}_s$, $\overline{N}$-SPT and $\overline{s}_u$ parameters of various locations in Bandung area, site classification for the city fall into category C and D (according to NEHRP or UBC97).

RESPONSE SPECTRA

Results of site response analyses from SHAKE91 program, employing 10 synthetic input motions. The response spectra plots shown in Fig. 7 represent response of approximately 50 different sites. The response spectra plots are categorized into 2 site-class (S_2 and S_3) according to the site location developed in Fig. 7 and Fig. 8, based on site classification proposed in Table 3.

Table 3. Proposed site classification

Site Class	Description	$\bar{v}_s$ (m/s)	$\bar{N}$-SPT	$\bar{s}_u$ (kPa)
S_0	Hard Rock	>1500	-	-
S_1	Rock	$760< \bar{v}_s \leq 1500$	>50	-
S_2	Hard Soil and soft rock	$360< \bar{v}_s \leq 760$	> 50	> 200
S_3	Medium soil	$180< \bar{v}_s \leq 360$	$15< \bar{N} \leq 50$	$100 < \bar{s}_u \leq 200$
S_4	Soft soil	$\bar{v}_s \leq 180$	< 15	< 100

The response spectra shown in Fig. 7 and Fig. 8, clearly indicate the effects of local soil conditions on the shapes of the spectra. In addition, the type of input motions representing variation in the frequency contents clearly effect the shape of the spectra and spectral amplification. In general, looking at the response spectra shown in Fig. 7 and Fig. 8, spectral amplifications increases with decreasing soil profile stiffness. Moreover, the Bandung deep and soft soil deposits seem to have produced greater proportions of long period (low frequency) motion.

Although the analyses are still based only on limited site data, efforts to roughly categorize the response of the sites have been done in this study. Each category has been made to represents the proposed site class. From the categorized responses, design response spectra for site class S_2 and S_3, are proposed as shown in Fig. 7 to 8. This design spectra is based on our engineering judgment as well as referring to NEHRP97. The design response spectra are developed to cover various frequency contents of predicted incoming earthquakes and variations in local soil stiffness. Summary of seismic design parameters for each site-class, as proposed from this study is presented in Table 4.

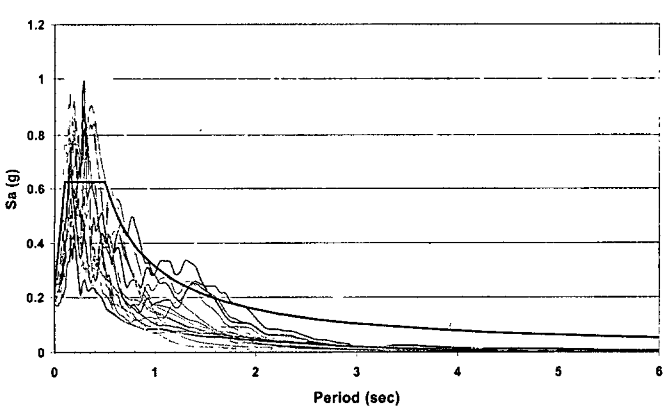

Fig. 7. Response spectra and recommended design spectra for S_2 site class

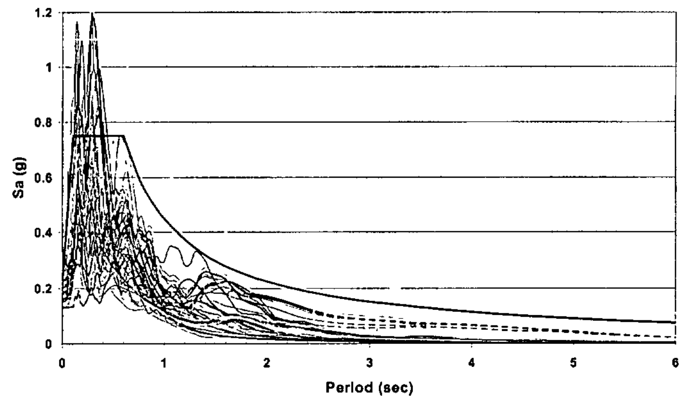

Fig. 8. Response spectra and recommended design spectra for *S_3 site class*

Table 4. Summary of proposed seismic design parameters for Bandung

Soil classification	Site class	A_o	T_c	S_a/A_o
Rock	S_1	1.00	0.4	2.5
Hard Soil	S_2	1.25	0.5	2.5
Medium Soil	S_3	1.5	0.6	2.5

where: A_0 : amplification factor
Tc : corner period
Sa : peak design spectral acceleration

CONCLUSIONS AND RECOMMENDATIONS

Seismic risk analysis for city of Bandung indicated that peak base-rock acceleration is 147 and 200 gal for 200 and 500 years return period, respectively. The analysis assumes Crouse attenuation function for subduction source zone and Joyner & Boore attenuation function for the strike-slip zones, since there are no attenuation functions available for Bandung,

For the purpose of city earthquake scenario, as an input to seismic hazard and damage estimate of buildings and lifelines, 500 years return period microzonation map has been generated. Amplification factor up to 1.35 was predicted for northern Bandung and up to 1.65 for southern Bandung. Site classification proposes that the city is fall into category S_2 and S_3-class although more detail classification still needs to be made further.

Seismic design parameters in the form of design response spectra for site-class S_2 to S_3 has been proposed for Bandung. It is observed that attenuation functions, input motions, and dynamic soil properties seem to be the important aspects that control the site responses. Therefore, to provide better recommendations of the design response spectra, further research is recommended. Further efforts are still needed to produce more refine microzonation map by using more complete seismic, geological, and geotechnical information.

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