SEISMIC HAZARD ANALYSIS OF THE BANDUNG TRIGA 2000 REACTOR SITE

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ABSTRACT

SEISMIC HAZARD ANALYSIS OF THE BANDUNG TRIGA 2000 REACTOR SITE. A seismic hazard analysis of the West Java region is carried out to estimate the peak ground acceleration at the Bandung TRIGA 2000 nuclear reactor site. Both the probabilistic and deterministic approaches are employed to better capture the uncertainties considering the enclosing fault systems. Comprehensive analysis is performed based on the newly revised catalog of seismic data, the most recent results of the construction of seismogenic structures, and on the up dated information on the geology and the seismicity of the region. Source parameters such as *b*-value, slip rate and maximum magnitude are reassessed for each seismic source. As none attenuation equation is available for the region, those developed some where else are used in the study, *i.e.*, Abrahamson & Silva (1997); Boore, Joyner & Fumal (1998); Boore & Atkinson (1997); Campbell & Bozorgnia (2003); Sadigh (1997); Spudigh (1997); and Young (1997). They are properly selected by considering the fault and subduction systems in question and are incorporated in the logic tree models derived herein based on the total probability theorem. The objective is to generate a horizontal three dimensional uniform risk spectral acceleration as dependent on the period as well as the return period for rock that is characterized by its average shear wave velocity of V_s = 1.050 m/s. A particular value of 0.172g is obtained as the peak ground acceleration for the site with its return period of 500 years.

Key words: Seismic hazard analysis, nuclear reactor, TRIGA 2000, logic tree, total probability, uniform risk.

2. Evaluation of the seismicity of each zone on the basis of historical, geological and estimation;
3. Selection of the attenuation equations;
4. Performing the probability analysis.

The steps have been incorporated into a logic tree algorithm as shown in Fig. 1, that reflects a scheme of a computational tree. The parametric contribution is separately evaluated and the result is statistically combined.

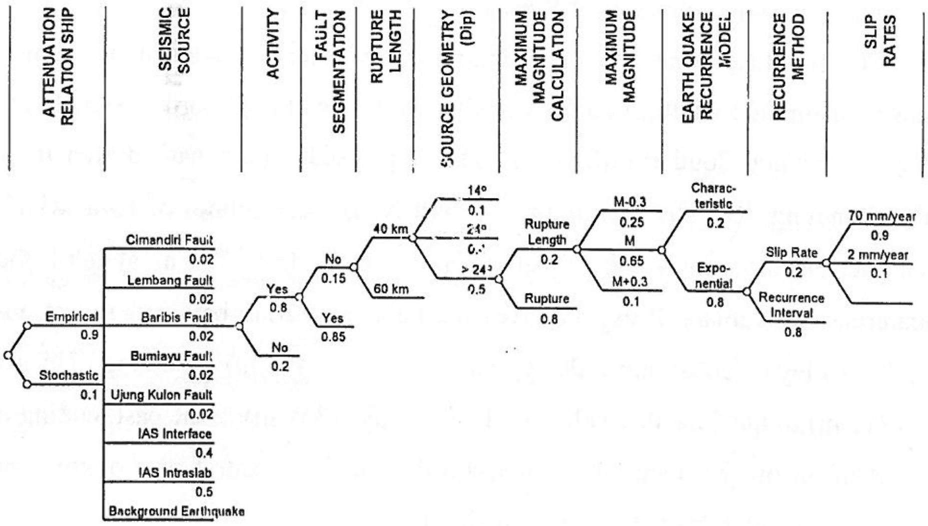


Figure 1. Logic tree.

II. TECTONIC SETTING FOR WEST JAVA AND ITS SURROUNDING

Most earthquakes influencing the site are due to the subduction mechanism of the India-Australia plate beneath Eurasia one at the Sunda arc. Relative plate motion is nearly orthogonal to the trench south of Java. For instance, on June 2, 1994, a large subduction thrust earthquake (M_w=7.6) occurred south of Java Island, and exhibited a

Cisarua. Investigations have always attributed that predominantly dip slip displacement of Lembang fault commenced after the big eruption of Sunda volcano that took place in Old Quaternary time.

III. SEISMICITY PARAMETER

i. Earthquake Catalog. It is generally acknowledged that sufficiently accurate data is not available, especially beyond the last 100-year period. The history of earthquake activity in West Java region dates back to the 17th century when the records describe only disastrous earthquakes. Over two hundreds thirty earthquakes were documented in the period of 0000 –1857. The documents merely provide information on the dates of the earthquake occurrences. The record for small earthquake is incomplete because of the limited number of seismograph distributed in the area. However, an earthquake catalog from 1970 to 2003 with magnitude greater than 5.0 was compiled. The earthquake source catalog can be summarized as follow:

a. Arthur Witchman (0000-1857)
b. Meteorology and Geophysics Agency (MGA) (1900 – 2003)
c. International Seismological Center (ISC) (1900-2003)
d. National Earthquake Information Center (NEIC)
e. US Geological Survey (1970 – 2003)

When necessary, a magnitude scale conversion is used in the analysis as proposed by Ekstrom & Dziewonski (1998) and expressible as follows:

$$M_s = \log A + 1.66 \log \Delta + 2.0$$

$$M_s = 1.33 m_b - 1.98$$

where: M_s is magnitude surface (Richter Scale),

m_b is magnitude body (Richter Scale),

A is the amplitude of surface waves and

Δ is the distance in degrees between the earthquake and the station.

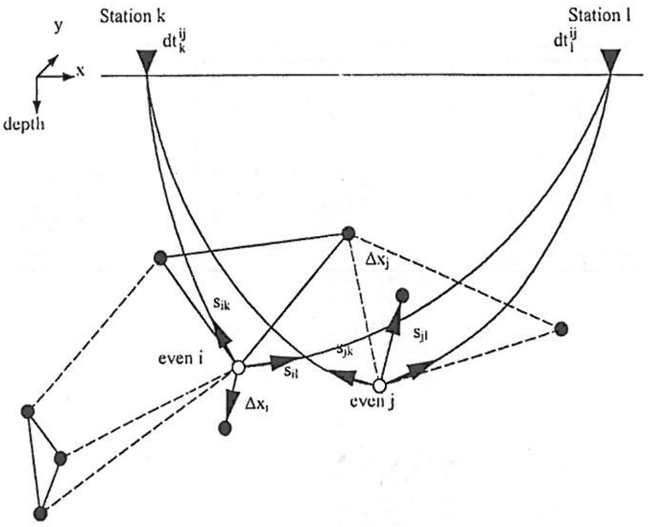


Figure 2. Double difference method.

Local data that may provide more precise estimates of location, depth, ground motion, and event location were analyzed by Hypocenter software package (Lienert and Havskov, 1995) using the velocity depth model. The result was plotted in West Java seismicity map shown in Fig. 3.

ii. **Seismic Source Zone.** To characterize each zone, the following parameters are evaluated:

- M_{max} and M_{min}, the upper and lower bound magnitude on the source;
- The Gutenberg-Richter earthquake recurrence parameter (b-value);
- The activity rate and the number of event per year having magnitudes equal to or larger than M_{min} on the source;
- The average hypocentral depth; and
- The tectonic setting.

Both the seismogenic structure and the capable tectonic source are considered in setting the seismic source zone. As the objective of the seismic hazard analysis is to estimate the probability of a specified level of ground motion being exceeded at a particular site for certain period, the following information is needed:

a. Seismogenic structure. A seismogenic structure is a part of the earth that is assumed to have uniform earthquake potential in terms of the expected maximum earthquake as well as the recurrence frequency, and distinct from the seismicity of the surrounding regions. The structure will generate ground motion but not to cause surface displacement, it may cover wide range of tectonic structures from well-defined one to a simple large region of diffused seismicity or seismotectonic province thought to be characterized by the same earthquake recurrence model. The structure is also characterized by its role in the present tectonic regime of the Quaternary, or approximately the last two million years. Based on the geological structure, the subduction model and the seismicity, a detail tectonic framework has been developed and shown in Fig. 4.

Most seismicities occur along subduction zones and the largest earthquakes are generated along the active margins. A closer look reveals that the largest event is due to the thrust type located within the couple plate interface at depth less than 50 km in West Java. This part of subduction zone or the seismogenic structure represent a down going and the over plate mechanism. A seismogenic parameter of the rupture plane d_{seis} can be calculated by the following equation, [Campbell, 2000b],

$$d_i = \begin{cases} \frac{1}{2}\left[H_{top} + H_{bot} - W\ sin(\gamma)\right] & \text{for } d_i \geq H_i \\ H_I & \text{otherwise} \end{cases}$$

where the subscript *I= rup* or *seis* is the distance measure of interest, H_{bot} is the depth to the bottom of the seismogenic part of the crust, H_{top} is the depth to the top of the fault, H_{seis} is the depth to the top of the seismogenic part of the fault, γ is the dip angle, and W is the down-dip width of the fault rupture.

A minimum value of 20 km has been found to be a reasonable limit for d_{seis} for West Java region.

Closest Distance. Various source to site distance measures have been used among researchers. Several of the distance measures (see Fig. 5) are

- r_{JB}, the closest horizontal distance to the vertical projection of the rupture (referred to as the Joyner-Boore distance);
- r_{rup}, the closest distance to the rupture surface;
- r_{seis}, the closest distance to the seismogenic rupture surface (assumes that the near surface rupture sediment is non-seismogenic);
- r_{hypo}, the hypocentral distance.

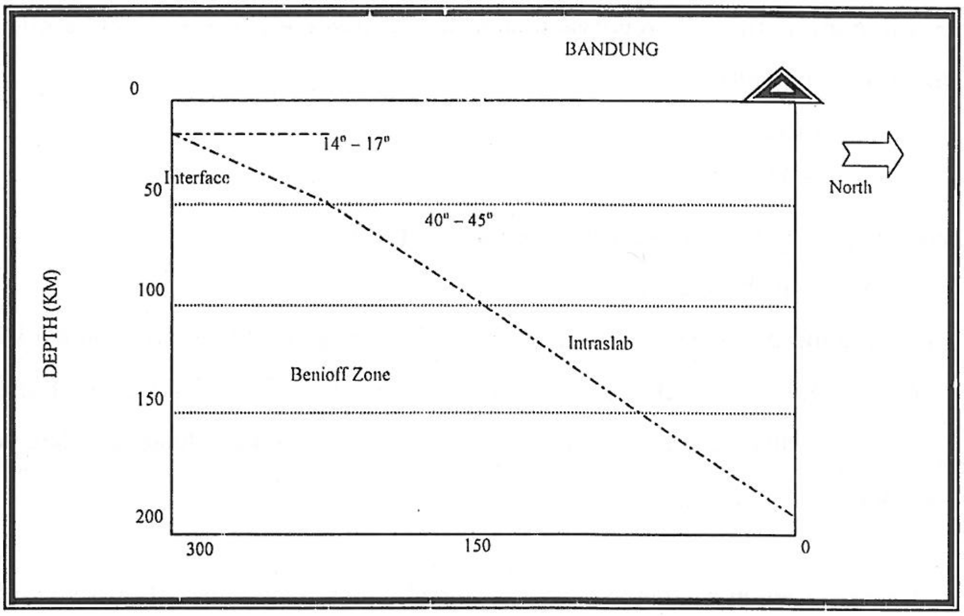


Figure 6. Schematical subduction zone of West Java.

c. Magnitude recurrence model. The frequency vs. magnitude occurrence relationship serves to characterize the activity of each source. The rate of recurrence of an earthquake on a seismic source is assumed to follow the Gutenberg-Richter relation expressible as follows,

$$\log\left[n(M)\right] = a - bM$$

$$\beta = b \ln 10$$

$$N(\geq M) = \alpha \frac{\exp[-\beta(M - M_{min})] - \exp[-\beta(M_{max} - M_{min})]}{1 - \exp[-\beta(M_{max} - M_{min})]}$$

where $n(M)$ is the number of annual events having magnitudes greater than M,

a is the productivity,

b is a constant commonly referred to as b-value;

Earthquakes in West Java region may originate from the shallow zone or from the deep subduction zone that of India-Australia and Eurasia Plates. For shallow zones the focal depth can be expected to be distributed uniformly from 5-30 km, while for deep subduction it can be expected to be in the range of 50 – 75 km at the thick benioff zones that dipping at an angle of 35° - 45° (see Fig. 7)

f. Rupture length vs. magnitude relationship. To estimate the rupture length vs. magnitude relationship, isoseismal contour is used. The proposed rupture length vs. magnitude relationship used is due to Wells and Coppersmiths (1997) as follow:

$$L = 10^{(0.59M_{max} - 2.44)}$$
$$W = 10^{(0.32M_{max} - 1.01)}$$
$$M_{max} = 5.08 + 1.16L$$
$$T_{max} = (1000/sliprate)10^{(5.46+0.82M_{max})}$$
$$N(M_{max}) = 1/T_{max} = 10^{(a-bM_{max})}$$

where M_{max} is the maximum magnitude,

L is the rupture length,

T_{max} is the return period for the maximum magnitude (year),

slip rate is the rate of displacement (mm/year), a, b are constants.

g. *Attenuation relationship.* A proper selection of attenuation equations constitutes the most important element in seismic hazard analysis. Given a large number of earthquakes and a site, attenuation relationships must be simple and easy to apply. Basically the attenuation relationship provides the ground motion level at a site as a function of magnitude and distance, but many have more parameters to allow for some different site types or kind of faulting. Different relationships have also been developed for different tectonic regimes. However, they may vary significantly in terms of predicted values where data are lacking.

iii. Attenuation Equation. Some attenuation equations and their types used in the analysis are described briefly as follow:

Sadigh, *et.al.*, (1997) for shallow crustal earthquake:

$$ln\,Y = C_1 + C_2 M + C_3 (8.5M)^{2.5} + C_4\, ln(r_{rup} + exp(C_5 + C_6 M)) + C_7\, ln(r_{rup} + 2)$$

where C_1, C_2, C_3, C_4, C_5, C_6 and
C_7 are coefficients that depend on the period.

Campbell & Bozorgnia (2003) for shallow crustal earthquake:

$$ln(Y_H) = C_1 + f_1(M) + C_4\, ln\sqrt{f_2(M, r_{seis}, S)} + f_3(F) + f_4(S) + f_5(H_W, F, M, r_{seis}) + \varepsilon$$

where r_{seis} is the seismogenic distance, f_1, f_2, f_3, f_4, f_5 are coefficients,
F for fault,
S is the soil condition.

Campbell (1997) for shallow crustal earthquake:
For horizontal component:

$$\begin{aligned}\ln(Y_H) = &-3.512 + 0.904M - 1.328\ln\sqrt{r_{seis}{}^2 + (0.149\exp(0.647)M)^2} + \\ &(1.125 - 0.112\ln(r_{seis}) - 0.0957M)F + (0.440 - 0.17\ln(r_{seis})S_{SR} + \\ &(0.405 - 0.222\ln(r_{seis}))S_{HR} + \varepsilon\end{aligned}$$

Young, *et.al.*, (1997) for subduction earthquake:

$$\ln(Y) = 0.2418 + 1.414M + C_1 + C_2(10 - M)^3 + C_3\ln(r_{rup} + 1.7818e^{0.554M}) + 0.00607h + 0.3846Z_T$$

where C_1, C_2, C_3 are coefficients,

$Z_T = 0$ for interface, and

$Z_T = 1$ for intraslab.

Atkinson & Boore (1997) for subduction earthquake:

$$ln(Y) = C_1 + C_2(M - 6) + C_3(M - 6)^2 - ln\, r_{hyp} - C_4 r_{hyp}$$

where C_1, C_2, C_3 are coefficients,

r_{hyp} is the hypocentral distance.

In all the above equations the following apply: M is the moment magnitude, H_w is the hanging wall, r_{rup} is the closest rupture distance (km), Y, Y_H, Y_V are the peak ground acceleration, the horizontal, and the vertical, respectively.

IV. THE PROBABILISTIC CALCULATION

The principle of the seismic hazard analysis is to establish a certain level of a site-specific peak ground acceleration that has a specified value of the probability of being exceeded for a period of time. The requirement can be transformed to the peak ground acceleration for some return period. The methodology for seismic hazard analysis as performed in the paper is based on the total probability theorem of McGuire (1976) with the aforementioned attenuation equations incorporated in the method. The peak ground acceleration is obtained by the following expression,

$$P[Y] = \iint p(Y \mid s, r) f_S(s) f_R(r)\, ds\, dr$$

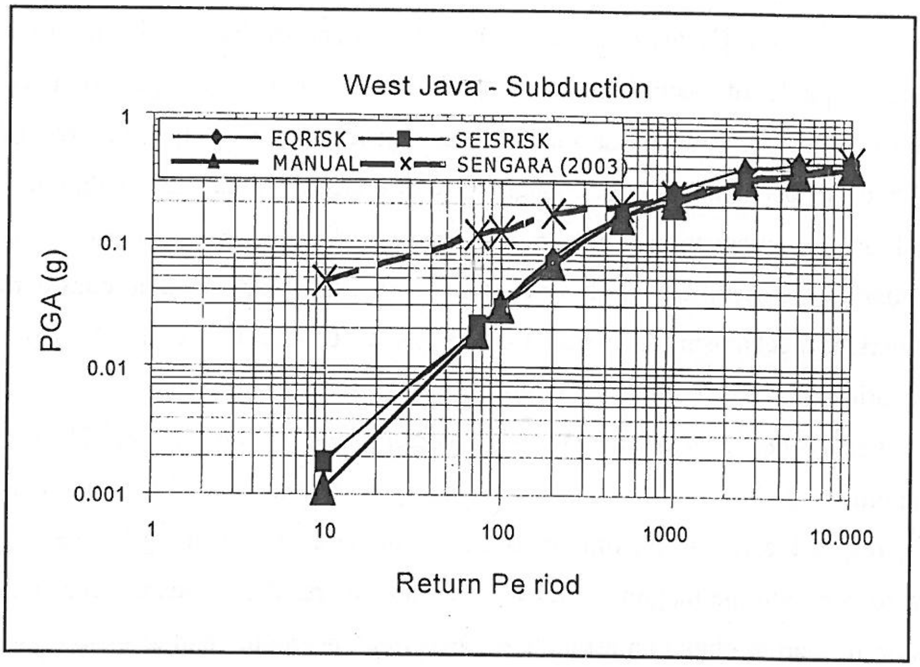
where r,s are the distance and site condition, respectively.

$$P_p(\ln Y, T) = 1 - e^{(-R_{tot}T)}$$

V. RESULTS

The results obtained by applying the above analysis are presented in what follows.

Horizontal Acceleration. The horizontal acceleration is presented as its spectral values for 0.1, 0.2, 0.3, 0.4, 0.5, and 1.0 second period and denoted as PSA0.1, PSA0.5, PSA0.1, etc. The peak ground acceleration (PGA) is its value when the period tends to zero. Fig. 8 represents the results of applying the attenuation equations selectively that is the plot of the peak ground acceleration (pga) vs. the distance as dependent on the magnitude. Fig. 9 shows the seismic hazard curve for the pga that is plotted vs. the return period. In the latter, their probability of being exceeded is of 0.5, 1, 2, 3, 5, 10, 15, 22, 40, and 50 per cent over 50 years period of time. A particular value of 0.172g is obtained as the peak ground acceleration at the site with its return period of 500 years, or with the probability of being exceeded of 10% in 50 years period of time.



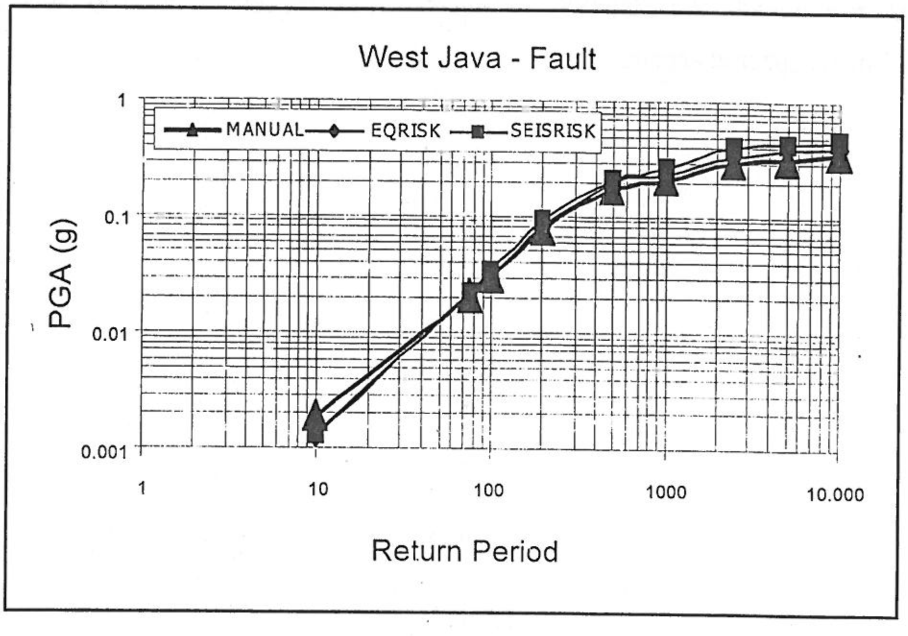


Figure 9. Seismic hazard curves of the peak ground acceleration for medium with $V_s = 1050$ m/s. (Propenta , 2003)

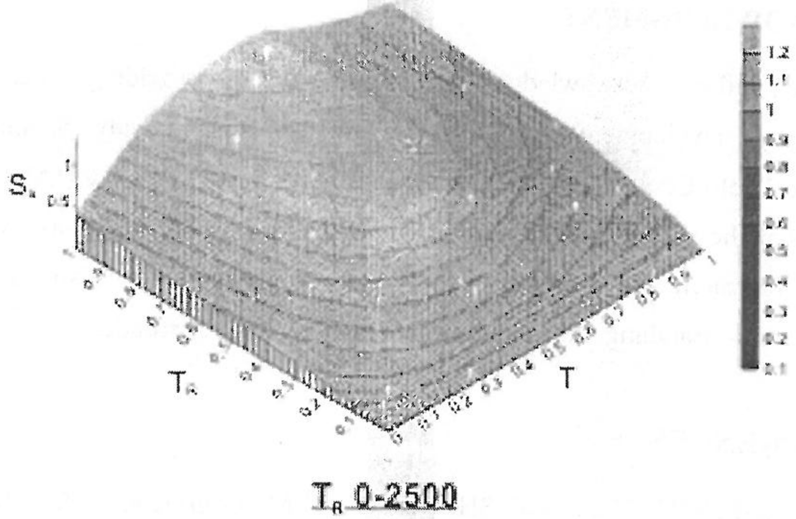


Figure 10. Uniform risk spectral acceleration as function of return period for subduction.

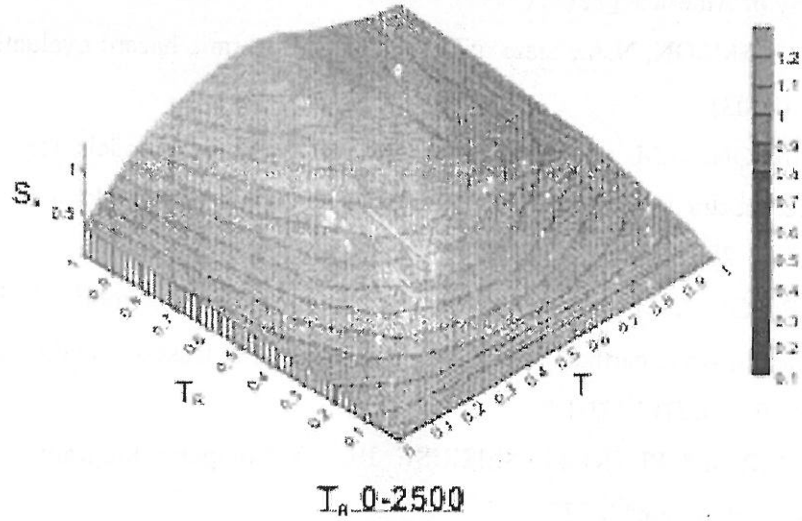


Figure 11. Uniform risk spectral acceleration as function of return period for faults.

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