Paper No. 1618. (quote when citing this article)
Eleventh World Conference on Earthquake Engineering
ISBN: 0 08 042822 3

INDONESIAN EARTHQUAKE ZONATION DEVELOPMENT

W. MERATI, A. SURAHMAN, and I. SIDI

Center for Earthquake Engineering Studies, Institute for Research, Institut Teknologi Bandung,
Jalan Ganesa 15, Bandung 40132, Republic of Indonesia

ABSTRACT

An analysis to generate a new Indonesian zoning map has been carried out. The peak ground accelerations were obtained by using attenuation formulas. Several methods have been used. The first method used the Donovan attenuation formula and a point source model. The peak ground accelerations were calculated for a return period of 200 years. The second method used the Joyner-Boore attenuation formula for earthquakes of strike slip mechanism and Crouse attenuation formula for earthquake of subduction mechanism. This method used rectangular source models. The third method used subduction zone segment models and the Crouse attenuation formula. It has been found that it is difficult to determine a single method that covers all cases of earthquake occurrences. The peak ground acceleration agreed with the Type I extreme distribution function. The most recent earthquakes agreed with the conservative iso-acceleration map.

KEYWORDS

attenuation; earthquake zone; epicenter; hypocenter; iso-acceleration; peak ground acceleration; return period

INTRODUCTION

Indonesia is one of the countries located in highly seismic area. It is surrounded by the Trans-Asian and Circum Pacific belts. In the last three years major earthquakes have occurred in Flores, Sumatra, Java, Halmahera, Irian Jaya, and Sulawesi islands causing damages and many fatalities. To avoid such casualties, all the buildings should be properly designed, namely, earthquake resistant. The basis of earthquake resistant building design consists of structural analysis, dynamic analysis and earthquake loading. Earthquake loading has been specified in the Indonesian earthquake code which divides Indonesia into several earthquake zones shown in Fig. 1.

The design of earthquake resistant buildings in Indonesia uses an earthquake zoning map produced for design purposes. The map has been initially generated from earthquake data obtained before 1962 and updated in 1987. Since then the data procurement systems have been significantly improved and more accurate empirical formulas have been introduced. The most recent earthquakes showed that there is a need for revising the existing Indonesian earthquake zoning map by using the most recent techniques.

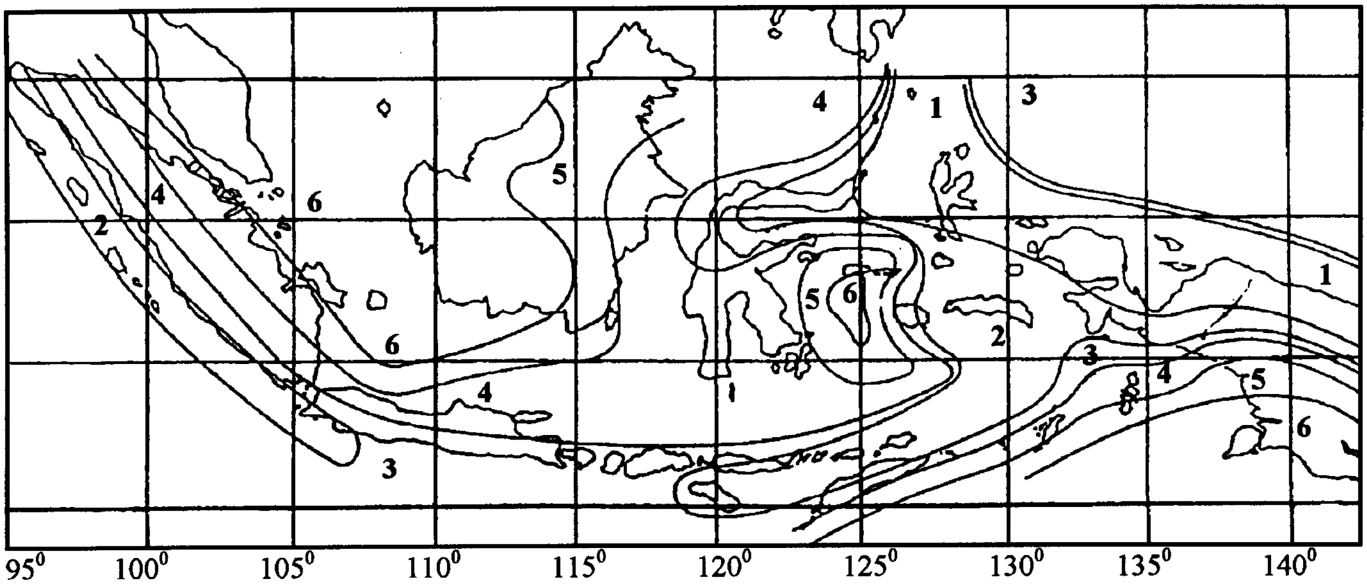

Fig. 1. Current Indonesian earthquake zoning map.

METHODOLOGY

Earthquake loading used in building design is construed as lateral loading obtained either by dynamic or static analysis. This lateral loading is proportional to the building mass and the peak ground acceleration (maximum horizontal ground acceleration). For zoning purposes, the knowledge of the peak ground acceleration at the base rock is sufficient. This ensures the uniqueness of the zoning map. The complete analysis to obtain the equivalent static earthquake loading to the building requires the response spectra calculation which depends on the structural stiffness and soil condition. This, however, can be carried out with ease, once the peak ground acceleration at the base rock is known.

From many attenuation formulas used to determine the peak ground acceleration of a point located at a certain distance from the hypocenter, the one proposed by (Donovan 1974) is still widely used by many Indonesian structural engineers (Wangsadinata 1993). The attenuation formula used was

$$a = 1080\, e^{0.5M}\, (R + 25)^{-1.32} \tag{1}$$

where
a = peak horizontal ground acceleration at the base rock [cm/s^2]
R = distance from the hypocenter [km]
M = earthquake magnitude in Richter scale

The attenuation formula used in Eq. (1) requires the data for earthquake magnitude and location. These data have been obtained from Geophysical and Meteorological bureaus throughout the country which provided data for more than 20,000 earthquakes occurred between 1970 and 1993. Before 1970 the data recording was considered to be incomplete since not all parts of the country have been covered by the recording system. The use of earlier data tends to under estimate earthquake intensities of regions not equipped with proper earthquake recording apparatus. Hence only the most recent data have been used. The data included the earthquake magnitude, epicenter location, focal depth and time of occurrence.

The attenuation formula was used for some 14,000 points defined by square grids of 0.25° size. Since the earthquake location is defined by a certain coordinate, the earthquake source used by this method was assumed to be a point source. For a given year, the peak horizontal ground acceleration at every point was calculated. Since many earthquakes may occur in the same year, for a certain site only the largest peak ground should follow the extreme distribution function. By carrying a regression analysis, it was obtained that the Type I extreme distribution function for the largest value satisfactorily fitted the generated data.

By using the data obtained between 1970 and 1993, the annual mean μ_1 and standard deviation σ_1 for peak ground acceleration at every grid point can be determined as follows:

$$\mu_1 = \frac{1}{n-1}\sum_{i=1}^{n} a_i \tag{2}$$

$$\sigma_1 = \sqrt{\left\{\sum_{i=1}^{n}\frac{(\mu_1 - a_i)^2}{(n-1)}\right\}} \tag{3}$$

where
a_i = the largest peak ground acceleration at a site for the i-th year
n = number of years considered

For practical designers, the use of probabilistic terminology is felt to be cumbersome. Despite its probabilistic nature, the structural design has been carried out deterministically. To facilitate this, the Indonesian earthquake loading code specifies the characteristic value for 200 year return period earthquake to be used as the design earthquake load for buildings with 50 year life time.

The relationship between the mean and characteristic values, is expressed by the following formulas are used:

$$\mu_1 = u_1 + 0.577/\alpha \tag{4}$$

$$\sigma_1 = \pi/2.449\alpha \tag{5}$$

where
u_1 = the annual maximum characteristic value
α = the dispersion coefficient

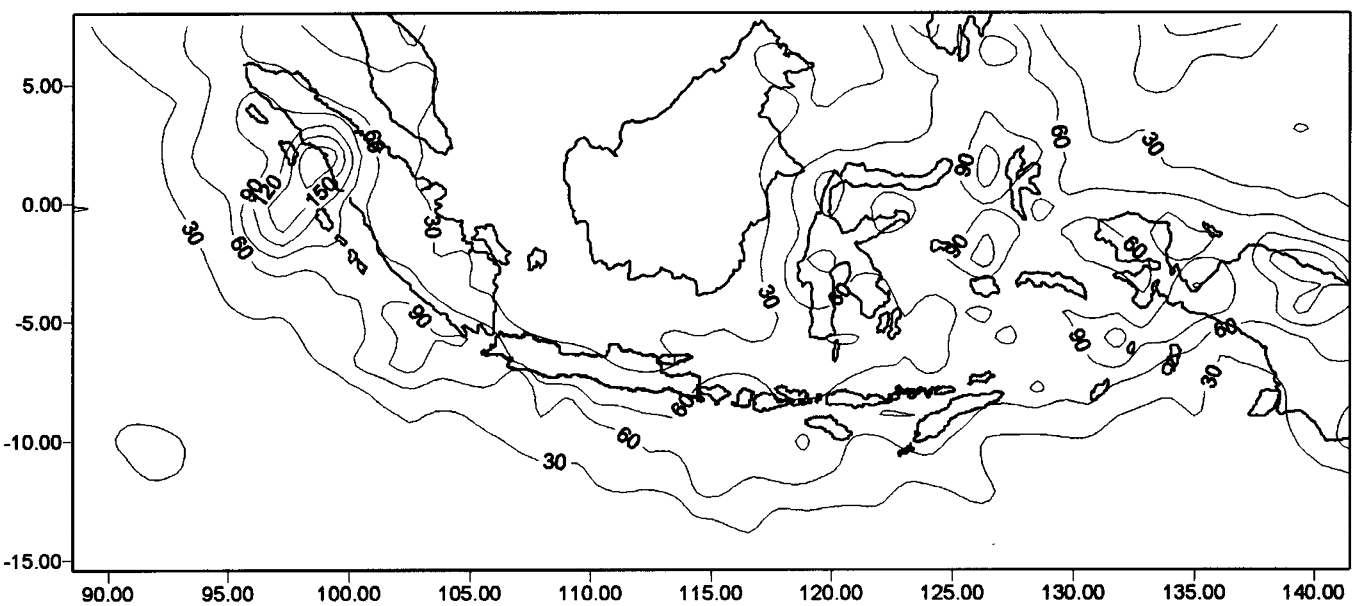

Fig. 2. Iso-acceleration map for 200 year return period (using the first method).

The cumulative distribution function for the Type I extreme distribution is expressed as

$$F_{X_1}(x) = \exp\{-\exp[-\alpha(x-u_1)]\} \tag{6}$$

To obtain the characteristic value for 200 year return period, the following formula can be used:

$$u_{200} = u_1 + [\ln(200/1)]/\alpha \tag{7}$$

By using the characteristic value for the 200 year return period, the iso-acceleration (peak ground acceleration contour) map for Indonesia has been generated as shown in Fig. 2.

ANALYSIS

As shown above, the peak ground acceleration has been obtained by using the attenuation formula proposed by Donovan seems to be very simplified to represent the complex nature of earthquake. Also, the characteristic value for 200 year return period was derived by using earthquake data from slightly more than 30 years. Before being used for design code purposes, the validity of the results has been tested by using the second and third methods.

The second method used the geological conditions as a starting point to differentiate the various locations according to their similarities such as fault type and focal depth. From these analyses, as many as 164 earthquake sources have been identified. Using the earthquake data from the year 1900 and later, the recurrent relationship using Gutenberg-Richter formula was determined:

$$\log N = A - B\,M \tag{8}$$

M = earthquake magnitude in Richter scale
N = number of earthquake occurrences with magnitude equal to M, or larger
A, B = constants

By using regression analysis from the data, the constants A and B have been found for all earthquake sources. The analysis also produced results for the maximum, minimum and average values of M for each earthquake source. The analysis to obtain the peak ground acceleration was carried out by using EQRISK program (McGuire 1976). Additional information was needed for using this program, i.e., the probability of exceedance and the attenuation formula to be used.

The probability of exceedance can be defined as the function of the return period (200 years) as follows:

$$1/T = 1 - \exp(-P) \tag{9}$$

where
P = probability of exceedance
T = return period (taken as 200 years)

The second method suggested that two different attenuation formulas can be used depending on the earthquake mechanism. The first is by Joyner and Boore (1988) which suggested an attenuation formula best fitting earthquakes due to strike fault mechanism such as Sumatra, Maluku (including Halmahera), and Irian Jaya islands.

$$\log(a) = 0.43 + 0.23\,(M-6) - \log(R) - 0.0027\,R + 0.28 \tag{10}$$

The second attenuation formula best fits earthquakes due to subduction mechanism. This can be used to predict the peak accelerations for Java, Nusa Tenggara (including Flores), Kalimantan, and Sulawesi islands. This formula was proposed by Crouse (1994).

$$\ln (a) = 6.36 + 1.76 M - 2.73 \ln [R + 1.58 \exp (0.608 M)] + 0.0091 H \tag{11}$$

where
H = focal depth [km]

The attenuation formulas were applied on sites located at grids of 0.5° size, assuming the earthquake source to be rectangular (Irsyam, 1996). The peak ground acceleration derived by using this method is shown in Fig. 3.

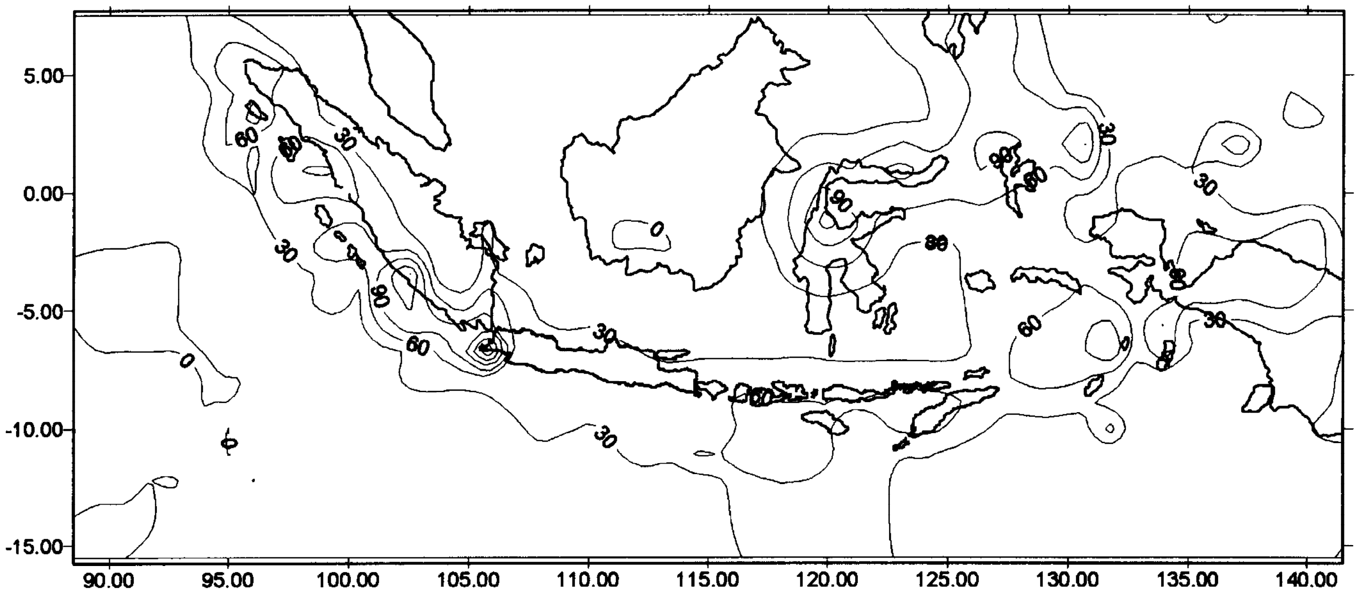

Fig. 3. Iso-acceleration map using the second method

The third method used Eq. (11) and assumed that most earthquakes in Indonesia occurred due to subduction mechanisms. This involved analysis to determine the widths and lengths of subduction zones. This attenuation formula was applied to sites located on grids of 1° size (Puspito, *et. al.*, 1994).

By using Kanamori (1986) equation, the maximum probable earthquake magnitude M can be found.

$$M = \log (A) + 4 \tag{12}$$

where
A = the area of the subduction zone

By setting the annual occurrence of 10^{-5} and using consecutively Eqs. (6) and (7), the peak ground acceleration for the 200 year return period was found. The results obtained by this method, is shown in Fig. 4.

From the analyses described above, it can be found that it is difficult to determine which one of the method used can be considered as the best. For evaluation purposes, before converting into official zonation map, the three maps produced are combined in two different ways. The first is by taking the average from 3 maps which is shown in Fig. 5.

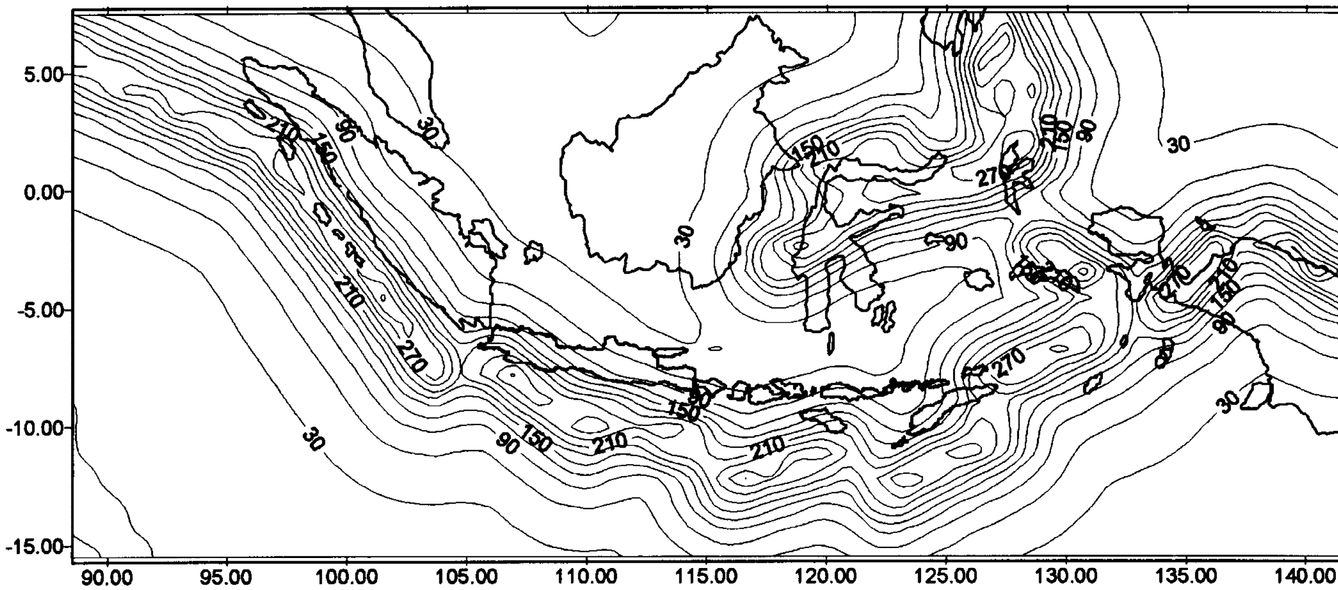

Fig. 4. Iso-acceleration map using third method

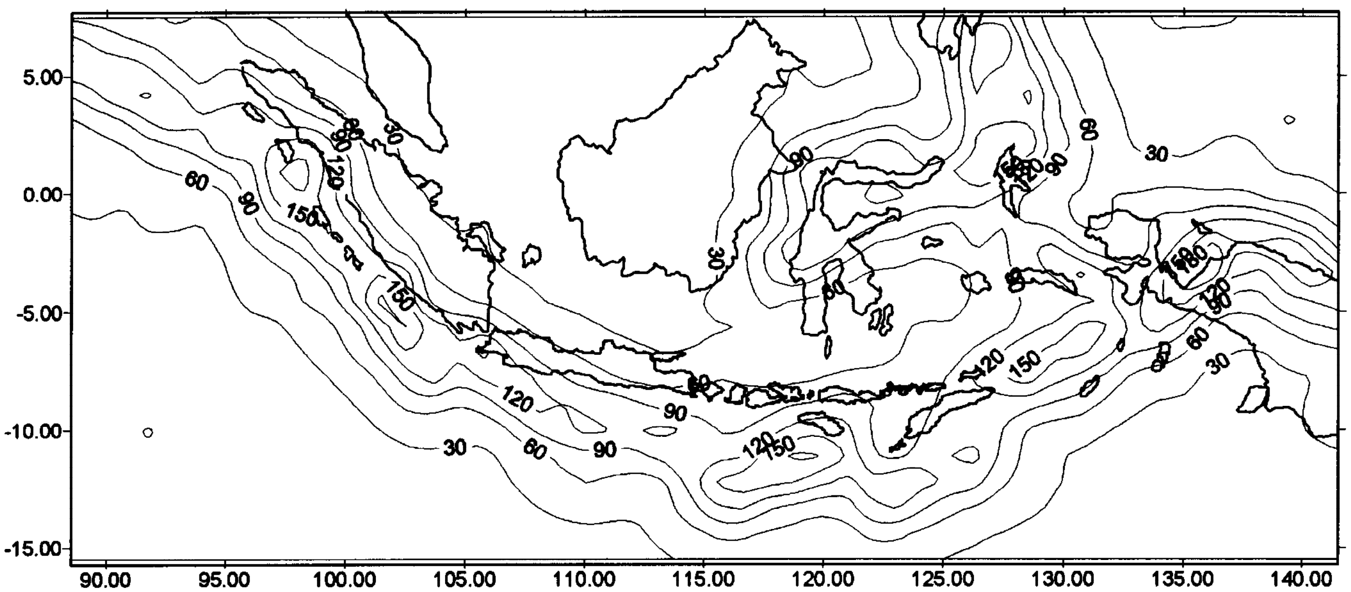

Fig. 5. Iso-acceleration map obtained by taking average from the three different methods.

The second way of combining the results from three different methods is by taking the largest from the three methods, which is shown in Fig. 6.

Table 1. Estimated peak ground acceleration for each earthquake zone

Zone	Estimated peak ground acceleration (cm/s^2)
1	144
2	112
3	80
4	48
5	16
6	0

Table 1 shows the estimated peak ground acceleration for each earthquake zone shown in Fig. 1. Comparing the peak ground acceleration values with the results shown in Figs. 2 to 6, the differences are quite significant.

Several studies have been conducted to evaluate most recent earthquakes in the country. One of them was conducted by (Merati, *et. al.*, 1994) who analyzed the actual peak ground acceleration at the site. Table 2 shows some recent earthquakes with peak ground accelerations calculated by the Donovan, Joyner-Boore, and Crouse attenuation formulas and compared against existing zonation map and one of the maps to be proposed for the basis of earthquake zonation. In this case the most conservative map (Fig. 6) is taken.

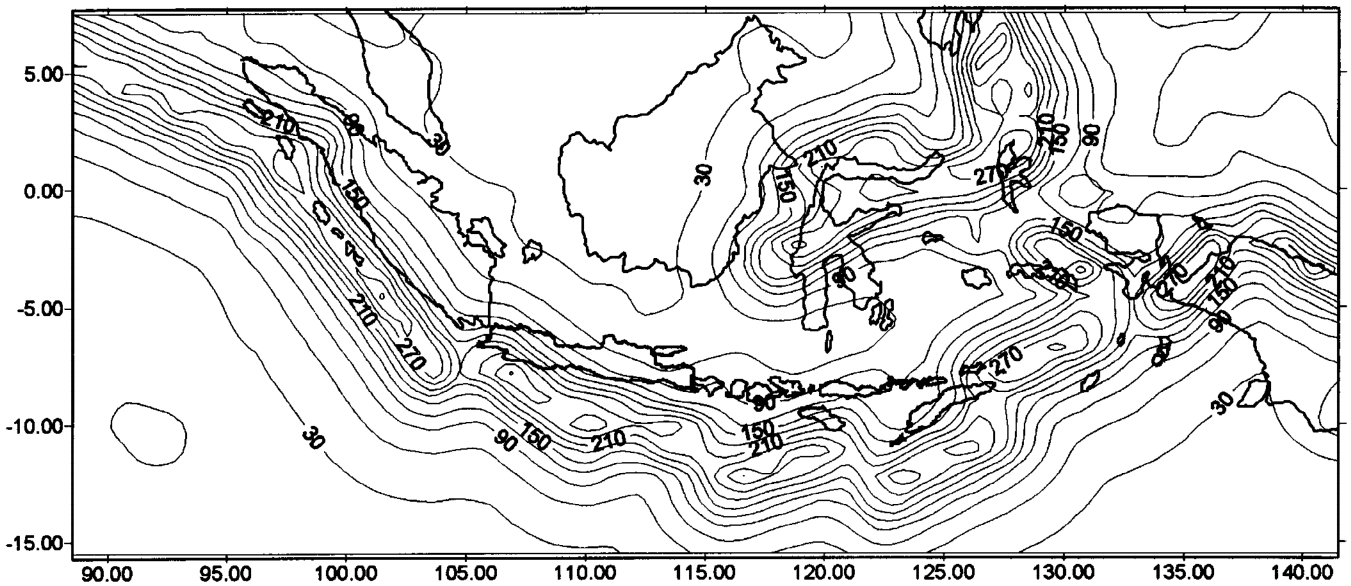

Fig. 6. Iso-acceleration map by taking the largest from the three different results.

Table 2. Peak ground acceleration estimates

Location	Year	Attenuation equations [cm/s^2]			Iso-acceleration map [cm/s^2]	
		Donovan	Joyner-Boore	Crouse	Fig. 1	Fig. 6
Jambi	1995	168	247	222	80	120
Liwa	1994	112	163	142	80	120
Banyuwangi	1994	97	139	116	80	90
Flores	1992	202	295	272	112	120
Tarutung	1987	109	161	132	80	180
Denpasar	1976	112	163	142	80	90

The results show that despite being conservative, the map shown in Fig. 6 provides peak ground accelerations in good agreement with those calculated by the attenuation formulas. For structural design purposes, this should be acceptable.

CONCLUSIONS

From the analysis using several methods to generate an iso-acceleration map for earthquake zonation in Indonesia, it has been found that due to the use of approximative formulas and complexity of the calculation procedures, it is difficult to determine a single method that covers all aspects of earthquake occurrences. The peak ground acceleration agreed with the Type I extreme distribution function. Considering the latest earthquake occurrences, a conservative iso-acceleration map can be used as the basis for the Indonesian earthquake zonation.

ACKNOWLEDGMENTS

The authors would like to express their gratitude to Drs. N.T. Puspito and M. Irsyam for providing two of the three methods described in this paper. Their contributions have been properly incorporated to produce the resulting iso-acceleration maps.

REFERENCES

Crouse, C. B. (1991). Ground-Motion Attenuation Equations for Earthquakes on the Cascadia Subduction Zone. *Earthquake Spectra*, **7**, No. 2, 201-235.

Donovan, N. C. (1974). A Statistical Evaluation of Strong Motion Data Including the February 9, 1971 San Fernando Earthquake. *The Fifth World Conference on Earthquake Engineering*, Rome, Proceedings, **1**, 1252-1261.

Idriss, I. M. (1985). Evaluating Seismic Risk in Engineering Practice. *XI International Conference on Soil Mechanics and Foundation Engineering*, San Francisco, August, Proceedings, 265-320.

Irsyam M., et. al. (1995). Indonesian Earthquake Zonation Based on Latest Attenuation Functions (in Indonesian). Center for Earthquake Engineering Studies, Institute for Research - Institut Teknologi Bandung, *Draft Report*.

Kanamori, H. (1986). Rupture Process in Great Earthquakes. *Journal of Geophysical Research*, **82**, 2981-2987.

Merati, W., Irsyam, M., Sengara, I. W., and Surahman, A. (1994). Lessons learned from the 1992 earthquake in Flores island. *The Second International Conference on Earthquake Resistant Construction and Design*, Berlin, **2**, 1091-1098.

McGuire, R. K. (1976). *EQRISK, Evaluation of Site for Earthquake Risk*. NISEE.

Puspito, N. T., Ibrahim, G., Triyoso, W., Ahmad, M., and Hendrawan, R. (1994). Indonesian Archipelago Seismicity (in Indonesian). Department of Education. *Open grant research*. Interim Report.

Wangsadinata, W. (1993). Earthquake Risks in Indonesia (in Indonesian). *Seminar on Civil Engineering Aspects and Related Disciplines in Earthquake Mitigation in Indonesia*, Bandung.