Hazard Consistent Strong Motion Simulation for Philippine Major Cities

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1. Introduction

Philippines is located in one of the most seismically active region in Asia. In this decade alone, more than 8 earthquakes with magnitudes Ms≧6.9 have occurred in different parts of the country. Many seismic hazard studies for Philippines in the past showed the expected ground motion parameters such as peak ground acceleration (PGA) but other characteristics of expected earthquake such as the expected magnitude and distances were not studied. In this paper probabilistic seismic hazard analysis for the major cities of the country was conducted based on historical earthquake since 1907. Hazard consistent magnitudes and epicentral distances due to source zone with highest hazard contribution are determined and based on these parameters, strong motion is simulated for the three major cities of the country.

2. Hazard consistent ground motion parameters[1].

The annual probability that the random earthquake intensity Γ at a specific site will exceed a value γ due to source k using Poisson model can be represented by $p_{0k} = 1-\exp\{-\nu_k q_k(\gamma)\} \cong \nu_k q_k(\gamma)$ where: ν_k = earthquake occurrence rate in the source k with upper and lower bound magnitudes m_{uk} and m_{lk} and $q_k(\gamma)$ represents the probability $\Gamma > \gamma$ given that an earthquake occurs in source k. Let x represent any parameter of interest. Assume that x can be a function of earthquake magnitude m and distance r, *i.e.* $x = \phi(m,r)$, the conditional mean of x, given that $\Gamma > \gamma_0(p_0)$ is

$$\bar{x}_k(p_0) = \frac{\int_M \int_R \phi(m,r) P(\Gamma > \gamma_0(p_0)) f_{Mk}(m) f_{Rk}(r) \mathrm{d}r \mathrm{d}m}{\int_M \int_R P(\Gamma > \gamma_0(p_0)) f_{Mk}(m) f_{Rk}(r) \mathrm{d}r \mathrm{d}m}$$

where: $f_{Mk}(m)$ = probability density function of magnitude m in source k, $f_{Rk}(r)$ probability density function of distance. The conditional mean of the magnitude $\overline{m}(p_0)$ and that of the distance $\bar{r}(p_0)$ obtained from equation by replacing x by m or r, are called the hazard consistent magnitude and distance respectively

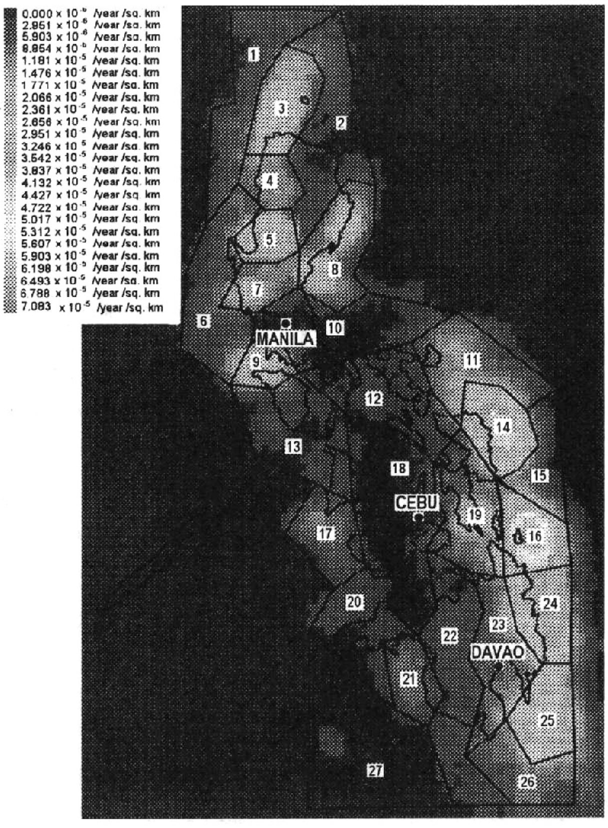

Figure 1 Occurrence rates and seismic zoning

3. Hazard analysis of Philippine major cities

Seismic hazard analysis is sensitive to the seismic source zones used therefore seismic source zoning for the country was carefully done. The seismic source zoning of the country was determined on the basis of occurrence rate of earthquakes with Ms≧5.0. For the identification of seismic source zones, the occurrence rates of Ms≧5.0 for all the areas of the country are obtained using spatial moving average method. Adjacent areas with nearly uniform occurrence rate per square kilometer are designated as a single seismic source zone. The occurrence rates of earthquakes Ms ≧5.0 for all the areas and the designated seismic source zones are shown in ***Figure 1***. A polygonal source area model is used to represent the seismic source zones. The source area model used in the analysis can represent complicated shapes of faults and plate boundaries. Probabilistic seismic hazard analysis was done for the three major cities of the country, i.e., Manila, Cebu and Davao. The estimation formulas for peak ground acceleration (*PGA*) used for the scaling of JMA seismic intensity are developed on the basis of the 118 components of strong ground motion database on engineering foundation level in Japan. Hazard curves for the three cities assuming 0.10 coefficient of variation for attenuation relation is shown in ***Figure 2***. Hazard consistent PGA corresponding to an annual probability of 0.002 is illustrated. From the given figure, hazard consistent peak ground accelerations (PGA) for the three cities can be determined. It was found out that at annual probability equal to 0.002, the contribution of zone 10 to the hazard of Manila is 99.5%, for zone 18 to the hazard of Cebu is 92% and for zone 23 to the

Table 1 Source zone Properties

zone	occurrence rate per sq km per year	b value	max. Magnitude	area square km
10	6.37E-06	0.5976	7.6	52,699
18	6.28E-06	1.32985	6.7	75,851
23	3.46E-05	1.42909	7.4	38,975

hazard of Davao is 99.2% of the total hazard. The properties of these zones are given in ***Table 1***. Based on the theory discussed in section 2, the hazard consistent magnitudes and epicentral distances expected in 500 years (*i.e. P=0.002*) due to these zones are determined and listed in ***Table 2***. The locations of cities indicated in ***Table 2*** could be understood as the center of the city. On the basis of these hazard consistent magnitude and hypocenter, the acceleration time histories were simulated using non-stationary strong motion prediction model[2]. This evolutionary process prediction model is developed on the basis of rock surface strong motion data set consisting of 118 components of major Japanese accelerograms. In the model used, simulation parameters are magnitude and hypo-central distance. Simulated earthquake ground motions are shown in ***Figure 3***. Depths of simulated earthquakes were assumed to be 16 kilometers. Results shows that Manila has a much higher expected magnitude in 500 years (i.e., 6.7) as compared to Cebu (i.e., 5.6) and Davao (i.e., 5.8). This could be attributed to the properties of the zones in which these cities are located. Manila has a much bigger hazard consistent magnitude than Cebu and Davao since the **b** value in zone 10 is much smaller than in zones 18 and 23. Therefore higher magnitude earthquake has higher probability of occurrence in zone 10 than in zone 18 and 23. However, **b** value is not the only factor here. If we look at zones 18 and 23, the former has a slightly lower **b** value but Cebu has lower expected magnitude when compared to Davao. This is because the maximum magnitude at zone 18 is only 6.7 whereas in zone 23, the maximum is 7.4. This is the reason why Davao has a higher expected magnitude than Cebu. The hazard curves in ***Figure 1*** showed that in 500 years, the expected PGA for Manila, Cebu and Davao are 287 gal, 201 gal and 132 gal respectively. It could be noted that although Cebu and Davao have much closer expected magnitudes compared to Manila but the hazard consistent PGA does not show this relation. This is because zone 18 has a low occurrence rate compared to zone 23. This shows that occurrence rate is a major contributing factor of hazard analysis. Our method of zoning based on occurrence rates is justified. From the simulated earthquake motion shown in ***Figure 3***, the results showed that characteristic earthquake in 500 years for Manila, Cebu and Davao will have PGA's of 320.8 gal, 98.0 gal and 132.3 gal respectively.

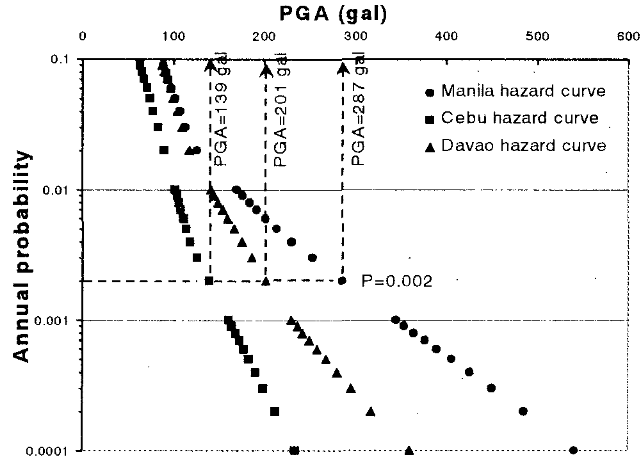

Figure 2 Hazard curves

Table 2 Hazard consistent magnitude and distance

city	longitude	latitude	magnitude (Ms)	distance
Manila	121° E	14.58° N	6.7	16.7
Cebu	123.9° E	10.30° N	5.6	11.2
Davao	125.6° E	7.10° N	5.8	8.7

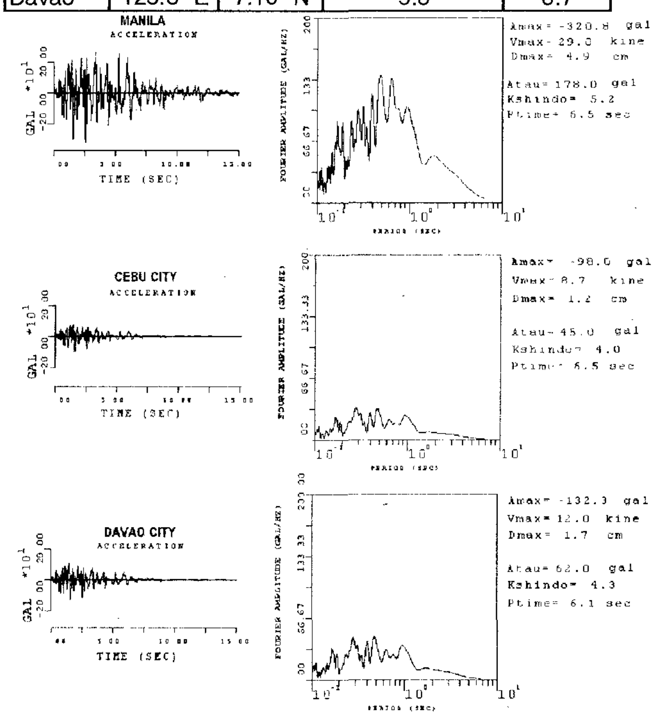

Figure 3 Simulated earthquake motion

4. Conclusion

The study was focused on the major cities of the country since these cities are expected to have a major damage relative to other places when earthquake occurs. For the three cities, the zones that have the greatest hazard contributions are the zones wherein the cities are located. This is because large accelerations can be found nearer to the source. Seismic source zoning method based on occurrence rates is presented and justified. This study does not include other potential hazard contributor such as fault systems. Future works incorporating the effects of faults is of greater interest.

References

1) Kameda H. and Nojima N. (1988), "Simulation of risk consistent earthquake motion," *Earthquake Eng. and Structural Dynamics* Vol. 16, pp.1007-1019.

2) Sugito M., Furumoto Y., and Sugiyama T. (2000), "Strong motion prediction on rock surface by superimposed evolutionary spectra", *12th World Conference on Earthquake Engineering*, Auckland, New Zealand, Jan. 2000.