SEISMIC AND TSUNAMIC RISK IN THE PHILIPPINES

HEMENDRA K. ACHARYA[I]

SUMMARY

A quantitative analysis of seismic threat on rock or firm ground has been carried out at a grid of sites in the Philippines. At all sites, annual risk was computed, based on historical seismicity, tectonics and all other known seismological and geological characteristics, together with conservative assessment of poorly defined parameters. The analysis shows that the coastal areas of southern Philippines are most susceptible to large earthquake and tsunami related damage.

INTRODUCTION

The Philippine Islands, because of its complex tectonic setting, experience frequent destructive earthquakes. Large earthquakes (Mag $>$ 7.0) occur almost once every year and cause loss of life and property. Therefore, annual risk - defined as the probability that in one year a particular specified ground motion will be equalled or exceed, has been computed at a grid of sites in the Philippines. To estimate the annual risk, the seismicity and other characteristics of past earthquakes have been examined and used to develop probabilistic predictions about future events. This prediction requires the integration of relative frequencies of (future) possible times, locations and sizes of important earthquakes and consideration of ground motion attenuation. The output of seismic risk analysis is a plot of annual risk versus ground motion at the site.

The aim of probabilistic seismic risk analysis is to estimate the likelihood that any specified level of ground motion intensity will be equalled or exceeded in an arbitrary future time period. The analytical methods used to carry out this analysis have been developed by Cornell (1968, 1971) and Merz and Cornell (1973) and applied recently by Algermissen and Perkins (1976). A computer program, developed by McGuire (1976) was used to determine earthquake associated risk at the specified grid of sites in the Philippines.

EARTHQUAKE DATA

As a result of recent studies (Acharya and Aggarwal, 1980; Seno and Kurita, 1978) we now know that the Philippine Islands are a tectonic bloc surrounded by active trench systems. In the east, the Philippine Sea Plate underthrusts along the Philippine Trench and localized subduction occurs along Benham Rise. In the west, several disjointed trench systems are locations of eastward underthrusting of Eurasian Plate. The Philippine Fault is a major left lateral strike slip fault, which extends through the entire archipelago. Large earthquakes have occurred along this fault in historic time (Rowlett and Kelleher, 1976). Acharya (1980) has shown that seismic slip on the Philippine Fault is comparable to slip along trenches east and west of it, suggesting thereby that motion on the Philippine Fault accomodates motions between Philippine and Eurasian Plates. Fig. 1 shows these principal tectonic elements, which are responsible for most of large earthquakes occurring in and near Philippines. Fig. 1 also shows active faults delineated by the Philippine Bureau of Mines and by Acharya et.al (1979). All of these active features are considered as earthquake sources.

[I]Consultant, Geotechnical Division, Stone & Webster Engineering Corporation, Boston, Massachusetts, U.S.A.

A maximum magnitude level is assigned to each source by considering the maximum possible linear dimension of each fault and utilizing the rupture length - magnitude relationship developed by Acharya (1978) for the Philippines. However, following Algermissen and Perkins (1976) the largest known earthquake on each source was also alternatively specified as the maximum magnitude earthquake for that source. This facilitated an examination of the sensitivity of risk to this parameter.

The Hypocenter Data File prepared by NOAA for the period 1900-1976 was examined for completeness of data for the Philippines by Stepp's (1972) method. The NOAA catalog was found to be complete for earthquakes with magnitude $>$ 4.5 during 1964-1976. Therefore the NOAA catalog during this period was used to determine the magnitude frequency relationship ($b = 0.90$) and activity rates for all earthquake sources. The focal depth of earthquakes on all sources was assumed to be 25km. As there are no strong motion data available for the Philippines, no specific attenuation relationship is known. Acharya (1978) examined isoseismal maps of large historic earthquakes in the Philippines, developed an intensity attenuation relationship and noted that ground motion attenuation in Philippines closely approximates attenuation characteristics of most of western United States. Therefore McGuire's relationship for western United States

$$a = 472 \times 10^{0.28M} (R+25)^{-1.3}$$

was used. In this equation "a" is the peak acceleration (gals), "R" is hypocentral distance (km) and M is earthquake magnitude. In the absence of strong motion data, it is necessary to include the standard deviation value to offset any uncertainty. Sites (55km apart) were selected on a rectangular grid to construct a comprehensive seismic risk map of the archipelago.

RESULTS

Ground motion values, for each site, with a 10% probability of exceedance during a 50 year period, were computed following Algermissen and Perkins (1976). These values were contoured and the results are shown in Fig. 2. Fig. 2 shows that maximum risk in the Philippine Islands exists on the eastern and western coastal areas in the south. In these areas, there is a 10% probability of exceeding 0.25-0.3g during a 50 year period. High risk in these areas exists primarily due to underthrusting on both sides. High risk also exists along the coast of eastern Luzon. The risk is not as high along western Luzon and is a reflection of lower frequency of large earthquakes along the Manila Trench. A similar explanation suffices for the somewhat lower risk along the Philippine Fault. Seismic risk is very low in south central Philippines. The annual risk computed at a site depends strongly on the parameters of attenuation relationship. It was noted that, if for example, the standard deviation is neglected, the annual risk decreases by an order of magnitude. Similarly the maximum magnitude earthquake specified for each source affects the results considerably. If one specifies maximum magnitude based on historical data, the risk decreases by almost half an order of magnitude, as compared to risk computed using maximum magnitudes esimated by magnitude rupture length relationship of Acharya (1978). This is at variance with Gupta and Tilford (1978) who noted that in central Luzon the results of seismic risk analysis are not sensitive to maximum magnitude. Depth of focus estimates also affect the results considerably. Annual risk at a site computed using a 10-15km depth was almost 2-3 times the case when a 25-30km depth was specified. This observation is also at variance with that of Gupta and Tilford (1978) for central Luzon.

Numerous studies have shown that tsunamis are generated by earthquakes associated with underthrusting. Therefore, it stands to reason that in coastal areas of southern Philippines, there will be a significant risk of tsunami damage. Similarly high potential for damage from tsunamis exists on the eastern coast of northern Luzon. This is also borne out by historical data (Berninghausen, 1969).

REFERENCES

Acharya, H.K., 1978, Magnitude - Rupture Length Relationship in the Philippines, Earthquake Notes, Vol. 49, pp. 81.

Acharya, H.K., 1978, Ground Motion Attenuation in the Philippines, Proceedings Second Int. Conf. Microzonation for Safer Construction, Vol. 1, pp. 379-390.

Acharya, H.K., Ferguson, J.F., and Isaac, V., 1979, Microearthquake Surveys in the Central and Northern Philippines, Bull. Seis. Soc. Am., Vol. 69, pp. 1889-1902.

Acharya, H.K., 1980, Seismic Slip on the Philippine Fault and its Tectonic Implications, Geology, Vol. 8, pp.

Acharya, H.K., and Aggarwal, Y., 1980, Seismicity and Tectonics of the Philippines, (submitted for publication)

Algermissen, S.T., and Perkins, D.M., 1976, A Probabilistic Estimate of Maximum Acceleration in Rock in the Contiguous United States: U.S. Geol. Surv. Open File Report, 76-416, 45 pp.

Berninghausen, W.H., 1969, Tsunamis and Seismic Seiches of Southeast Asia, Bull. Seis. Soc. Am., Vol. 59, pp. 289-298.

Cornell, C.A., 1968, Engineering Seismic Risk Analysis, Bull. Seis. Soc. Am., Vol. 58, pp. 1583-1601.

Cornell, C.A., 1971, Probabilistic Analysis of Damage to Structures Under Seismic Loads, in Howell, D.A., Haigh, I.P., and Taylor, C., eds., Dynamic Waves in Civil Engineering, London, Interscience, pp. 473-488.

Gupta, I.N., and Tilford, N.R., 1978, Seismic Risk Study for a Nuclear Power Plant Site in the Philippines, Earthquake Notes, Vol. 49, pp. 14.

McGuire, R.K., 1974, Seismic Structural Response Risk Analysis, Incorporating Peak Response Regressions on Earthquake Magnitude and Distance: M.I.T., Dept. of Civil Eng., Research Rept. R74-51, 371 pp.

McGuire, R.K., 1976, FORTRAN Computer Program for Seismic Risk Analysis, U.S. Geol. Survey Open File Rept. 76-67, 90 pp.

Merz, H.A., and Cornell, C.A., 1973, Seismic Risk Analysis Based on a Quadratic Magnitude Frequency Law, Bull. Seis. Soc. Am., Vol. 63, pp. 1999-2006.

Rowlett, H., and Kelleher, J.A., 1976, Evolving Seismic and Tectonic Patterns along the Western Margin of the Philippine Sea Plate, J. Geophys. Res., Vol. 81, pp. 3518-3524.

Seno, T., and Kurita, K., 1978, Focal Mechanism and Tectonics in the Taiwan - Philippine Region, J. Phys. Earth. Suppl., S249-S263.

Stepp, J.C., 1972, Analysis of the Completeness of the Earthquake Sample in the Puget Sound Area and its Effects on Statistical Estimates of Earthquake Hazard, in Proceedings of the Int. Conf. Microzonation for Safer Construction, Seattle, Washington, Vol. 2, pp. 897-909.

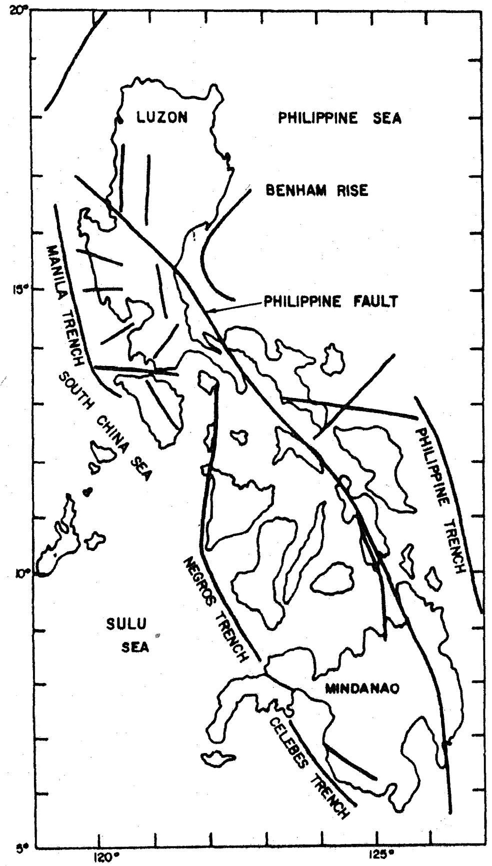

FIGURE 1 - TECTONIC ELEMENTS AND EARTHQUAKE SOURCES IN AND NEAR THE PHILIPPINE ISLANDS

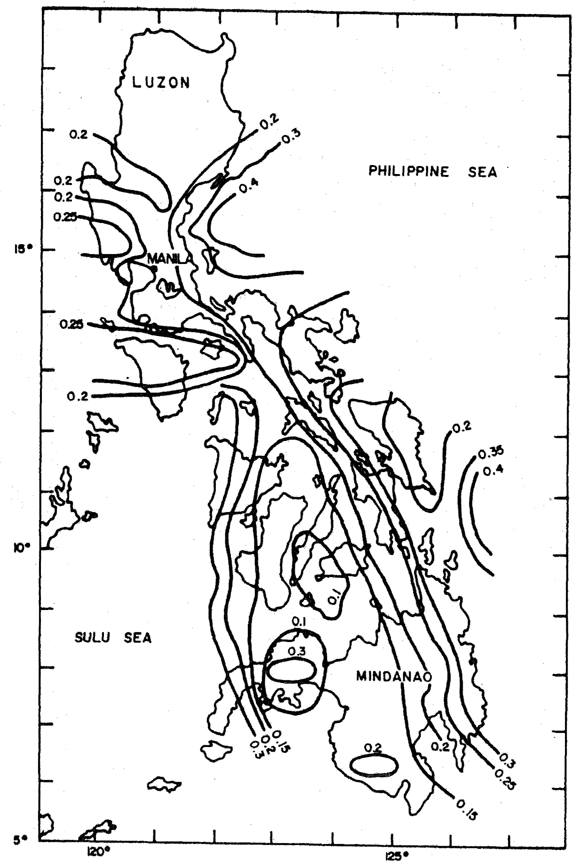

FIGURE 2 - SEISMIC RISK IN THE PHILIPPINES. CONTOURS REPRESENT PEAK ACCELERATION VALUES FOR WHICH THERE IS A 10% PROBABILITY OF EXCEEDANCE IN 50 YEARS.