Seismic Hazard Analysis in Taiwan: Uniform Risk Response Spectra

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ABSTRACT

This paper presents the method for conducting a seismic hazard analysis of two nuclear power plant sites in Taiwan using fault-rupture model. First, based on a peak ground acceleration attenuation formula, the annual probability of exceedance at these specific sites was calculated. Second, based on spectral amplitude attenuation formula, the uniform risk response spectra were developed. These spectra based on constant hazard are considered superior to these developed by anchoring a fixed site-dependent spectral shape to a probabilistic estimate of peak ground acceleration. Finally the stochastic characterization of earthquake from response spectrum was discussed.

1. INTRODUCTION

Taiwan is a member of the Ryukyu-Philippine island arc chain which rims the western border of the Pacific Ocean. The area has frequently suffered severe damage from destructive earthquake throughout her historic line. To establish the seismic design criteria for major projects (such as nuclear power plant), it is important that full use be made of all pertinent historical evidence of seismic activity in Taiwan area and corrected these information with regional tectonics, geology factors, and soil conditions. For the reasons above, it is proposed to establish seismic design criteria for large important structures in Taiwan (in this study nuclear power plant of site A and site B are discussed). Figure 1 shows the location of two sites and the seismicity of Taiwan area.

The principal objective of this study is to estimate the likelihood the different levels of response spectra will be experienced at a specific site. To achieve such purpose, seismic risk analysis must be performed. A seismic risk analysis integrates the contributions of all possible earthquakes and calculates the probability that selected ground motion parameters will be exceeded within the specified exposure time. Based on the proposed peak ground acceleration attenuation model, the result of an seismic risk analysis for an individual site is displayed as a seismic risk curve — a plot of annual probability of exceedance versus a specified ground motion parameters. Since the attenuation curves can


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be defined for spectral amplitude at different period (either spectral acceleration, spectral velocity or spectral displacement), the seismic risk curves can be developed for spectral amplitude with specified annual probability of exceedance, the spectral shape to represent the ground motion can be constructed — uniform risk response spectrum. These spectra based on uniform risk are generally considered superior to those developed by anchoring a fixed spectral shape to a probabilistic estimate of peak ground acceleration.

2. UNIFORM RISK RESPONSE SPECTRUM

2.1 Spectral Amplitude Attenuation Formula

Strong motion data are available not only as time series, but also as response spectra. As a result, regression analysis have also been carried out on spectral amplitudes in order to determine the effects of magnitude, distance, and site conditions on the amplitude and shape of these spectra. A regression model of the spectrum $S(f)$ is expressed in terms of the above-mentioned seismic parameters and their associated coefficients. The ground motion model used in this study was shown as follow:

$$ S(f) = b_1(f) e^{b_2(f) M} [R + b_3(f) e^{b_4(f) M}]^{-b_5(f)} $$

where $b_1$, $b_2$, $b_3$, and $b_4$ are frequency dependent coefficients; $M$ and $R$ are, respectively, the magnitude and hypocentral distance (km). This expression has been used to represent the spectral amplitude of acceleration, velocity, and displacement. The spectral amplitude was calculated from data recorded on hard site with structural damping of 5% critical. Different functional forms may be selected in the characterization of ground motion attenuation. The spectral amplitude at twelve discrete frequencies were calculated (i.e., 0.1 Hz, 0.2 Hz, 0.8 Hz, 1.0 Hz, 2.0 Hz, 5.0 Hz, 7.0 Hz, 10 Hz, 20 Hz, 25 Hz, 34 Hz) for damping ratio of 5%. In the final regression analyses, carried out to establish the attenuation equations for each discrete frequency, only the time history with the longer of the two horizontal peak acceleration values as well as the vertical component for hard sites have been used [Loh, 1990]. Coefficients for the median attenuation equations were determined through non-linear regressional analyses and coefficients of variation ($\sigma_{1n,y}$) were obtained by the relation

$$ \sigma_{1n,y} = \frac{\sigma_{1n,y}}{\mu_{1n,y}} $$

in which $\sigma_{1n,y}$ is the root mean square value and $\mu_{1n,y}$ is the mean value.

2.2 Uniform Risk Response Spectrum (URRS)

A seismic risk analysis was conducted with the same procedures as in generally seismic risk analysis for site A and site B. The annual probability of exceedance for each frequency was calculated based on spectral amplitude attenuation formulae. Procedures for developing the hazard curves as well as the uniform risk response spectrum for these two sites are shown as follows:

Site A: The seismic hazard analysis of this site had been performed on 1987. It
included the following study:

a. Seismic source zones surrounding the site were identified.

b. The parameters for seismic hazard analysis were calculated. It included the $b$-value, upper bound magnitude, occurrence rate, and source model in each zone.

c. The final hazard curve for site A was determined as the annual probability of exceedance for each ground intensity.

The result of SHA of site A was shown on the reference (IES 1987).

In developing the uniform risk response spectrum, three ranges of structural period must be identified. In the range of short period, the uniform risk response spectrum developed by using spectral acceleration attenuation formula has more meaningful than using different types of attenuation formula. In the range of long period, the uniform risk response spectrum developed by using spectral displacement attenuation formula has more meaningful than others. Based on this idea, each range of structural period must use different section of uniform risk response spectrum developed by three different spectral amplitude attenuation forms. Since the safe shut down earthquake (SSE) for that site is 0.4 $g$, it is easy to evaluate the probability of exceedance from the result of SHA. The annual probability of exceedance for the SSE level is $5.688 \times 10^{-4}$, as shown in Figure 2. Based on this result by picking the amplitude at each frequency that has $5.688 \times 10^{-4}$ probability per year of being exceeded, the spectral shape to represent the uniform risk can be constructed.

Figure 3 shows the uniform risk response spectra of site A. Four curves are shown in this figure. In the long period range, the URRS was determined based on $S_a$ attenuation form (curve $EF$), in the short period range, the URRS was determined based on $S_a$ attenuation form (curve $AB$), in between the URRS was calculated based on $S_a$ attenuation form (curve $CD$). The final uniform risk response spectrum was determined by identifying the two discrete frequency, $t_1 = 0.2$ sec and $t_2 = 5.0$ sec, and draw the uniform risk response spectrum follow the procedure mentioned above. The final design spectra can be developed in accordance with the above mentioned criteria. The vertical uniform risk design spectra was shown in Fig 4.

Site B: The same procedures were followed for the uniform risk analysis of the site A. From previous study the seismic hazard curve for site B, had been studied. Figure 2 also shows the hazard curve at this site. Based on the experience we choose the value $5.0 \times 10^{-4}$ annual probability of exceedance as the design value. The corresponding peak ground acceleration for this value is about 0.53 $g$. Figure 5 shows the spectral shape of this site based on Campbell's spectral amplitude attenuation forms. The design spectrum based on the uniform risk spectrum of that site is shown on Figure 5. The vertical uniform risk response spectrum is also shown on Figure 6. The design spectra are shown on these figures in dark piece-wise linear curves.

3. STOCHASTIC CHARACTERIZATION OF EARTHQUAKES FROM RESPONSE SPECTRUM

In addition to the development of seismic hazard curves, site-dependent spectrum and uniform risk response spectrum, the acceleration time histories compatible with the
mean-plus-one-standard-deviation design spectrum of 5% damping ratio must also be generated. It must satisfy the response spectra enveloping requirement. According to the recommendation on minimum power spectral density functions (PSDF) compatible with NRC regulatory guide 1.60 response spectrum, the generated time history can be justified by demonstrating sufficient energy at the frequencies of interest through the generation of PSDF which is greater than some specified values throughout the frequency range of significance.

Based on the previous analysis on the development of design spectrum, the target PSDF can be generated through the following equation [Kaul, 1978]:

\[ f(\omega) = \frac{2\xi}{\pi\omega} R^2(\omega) \left\{ -2 \ln \left[ \frac{-\pi}{\omega T} \ln(1 - r) \right] \right\} \]

in which \( R(\omega) \) is the response spectrum, and \( r \) is the probability of exceedance, \( T \) is the duration. Figure 7 shows the derived acceleration response spectrum. The PSDF of spectrum compatible time history was also plotted on Figure 7. Generally, the ground motion time histories which produce a response spectrum that closely fits the design response spectrum should be able to pass the PSD requirement. In this study, the PSDF was generated by the assumption of stationary random process still can meet the requirement.

4. CONCLUSION

The purpose of this study is to develop the uniform risk response spectrum of two specific sites in Taiwan area. Combine the seismic hazard curves and the uniform risk response spectrum, the effect of seismicity on the response of specific site can be studied. To meet the requirement on minimum power spectral density functions with response spectrum, the stochastic characterization of earthquakes from response spectrum was adopted which provided a method for the check the requirement on PSDF.

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6. REFERENCES

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Fig. 1: Epicenter of earthquakes (1998-1989) with magnitude greater than 4.5, and the locations of site A & B.

Fig. 2: Seismic hazard curves for site A (solid line) and site B (dash line).

Figures 3 & 4: Comparison between the developed uniform risk response spectrum for Site A. Fig.3 is for horizontal direction and Fig.4 is for vertical direction.
Figures 5 & 6: Comparison between the developed uniform risk response spectrum for Site B. Fig. 5 is for horizontal direction and Fig. 6 is for vertical direction.

Fig. 7: Comparison between the power spectral density function (PSDF) of spectrum compatible time history and the PSDF of derived acceleration response spectrum.