SENSITIVITY OF SEISMIC HAZARD TO VARIOUS PARAMETERS AND CORRELATION FOR PEAK GROUND ACCELERATION

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SUMMARY

The design basis ground motion of a site is generally specified in terms of the peak ground acceleration (PGA), ground motion response spectrum and time-history. The probability of exceedence of the design level PGA is one of the factors to quantify the seismic risk at the given site. The present paper extends the work of Cornell to consider an aerial source model and a more general form of the correlation for PGA to evaluate the seismic risk. It is further recognised that the predicted seismic risk can vary with various parameters involved. Numerical results have been presented to show this variability. These results will help to determine the seismic hazard at a given site and the associated uncertainties.

INTRODUCTION

The safety of a nuclear power plant (NPP) depends upon a number of factors - intrinsic and external to the plant. The safety of the plant or, alternatively, the risk associated with it depends, among others, on seismic ground motion. The various uncertainties and randomness associated with the occurrence of earthquakes and the consequences of their effects on the NPP components and structures call for a probabilistic seismic risk assessment (PSRA).

The PSRA comprises the evaluation of the following parameters considering variations due to their randomness and uncertainties[Kennedy and Ravindra,1984].

Seismic hazard at the site

Response of plant systems and structures

Component fragilities

The effect of various accident sequences

The design basis ground motion of a site is generally specified in terms of the peak ground acceleration (PGA), ground motion response spectral shapes and ground motion time-history [AERB,1990]. The seismic hazard at a given site is quantified in terms of the probability of exceedence of the design level PGA(Cornell,1968) and the probability of exceedence of the specified ground motion response spectral shapes[USAEC(1973); Seed et al.(1976); Ghosh et al.(1986)].

The seismic risk analysis presented by Cornell considers (i) point source model, (ii) line source model and (iii) aerial source model for earthquake occurrence. The severity of ground motion has been considered in terms of (i) felt intensity of the earthquake at site and (ii) peak ground acceleration. The peak ground acceleration (a_p) has been assumed to be of the form

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$$a_p = b_1 \exp(b_2 M) R^{-b_3} \qquad (1)$$

where b_1, b_2 and b_3 are constants, M is the earthquake magnitude and R is the hypocentral distance.

It has been observed [Campbell(1985)]that PGA predicted by relations of the type given by equation (1) does not agree very well with observations particularly for smaller values of R and a distance correction term (D) has been considered by many workers.

The present paper extends the work of Cornell to consider an aerial source model and a more general form of the correlation for PGA. It is further recognised that the predicted seismic risk can vary with various parameters involved. Numerical results have been presented to show this variability. These results will help to determine the seismic hazard at a given site and the associated uncertainties.

THEORY

It is assumed that earthquakes are equally likely to occur anywhere in a circular area of radius l around the site and there is no earthquake occurring in a circular area of radius Δ around the site. The earthquakes are assumed to occur at a depth d. A circular area of radius l around the site is considered for evaluation of seismic risk.

The peak ground acceleration (a_p) is assumed to be of the form

$$a_p = b_1 \exp(b_2 M)(R + D)^{-b_3} \qquad (2)$$

where D is the distance correction term. Some well known correlations for PGA are of the type

$$a_p = b_1 10^{b_2 M} (R + D)^{-b_3} \qquad (3)$$

Equation (3) can be rewritten as

$$a_p = b_1 \exp(b_2 \ln 10 M)(R + D)^{-b_3} \qquad (4)$$

which is of the same form as equation (2) The constants b_1, b_2 and b_3 and D are derived from the observed values of PGA.

The annual rate of occurrence of earthquakes of magnitude greater than or equal to M is given by the Richter equation [Richter (1959)]

$$\log_{10} N = a - bM \qquad (5)$$

The constants a and b are derived from the earthquake records of the region under consideration. From the probability density function for the spatial distribution of earthquakes and equation (2) and (5) the probability of exceedence of a certain specified value of a_p can be evaluated by considering earthquake occurring anywhere within the area under consideration.

The temporal distribution of earthquakes is assumed to follow a Poisson distribution. Thus it is possible to predict the probability of exceeding (P/A > a_p) a certain specified level of PGA in a given time span or, alternatively, to evaluate the mean recurrence interval, T_y of the specified PGA. The methodology of evaluating P(A > a_p) and T_y is described in detail in [Ghosh (1998b)] which also brings out the relation between these two quantities.

$$T_y = \frac{1}{C\hat{v}G} a_p^{\frac{\beta}{b_2}} ; \quad P = 1 - \exp(-t/T_y) \tag{6}$$

The seismic hazard associated with the PGA at a site is quantified by the probability P(A > a_p) and T_y and the uncertainties in these quantities due to variations in the correlations for PGA and uncertainties in the seismic source and occurrence models, depth of focus d, a and b.

NUMERICAL RESULTS

The correlations for PGA considered in this study are summarised in Table-1. The logarithmic standard deviations for these correlations have been evaluated in independent studies with a fairly large database [Ghosh (1987); Ghosh et al. (1998a)].

Therefore the choice of the correlation for PGA is quite critical. The prediction of PGA should be conservative and the error in the predicted value over the observed value in the range of PGA of design interest should be low. The latter condition can be satisfied by choosing a correlation with a low value of standard deviation. Generally the standard deviation of the logarithm of PGA is considered.

Fig.1 shows T_y versus PGA and Fig.2 shows P[A > a_p] for fifty years for four chosen correlations. Esteeva and Rosenblenth (1964) correlation has been considered since this form of equation ($a_p = b_1 \exp(b_2 M) R^{-b_3}$) has been used in the paper by Cornell and in various earlier studies. But it has a rather high standard deviation. [McGuire (1978)] correlation has been considered since its use has been recommended in a Safety Guide [AERB (1990)]. [Esteeva and Villaverde (1974)] correlation is an extension of the [Esteeva and Rosenbleuth (1964)] correlation with a distance correction factor (D) and has a lower value of logarithmic standard deviation than that of either of the two correlations mentioned earlier. However, due to its widespread use, [McGuire (1978)] correlation has been used for the parametric studies described in the following paragraphs. In any parametric study while one parameter is varied the remaining ones are fixed at the base values (l= 300km, a=3.10 and b=1.05).

Next the influence of l on the seismic risk has been studied. P (A > a_p) vs. PGA for various values of l is presented in Table-2. It is seen that for any value of PGA the difference in the results with increase in l beyond 200 km is practically insignificant. The variation with distance is significant only for smaller values of PGA. This is natural since within the realistic limits of magnitude distant earthquakes can produce relatively lower values of PGA and the higher values of PGA are due to earthquakes nearer the site. It may be noted that various codes require that the seismic studies be carried out over a circular area of radius 300 km around a critical facility like an nuclear power plant [see AERB(1990)] for example].

The a and b values in the magnitude-frequency relationship are generally derived by a regression analysis of the earthquake occurrence data and are thus associated with some uncertainties. Figs.3 and 4 show P vs. PGA for various values of a and b. A higher value of `a' and a lower value of `b' denote higher earthquake occurrence rates which explain the trends of these two graphs.

CONCLUSION

At a PGA of 0.2g the T_y value varies from 7400 yrs to 3.44 x 10^6 yrs. P[A > 0.2g] in 50 yrs varies from 6.73x10^{-3} to 1.45x10^{-5}. These results show the uncertainties in T_y and P (A $> a_p$) for uncertainties in modelling and various earthquake occurrence parameters and will be useful in determining the uncertainties in the predicted seismic hazard.

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TABLE-1

CORRELATIONS CONSIDERED FOR PGA

Correlation / Parameter	1 Donovan (1974)*	2 Donovan (1973) *	3 Esteeva (1970) *	4 Esteeva and Rosenbleuth (1964) *	5 Esteeva and Villaverde (1974)*	6 McGuire (1978)$ *
b1	1.10	1.35	1.25	2.0387	5.71	0.0306
b2	0.5	0.58	0.8	0.8	0.8	0.89
b3	1.32	1.52	2.0	2.0	2.0	1.17
D	25	25	25	0	40	0
σ ln a	0.722	0.699	1.390	1.090	0.793	0.861

Table 1

Correlation / Parameter	7 Ghosh (1986)$	8 Ghosh (1998)$	9 McGuire (1974) *	10 Orphab and Lahoud (1974) *	11 Mickey (1971) *
b1	1.04	4.63	0.472	0.066	0.000304
b2	0.483	0.528	0.28	0.4	0.74
b3	1.2	1.6	1.3	1.39	1.4
D	40	40	25	0	0
σ ln a	0.731	0.678	0.770	0.815	1.750

$ For rock sites

Correlations 1 to 8 are of the type : $a_p = b_1 \exp(b_2 \; M)(R + D)^{-b_3}$

Correlations 9 to 11 are of the type : $a_p = b_1 10^{b_2 M} (R + D)^{-b_3}$

R is hypocentral distance for correlation nos. 1,3,4,5,6,9,10 and 11

R is epicentral distance for correlation nos. 2,7 and 8; (* see Campbell (1985))

TABLE-2

VARIATION OF P [$A \geq a_p$] WITH PGA EVALUATED BY MCGUIRE (1978) CORRELATION : EFFECT OF THE AREA INCLUDED IN ANALYSIS

l (km) PGA (g)	300	200	100	50
.100E-01	.628E+00	.621E+00	.598E+00	.544E+00
.200E-01	.140E+00	.137E+00	.129E+00	.113E+00
.300E-01	.488E-01	.479E-01	.450E-01	.389E-01
.400E-01	.226E-01	.222E-01	.209E-01	.180E-01
.500E-01	.124E-01	.122E-01	.114E-01	.986E-02
.600E-01	.758E-02	.744E-02	.699E-02	.602E-02
.700E-01	.499E-02	.490E-02	.460E-02	.396E-02
.800E-01	.348E-02	.341E-02	.320E-02	.276E-02
.900E-01	.253E-02	.248E-02	.233E-02	.200E-02
.100E+00	.190E-02	.186E-02	.175E-02	.151E-02
.110E+00	.147E-02	.144E-02	.135E-02	.116E-02
.120E+00	.116E-02	.114E-02	.107E-02	.918E-03
.130E+00	.931E-03	.914E-03	.858E-03	.739E-03
.140E+00	.761E-03	.747E-03	.701E-03	.604E-03
.150E+00	.631E-03	.620E-03	.582E-03	.501E-03
.160E+00	.530E-03	.520E-03	.488E-03	.420E-03
.170E+00	.449E-03	.441E-03	.414E-03	.356E-03
.180E+00	.385E-03	.378E-03	.354E-03	.305E-03
.190E+00	.332E-03	.326E-03	.306E-03	.264E-03

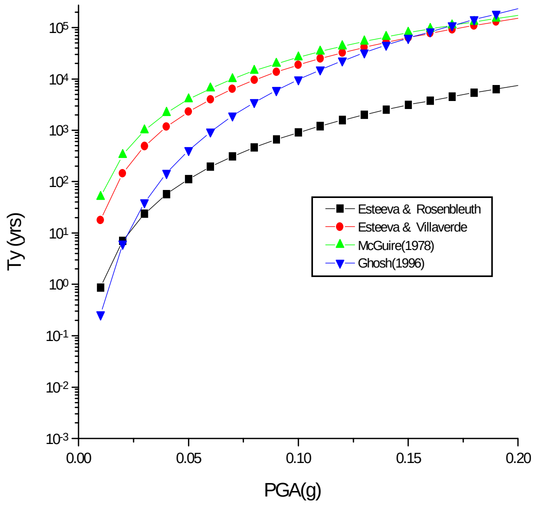

Fig. 1 : Variation of Mean Recurrence Interval Ty with PGA: Influence of the Correlation for PGA

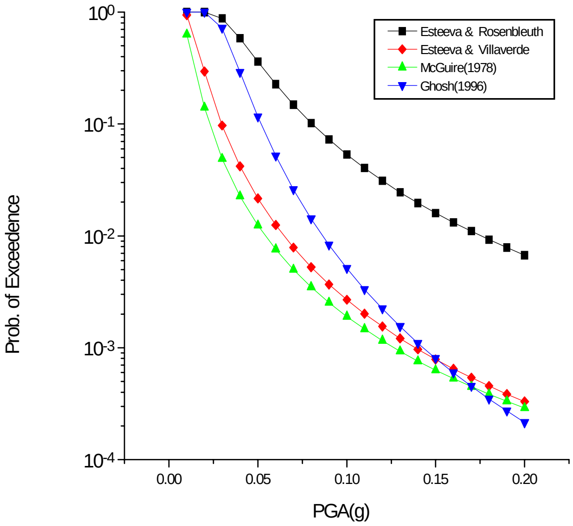

Fig. 2 : Variation of Probability of Exceedence (in fifty years) with PGA: Influence of the Correlation for PGA

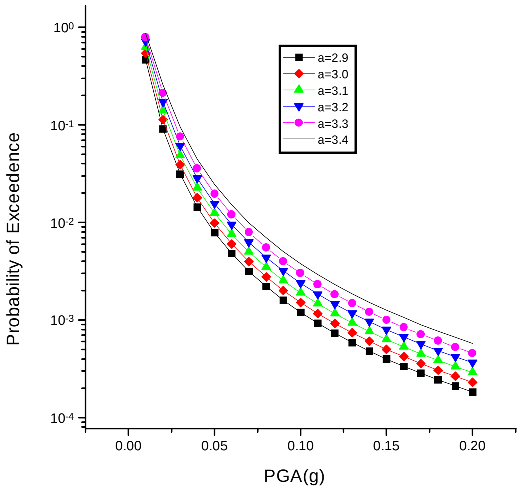

Fig. 3 : Variation of Probability of Exceedence (in fifty years)of PGA: Influence of a; (PGA Evaluated by McGuire(1978))

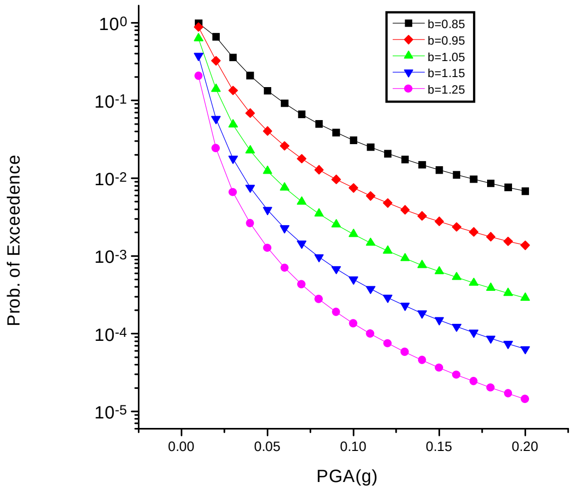

Fig.4 : Variation of Probability of Exceedence (in fifty years) with PGA: Influence of b