SEISMIC RISK ANALYSIS OF INDIAN PENINSULA

by

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SYNOPSIS

A statistical analysis of seismic risk of Indian Peninsula bounded by lattitude (6°,40°] and longitude (66°,98°] is made to determine the design acceleration, velocity and displacement for a 100-Year return period. The analysis is based on the available seismic data. The focal depth is assumed to be independent of time. Two distributions, (a) Uniform and (b) Log-normal, truncated at 600 Kms. depth are considered. The spatial properties of the earthquakes are considered homogeneous in tectonic features. Seismic zoning maps are prepared, based on the study, and compared with the existing map.

INTRODUCTION

The analysis of seismic risk defined as the maximum generalized intensity of ground motion likely to occur for a specified return period provides the basic information for the preparation of seismic zoning maps. Usually seismic zoning map are prepared on the basis of peak ground acceleration. Since the attenuation laws are different for peak ground acceleration, velocity and displacement and since the design of different types of structures may be governed by one of these, it is meaningful to prepare separate zoning maps based on return period analysis of peak ground acceleration, velocity and displacement.

In this paper the seismic risk analysis is carried out through classical and Bayesian statistics to obtain both local and regional seismicity(1) for the region in Indian peninsula bounded by longitude (66°,98°] and lattitude (6°,40°]. The focal depth is assumed to be a) uniform b) lognormal and truncated at 600 Kms. Assuming that the region is homogeneous in tectonic features and a volume source with an arc length of 150 Kms. from the site influence the seismicity, peak ground acceleration and displacement intensities are compared for 100 Years return period at 2° grid points. Contour maps are drawn and used to prepare the seismic zoning map.

ASSUMPTIONS

1. The magnitude distribution is stationary and independent of earthquake occurence rates. The probability density of the magnitude M is(2)

$$f_M(m) = \beta \exp\ [-\beta(m-m_0)] \quad ; m > m_0 \qquad (1)$$

in which m_0 is the threshold magnitude taken as 5 in this study. A second distribution of earthquake magnitude is also considered with an upper bound of the magnitude $m_1 = 9$. The probability density is given by

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$$f_M(m) = \beta \exp[-\beta(m-m_o)]/[1-\exp\{-\beta(m_1-m_o)\}] \; ; \; m \in (m_o,m_1] \quad (2)$$

2. Focal depth is temporal and spatial homogeneous and independent of earthquake occurence rate. Focal depth distribution considered are (a) uniform

$$f_H(h) = 1/H_o \; ; \; h \in (0,H_o] \quad (3)$$

and (b) truncated lognormal.

$$f_H(h) = \exp[-1/2(\ln h-\theta_1)^2/\theta_2]/[\sqrt{2\pi\theta_2}\, h\, \phi\{(\ln H_o-\theta_1)/\sqrt{\theta_2}\}] \; ; \; h \in (0,H_o] \quad (4)$$

where H_o is the upper bound of focal depth and taken as 600 Kms. and $\phi(\cdot)$ is the distribution function of N(0,1).

3. The generalized attenuation law is[3,4]

$$Y = C_1 \exp[C_2 M - C_3 \ln(R+C_4)] \quad (5)$$

where Y is the required ground motion, M is the magnitude, R is the focal distance, C_1, C_2, C_3 and C_4 are emperical constants. This relation is taken with (C_1, C_2, C_3, C_4) as (2000, .8, 2., 25.), (16,1.0,1.7,25) and (7,1.2, 1.6,25) for peak ground acceleration, peak ground velocity and peak ground displacement respectively

4. The earthquake process is Poisson of rate of occurence μ for magnitude greater than 5.

PROBABILITY DISTRIBUTION OF GENERALIZED INTENSITY

The joint probability density of $Z = C_1 e^{C_2 M}$ and $W = (R+C_4)^{-C_3}$, assuming statistical independence of focal distance R and magnitude M, is obtained as,

$$f_{Z,W}(z,w) = f_Z(z)\, f_W(w) \quad (6)$$

where

$$f_W(w) = f_R(w^{-1/C_3} - C_4)/[C_3 w^{(C_3+1)/C_3}] \; ; \; w \in [(R_o+C_4)^{-C_3}, C_4^{-C_3}] \quad (7)$$

R_o is the maximum focal distance and $f_R(\cdot)$ is the focal distance density. For magnitude density given by equation (1,2), the density f_Z is given by

$$f_Z(z) = \frac{\beta\, C_1^{\beta/C_2}}{C_2} \exp\left[-\beta\left\{\frac{1+C_2/\beta}{C_2} \ln z - m_o\right\}\right] \; ; \; z \geq C_1 e^{C_2 m_o} \quad (8)$$

and

$$f_Z(z) = \frac{\beta\, C_1^{\beta/C_2}}{C_2} \; \frac{\exp\left[-\beta\left\{\frac{\beta+C_2}{\beta C_2} \ln z - m_o\right\}\right]}{1-\exp[-\beta(m_1-m_o)]} \; ; \; z \in (C_1 e^{C_2 m_o}, C_1 e^{C_2 m_1}] \quad (9)$$

respectively.

A volume source subtending an angle γ to the centre of earth and having an arc length of 150 Kms. from the site and 600 Kms. depth is assumed to influence the seismic risk of the place of interest. The probability density of the focal distance R from the site when focal depth H has uniform and lognormal density is given elsewhere[5].

The probability, generalized intensity Y = ZW exceeding a value y, is obtained from Eq. (6) and Eq. (8) for magnitude $M \in (m_o,\infty)$ and is given by,

$$F_Y^*(y) = P[Y \geq y] = 1 \; ; \; y \leq y_1 = C_1 \exp[C_2 m_o - C_3 \ln(R_o+C_4)] \quad (10a)$$

$$F_Y^*(y) = \int_{x_1^*}^{R_o} S\, f_R(x)\, dx + F_R(x_1^*) \quad ; y_1 \le y \le y_2 \tag{10b}$$

$$F_Y^*(y) = \int_0^{R_o} S\, f_R(x)\, dx;\ y \ge \quad y_2 = C_1 \exp\, [C_2 m_o - C_3\, \ln\, C_4] \tag{10c}$$

where $S = \exp\, (\beta m_o)\{C_1(x+C_4)^{-C_3}/y\}^{\beta/C_2}$; $x_1^* = \exp\,[C_2 m_o/C_3 - \ln(C_1/y)/C_3] - C_4$

When magnitude $M(m_o, m_1]$ the above relation is obtained through Eq. (6) and Eq. (9) and is the following :

$$F_Y^*(y) = 1\ ;\ y \le y_1 = C_1 \exp\, [C_2 m_o - C_3\, \ln\, (R_o + C_4)] \tag{11a}$$

and defining $x_i^* = \exp\, [C_2 m_{i-1}/C_3 - \ln(C_1/y)/C_3] - C_4;\ i = 1,2$

$$Q = [\{C_1(x+C_4)^{-C_3}/y\}^{\beta/C_2} - \exp(-\beta m_1)]\exp(\beta m_o)/[1-\exp\{-\beta(m_1-m_o)\}]$$

$$F_Y^*(y) = \int_{x_1^*}^{R_o} Q\, f_R(x)\, dx + F_R(x_1^*)\ ;\ y_1 \le y \le \min\, (y_2, y_3) \tag{11b}$$

$$F_Y^*(y) = \int_0^{R_o} Q\, f_R(x)\, dx;\ y_2 \le y \le y_3 = C_1\, \exp[C_2 m_1 - C_3\, \ln(R_o + C_4)] \tag{11c}$$

$$F_Y^*(y) = \int_{x_1^*}^{x_2^*} Q\, f_R(x)\, dx + F_R(x_1^*)\ ;\ y_3 \le y \le y_2 = C_1 \exp[C_2 m_o - C_3 \ln C_4] \tag{11d}$$

$$F_Y^*(y) = \int_0^{x_2^*} Q\, f_R(x)\, dx\ ;\ y \ge \max\, (y_2, y_3) \tag{11e}$$

One of Eq. (11c) and Eq. (11d) is to be used according to the numerical values of the relevent parameters.

T-YEAR INTENSITY

The earthquake process is assumed to be Poisson, the special event which causes the generalized intensity at site to exceed a value y is a Poisson process of random selection. Thus the number of times intensity at site will exceed y during a time interval t is M(t) and is given by,

$$P_M(m,t) = P[M(t)=m] = \{P[Y \ge y]\ \mu t\}^n\ \frac{\exp[-P[Y \ge y]\, \mu t]}{m!}\ ;\ m = 0,1,2,\ldots \tag{12}$$

Putting m = 0, probability of zero exceedence may be obtained. The annual return period T_y is defined as

$$T_y = \frac{1}{1 - P_M(0,1)} \approx \frac{1}{P[Y \ge y]\mu} \tag{13}$$

The T-Year intensity is obtained by solving Eq. (13) for y given time period T_y.

RESULTS AND DISCUSSIONS

Parameters related to the distribution of magnitude, focal depth and occurances are estimated using data of 55 years (January 1917 to December 1972). Total number of earthquakes occured during the period are 1374. Numbers of samples for determining the distribution of focal depth is 624 after deleting all earthquakes of 33 kms focal depth and those shocks for which focal depth is not available.

Parameters for the magnitude of earthquakes exceeding a threshold value is obtained by linear regression $\ell n\ N = a + bM$, 95% confidence interval of b is (1.9031 ± 0.0996), the multiple correlation coefficient square is found to be 0.987. A Horel function, $\ell n\ C(\mu) = a_0 + a_1 \ell n\ M + a_2 M$, is fitted with the coefficient of variation of rate of occurence and magnitude and 95% confidence interval for a_0, a_1 and a_2 are (5.826 ± 2.505), (-17.097 ± 3.345) and (3.658 ± 0.558) respectively. The value of multiple correlation coefficient square is 0.981. To determine the parameters at a particular location, it is assumed that expected number of earthquakes per unit time is a function of the volume of earth under consideration. If μ' is the rate of occurence in microzone and μ is that of macrozone, it is assumed that they are only dependent on their volume ratios. Consequently a least square fit is obtained between coefficient of variation and volume ratio as $\ell n[1 + C^2(\mu'/\mu)] = (V/V')^{\gamma}$. For magnitude greater than 5,95% condidence interval of γ is $(.408 \pm 0.021)$ and value of multiple correlation coefficient square is 0.955. From the macrozone to point of interest the rate of occurence μ' is obtained following the procedure proposed by Esteva[6]. The truncated log normal parameters of focal depth is estimated by method of maximum likelihood and found to be $\hat{\theta}_1 = 4.252$ and $\hat{\theta}_2 = 1.076$. The nonlinear equations obtained are solved by parametric differentiation technique[7]. Both Chi-square and Kolmogorov-Smirnov goodness of fit test reject this hypothesis. This is expected, since maximum likelihood estimate is mean biased and shallow focus earthquakes are more compared to deep focus earthquakes in the data. The estimate is towards the mean of shallow focus. Hence the assumption of focal depth lognormal provides an upper bound of seismic risk. Following similar argument the assumption of uniformly distributed focal depth provides a lower bound of seismic risk Fig. (1 & 2). Maximum difference in seismic risk based on peak ground acceleration due to truncation of magnitude is 7.03% and that due to the assumption of lognormal and uniform focal depth is 41.3% for 100 Year return period and corresponding changes in seismic risk based on peak displacement is 14.88% and 48.62% respectively. The seismic risk is maximum for lognormal focal depth and magnitude(5,∞). Seismic zone map for acceleration and displacement basis for 100 Years return period is shown in Fig. (3 & 4). The map obtained by this method differs in Southern and Central Indian region from that of Indian Standard[8].

In case the tectonic features e.g. fault plane or fault line of a region are known the method proposed by Cornell[9] may be applied. Moreover, this study does not differentiate between different kind of earthquakes and spatial correlation between them. Seismic risk analysis, assuming the earthquake process to be semi-Markov, is in progress.

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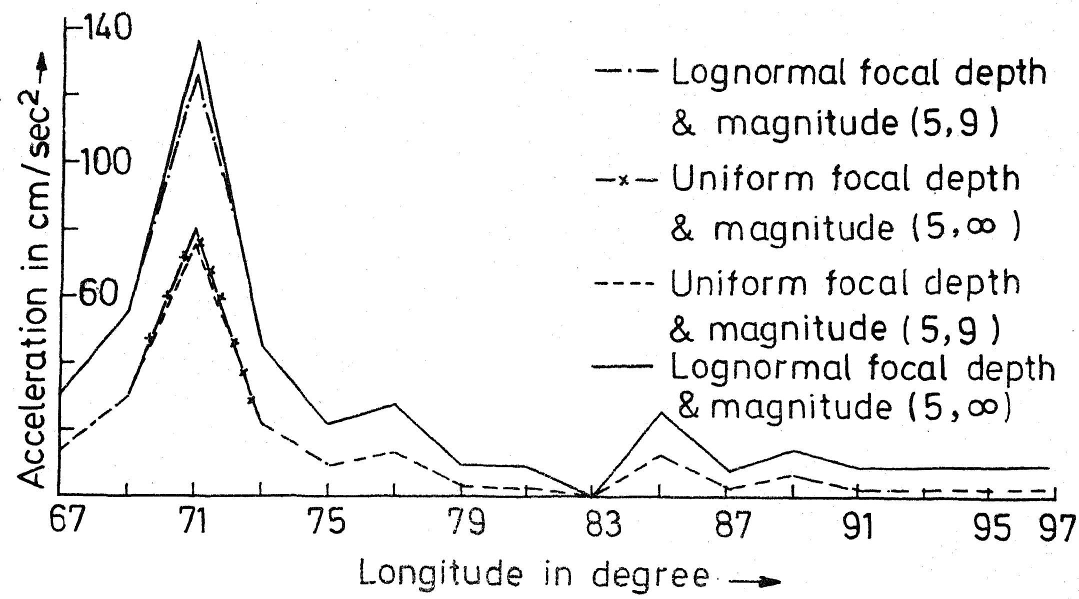
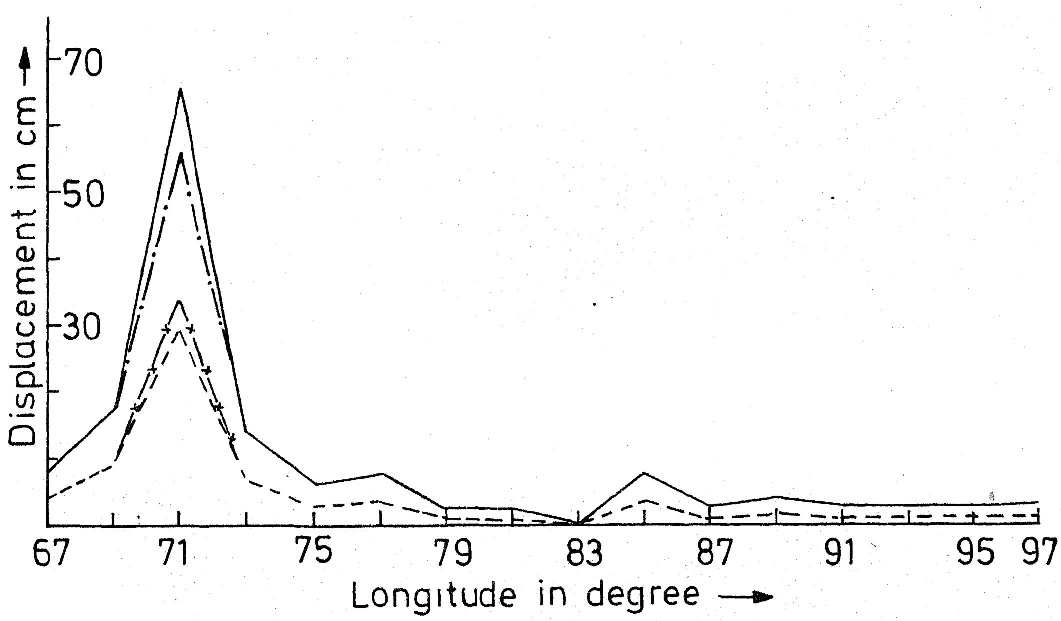


FIG·1 ACCELERATION AT 37° LATTITUDE



FIG·2 DISPLACEMENT AT 37° LATTITUDE

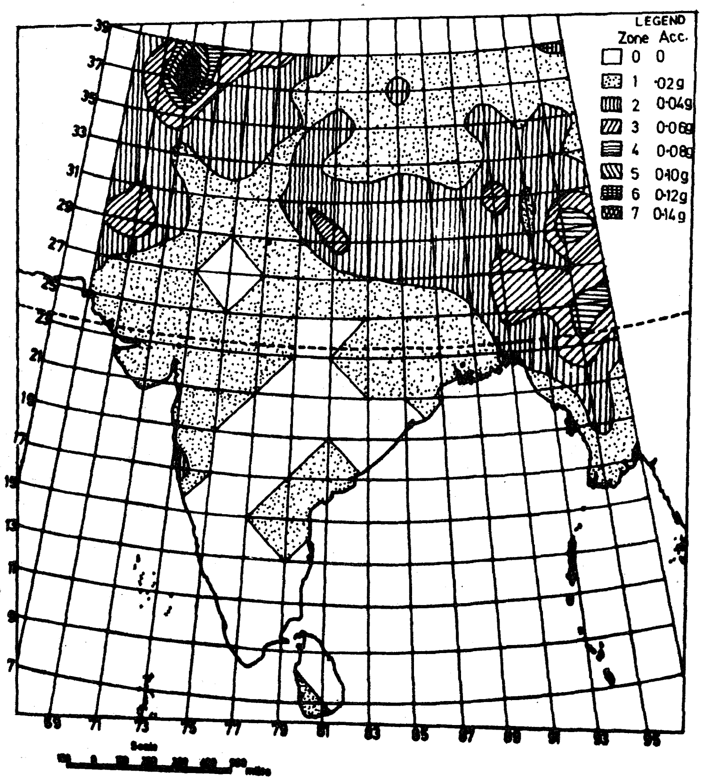


FIG. 3 ZONING MAP BASED ON ACCELERATION

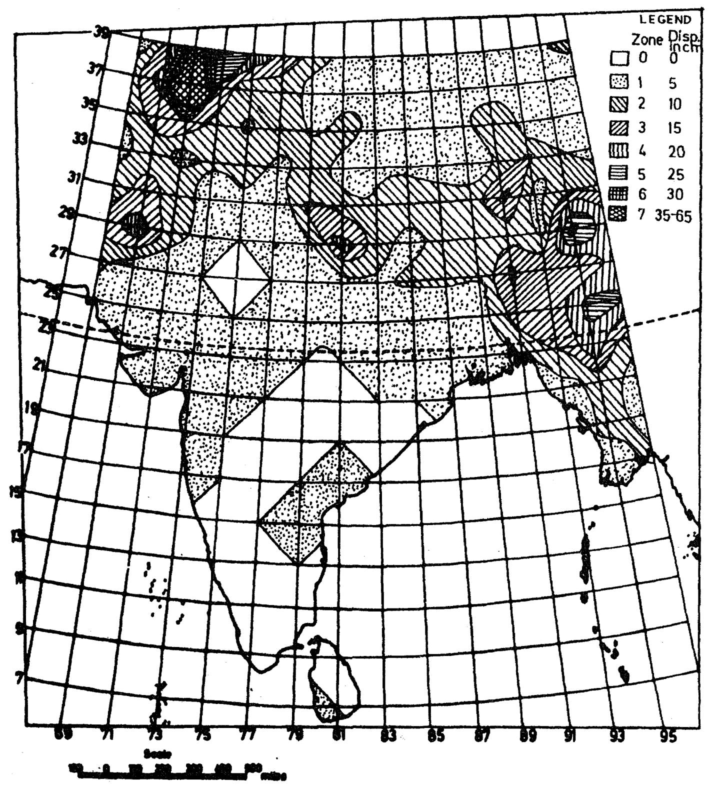


FIG. 4 ZONING MAP BASED ON DISPLACEMENT

DISCUSSION

B.O. Skipp (U.K.)

Our general reporter has referred to this paper in comparison with paper No. 58. My question relates to the differences be noted. Did the author use a single b value for all India as implied on P 428 and how did he take into account different seismo-tectonic provinces ?

B. Ramachandran (India)

Basu has assumed that the Indian Peninsula is homogenous in tectonic features. This basic assumption is incorrect as the Indian Peninsula (between lat 6°, 40° and long 66°, 98°) consists of the shield, the Deccan Trap, the Indo-Gangetic Alluvium and the Himalayan Chain all of which are different from each other in their geological and physical characteristics. So the basic assumption of the author is open to question.

S.K. Guha (India)

From Figs. 3 and 5 of the paper, Southern Tip of Indian peninsula below lat. 10° is rated acceleration zero; but then a number of earthquakes in the area in the past had up - to magnitude 6.0. Kindly clarify how zero acceleration is designated for the area ?

Author's Closure

With regard to the question of Mr. Skipp, we wish to state that a single value of b has not been used. The value on page 428 refers to the 'local' value which has been modified to a 'regional' value at each grid point using Bayesian method.

With regard to the question of Mr. B. Ramachandran, we wish to state that the seismic risk analysis presented in the paper is based on the available seismic data, ignoring the tectonic features. The non-homogeneous geo-tectonic features of Indian Peninsula enter indirectly through seismic data in our analysis. Subsequent work indicates that seismic risk analysis based on non-homogeneous tectonic feature model shows only marginal changes locally.

With regard to the question of Mr. S.K. Guha, we wish to state that the actual value is not zero in any part of the Indian peninsula. In the part referred to by Guha, the peak ground acceleration is 0.265 cm/sec^2. Since the contours have been drawn at intervals of 0.02g/5cm., the acceleration/displacement appear as zero in some parts. It is obvious from equations (10a) and (11a) that the minimum value cannot be less than y_1.

The catalogue of Indian Meteorological Department, New Delhi, gives three earthquakes of magnitude 5 and more in the region (6°, 12°) latitude, and (66°, 84°) longitude, during the period 1917-72. The peak intensities are consistent with this data over a 2° x 2° grid.