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ASSESSMENT OF THE EARTHQUAKE POTENTIAL OF A REGION

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INTRODUCTION

The design of earthquake resistant structures is largely based on the data supplied by the seismologists. The parameters of interest are the epicentres, focal depths, the magnitudes of the earthquakes and their frequency of occurrence. In our country, the India Meteorological Department has played the key role to provide such data to the engineers. This department is now running about 40 seismological observatories in the country. Of these, ten observatories were opened to study the seismicity for Beas project region. A network of four seismological observatories is operating around the Visakhapatnam Steel Project while another four observatories are monitoring the seismic status of the capital.

EPICENTRAL MAP

The first requisite in any seismicity study is the preparation of an uptodate catalogue of earthquakes containing not only macroseismic data but also information about the location and magnitude of earthquakes. With this view the work of preparation of an uptodate catalogue was undertaken and an uptodate catalogue showing the location of epicentres, and the magnitudes of earthquakes has since been prepared. The chief sources of information were (1) Report of British Association for the advancement of Science (2) Seismicity of the Earth by Gutenberg and Richter (3) ISS and ISC (4) B.C.I.S. (5) USCGS epicentral data sheets (6) Seismological bulletin of the India Meteorological Department supplemented by the data from 'Meteorology in India' and 'Monthly Weather Reviews' of the India Meteorological Department. The catalogue of earthquakes has since been published (Tandon and Srivastava, 1974). Some improvements are still needed in the catalogue in respect of assigning magnitudes, further research into the past data and inclusion of events of magnitude less than 5 also. A close look into the distribution of events with respect to their magnitudes shows that the major events were restricted along the Alpide belt ranging from Hindukush to Manipur Burma, whereas other parts of the country were free from such damaging events. In the concept of plate theory this phenomenon can be readily explained in terms of the underthrusting of the Indian plate below the Eurasian plate. In this type of continent continent collision, large stresses are built up near the edges due to the frictional resistances when the fracturing of the rocks is manifested, in the form of earthquakes. Analysis of the focal mechanism of earthquakes, in the region however, shows that this ideal picture needs to be modified to explain the occurrence of strike slip and normal faults. Tandon and Srivastava (1975) have supported the concept of flake tectonics to explain some of the anomalies but many questions still remain to be answered.

However, the application of the new plate tectonics theory in the region allows us to broadly estimate the maximum magnitude earthquakes in our region.

DEPTH OF FOCUS

The determination of focal depths of earthquakes has always been difficult particularly if the observations close to the epicentre or the depth phases are not available.

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Numerous discrepancies between the focal depths reported by international agencies like U.S. Geological Survey and International Seismological Centre have been found. Some attempts have also been made to estimate the focal depth with the spectral analysis of surface waves. The seismic effects for reliable focal depths are therefore to be carefully assessed.

MAGNITUDE

Magnitude calculations are generally recognized by seismologists as not being in a very satisfactory state at present. Different scales are in current use and it is practically impossible to combine different magnitude determinations and even less possible to compute seismic wave energy from them—the relation between magnitude and energy being even less reliable in any individual case.

It has been observed that there is discrepancy in the magnitudes compiled from apparently the same data by the U.S. Geological Survey and the International Seismological Centre. There are several possible explanations. In the distance range of 14 to 17 degrees the Gutenberg Q factor changes radically from 7.0 to 5.9 at the 25 kms depth level. The slightly different location and hence distances, and possible differences in interpolation and round off procedure may account for the difference. The reduction of the data by I.S.C. as log A/T with only one decimal value may also lead to a difference of a tenth of a unit in magnitude.

However, there are two principal advantages to the method of magnitude computations gained by the use of reported P wave data. In having radiation observations reported from many areas the effects of the pattern of radiation of energy is reduced. Secondly, for earthquakes in the magnitude range of about 4 to 5½ which includes most of those presently located, the P phases are just about the only data available.

Since a number of empirical ralations between magnitudes and related quantities like intensity, felt radius, acceleration seismic moment etc. are being used, the limitations in the magnitude determination are to be properly understood.

EARTHQUAKE RECURRENCE CURVE

It has been realised that in order to determine the seismic status of any region, the frequency distribution of earthquakes with respect to their magitudes should be studied. With this objective, studies had been undertaken for areas around Chatra and Dehra Dun located at the foothills of Himalayas and also Delhi where large number of minor events occurred (Tandon and Chatterjee 1968, Chaudhury, Bhattacharya and Basu 1970). Similar studies were undertaken in the Beas Sutlej region. Even though the occurrence or recurrence of an event depends on many independent factors, it may be considered to follow the laws of chance and its relative frequency usually is assumed to be the same as the *probability of occurrence* in any one trial. This equivalence which appears intuitively sound to the Engineer, is questioned by the mathematician, and has encouraged much statistical discussion.

The widely accepted magnitude-frequency relation of a given group follows the Gutenberg-Richter statistical relation

$$\text{Log } N = a - bM \qquad \ldots(1)$$

where N and M represent the number of events for a certain class between $M \pm dM$

and $M - dM$ for a relatively large time interval, whereas '*a*' and '*b*' are constants. The value of '*a*' depends mainly on the period of observation and on the level of seismicity of the observed region, and therefore may be regarded as an index to the mean seismic activity for that particular seismic region. The constant 'b' does not depend theoretically on the period of observation and it could be regarded as a characteristic parameter for each seismic region. According to Miyamura (1962) and Mogi (1967) the '*b*' value is directly dependent on the tectonic characteristics of each seismic region, differing significantly from one seismic region to the other.

The values of *a* and *b* obtained in our studies are given in Table 1. It may be noticed that the value of '*b*' (slope of the recurrence curve) is nearly the same for all the cases whereas the value of '*a*' varies significantly from one region to the other. The former result is found true inspite of changing the region area or interval of sampling. Interpreted in terms of Miyamura's and Mogi's views, that would imply similar tectonic characteristics in the regions. The above method, however, has its limitations even for large populations both in time and space. In other words, the return period of a particular class cannot be interpreted for a short span of time. The method should not be attempted for places where meagre data is available. The frequency magnitude relationships at Dehra Dun, Delhi, Chata and Beas Project as reported earlier gave nearly the same value of '*b*'. The values of '*a*' were however different. By examining the catalogue of earthquakes which have occurred in these regions, it was noticed that the '*a*' values bear some relationship with the maximum magnitude experienced at these places.

TABLE I

Region	*a*	*b*	Maximum Magnitude experienced.
Delhi	2.60	0.92	6.5
Dehra Dun	3.71	0.94	7.5
Chatra	2.87	0.80	—
Beas Project	4.60	0.87	8.5

FAULT LENGTH AND EARTHQUAKE ENERGY RELEASE

There are several physical quantities recently introduced in the framework of shear dislocation theory which are not sensitive to the details of the models. They are:

(1) Seismic moment:

$$M_0 = \mu \bar{u} S \qquad \ldots(3)$$

Here S is the fault area, $\bar{u}$ is the final dislocation averaged over the fault area.

(2) Apparent Stress:

$$\eta \bar{\sigma} = \mu E / M_0 \qquad \ldots(4)$$

where E is the seismic energy, η is the efficiency of seismic radiation and $\bar{\sigma}$ is the average of initial stress σ_0 and final stress σ_1 along the fault plane.

(3) Stress-drop:

$$\Delta\sigma = C\mu \frac{\bar{u}}{\sqrt{S}} = c\frac{M_0}{S^{3/2}}$$

This is the difference between σ_0 and σ_1. C depends on the fault shape and slip direction. For example C is equal to $7/16\,(\pi)\,3/2 = 2.4$ for a circular crack, $(4/\pi)\sqrt{L/W}$ and $(2/\pi)\sqrt{L/W}$ for a buried and surface strike slip, respectively, on a rectangular fault with length L and width W, $(16/3\pi)\sqrt{L/W}$ for a buried dip slip, where $L > W$ in both cases. In most practical cases, therefore, C will very from 2.4 to 5. Therefore, when we know the seismic moment and fault area, we can estimate the stress-drop within a factor of 2. This relationship is seen to hold good in comparing stress drops between large and small earthquakes, shallow and deep earthquakes. Tandon and Srivastava (1974) have determined these parameters for some earthquakes in the Indian region. Recently, Savage (1971) proposed the following inequality relationship between stress-drop and apparent stress:

$$\eta\bar{\sigma} < \Delta/2 \qquad \ldots(6)$$

The relationship is based on the assumption that the frictional stress during the slippage is greater than the final stress along the fault. This inequality (eq.4) can be obtained by putting $\eta\bar{\sigma} = (\bar{\sigma} - f)$ and making $f > \sigma_1$. This is a controversial assumption. For example, Brune (1970) implicitly assumes that frictional stress drops below the final stress during the slippage in formulating a simplified stress-release process.

OBSERVED EARTHQUAKE FAULTS, ENERGY AND MAGNITUDE

If we denote by *Es* the earthquake energy due to strain and by *Ew* the seismic wave energy, then *Es* should be equal to *Ew*. Generally the relation used is

$$Es = \tfrac{1}{2}\, ex^2\, V$$

Where

e: is the elastic constant of the crustal material, in this paper taken as 5×10^{11} dynes/cm^2.

x: is the ultimate strain of the crustal material assumed to be in the order of 10^{-4}.

V: is the earthquake volume, in which the material is assumed to be uniformly strained up to a value of x.

According to C. Tsuboi (c.f. Fielder, 1967) the earthquake volume V cannot vertically exceed the thickness d of the earth's crust, nor horizontally 3d; the factor 3 has been derived by C. Tsuboi (2) from the study of regional isostacy.

From such considerations as given above, the earthquake volume is given as

$$V = d.\,3d.\,3d \qquad (8)$$

therefore, the energy in terms of d becomes

$$Es\,(d) = \tfrac{9}{2}\, ex^2 d^3 = 2.25.10^4.d^3.10^{15}\ \text{(ergs)} \qquad \ldots(9)$$

inserting the numerical values for e and x, as given above.

Now if L' (km) is the length of the fault, being generated by an earthquake situated within the crust, then L' corresponds to $3d$ in Tsuboi's model of the earthquake volume and we can apply the simple comparison between d and L', and the corresponding coefficients. From $9d^3 = (L'^3)/3$ we obtain

$$Es\,(L') = \tfrac{1}{6}\, ex^2 L'^2 \text{ (kms)} = 8.33.10^2 L'^3.10^{15} \text{ ergs} \qquad \ldots(10)$$

In some literature, the differences of these coefficients of equation (3) and (4) has been overlooked in comparing strain energy results, inserting fault lengths, with results of seismic wave energy. This makes it necessary to apply a certain factor on equation (1) depending on magnitude.

Setting the Gutenberg Richter energy magnitude relation, which has the following basic form, Fiedler (1967) deduced

$$M = 5.2 + 1.5 \text{ Log } L \text{ (kms)} \qquad \ldots(11)$$

It seems more reasonable that an earthquake with $M = 5.2$ produces a visible surface fault of 1 Km of length than an earthquake with $M = 4.0$ does, as obtained from the equation

$$M = 4.08 + 2 \log L \text{ (km)} \qquad \ldots(12)$$

The above equation can be readily deduced from the Gutenberg Richter's relation

$$\log E = 11.8 + 1.5\, M \qquad \ldots(13)$$

and Iida's (7) formula

$$M = (6.07 \pm 0.12) + (0.76 \pm 0.08) \log L \qquad \ldots(14)$$

Table 2 provides ready reference to the parameters concerned. The shortest surface fault length observed, corresponding to the smallest magnitude is 8.8 km for $M = 5.6$ (California). But this relatively long length is an exception for which equation (12) yields a better result ($M = 5.9$) than eqn (11) ($M = 6.6$) due to the fact that this fault length belongs to slope 2 than the slope 1.5 (Fiedler, 1967).

TABLE 2

d(km)	L(Km)	Es(Ergs)	M	M^*	$F{=}3d^2$(km^2)
0.33	1	8.1×10^{17}	4.1	5.1	3.3×10^{-1}
3.3	10	8.1×10^{22}	6.0	6.7	3.3×10^{1}
10.0	30	2.2×10^{22}	7.0	7.4	$3.0\times10^{+2}$
20.0	60	1.8×10^{23}	7.6	7.8	$1.2\times10^{+3}$
30.0	90	6.1×10^{23}	8.0	8.1	$2.7\times10^{+3}$
40.0	120	1.4×10^{24}	8.2	8.3	4.8×10^{3}
50.0	150	2.8×10^{24}	8.4	8.4	7.5×10^{3}
60.0	180	5.0×10^{24}	8.6	8.6	1.1×10^{4}

Since fault lengths can also be estimated from the aftershock areas, Tandon and Srivastava (1974) have derived the following relationship for the Indian region

$$\log A = 0.89\, M_L - 2.67 \qquad \ldots(15)$$

$$\text{for } 5 \leqslant M_{L_2} \leqslant 7$$

where A is area in km^2 and M_L is the magnitude as determined from the Wood Anderson Seismographs.

The fault length, L' is connected with the magnitude, M of the earthquake by the relation

$$\log \frac{L'}{V_F} = 0.5\, M - 1.9 \qquad \text{for} \quad 2.5 \leqslant M \leqslant 8.5 \qquad \ldots(16)$$

where V_F is the rupture velocity in km/sec.

SOURCE MECHANISM AND GROUND MOTION

In addition to the effect of the magnitude and the local geological conditions, the ground motion at the given site is governed by the predominant focal mechanism. This would introduce a factor depending upon the disposition of the fault plane and the slip vector. Put in a different way, this factor could be incorporated in the maximum magnitude of and arthquake expected in the area.

DESINGN MAGNITUDE EARTHQUAKE

Realising that the accuracy of the seismological data and the limitations in using different types of magnitude scales is best known to the seismologist, an earthquake engineer usually consults the seismologists to estimate the probability of an earthquake greater than the design magnitude. This is often needed by the earthquake engineers to plan a building so that it may not suffer any structural damage in an earthquake with magnitude less than some design magnitude. This study becomes fairly involved based on the probability theory and will not be discussed here.

CONCLUSION

1. Data from historical earthquakes in Indian region needs to be collected.

2. For the places for which no seismological data exist, the maximum magnitude can be estimated by opening a network of highly sensitive seismological observatories and determining the recurrence curve for various magnitudes. In addition, a network of observatories for crustal deformation measurements are also necessary to assess the nature and magnitude of strain parameters.

3. For effective evaluation of seismic factor in a region, it is necessary to gather a first hand knowledge of the predominant ground period. This can be known if microtremor measurements are made at the surface and also in a bore hole so that the effects of the structure versus the foundation can be assessed (Omote et al 1971).

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