STUDIES ON PREDICTION OF SEISMIC RISK IN NORTH EASTERN INDIA (20°-30° N; 90°-100° E)

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SUMMARY

Historical and recent earthquake data amply corroborate that North Eastern Region of India is one of the most intense seismic regions of the world - two major earthquakes over magnitude 8.5 occurred in the region during last hundred years. Significant precursory decrease in b-values during the last one and half decade indicates contemporaneous high stress concentration over the lithospheric plate in the region and probability of occurrence of a major earthquake of magnitude about 8.25.

SEISMICITY

Regional Seismicity

North Eastern India has, of late, been identified as one of the six most intensely seismic regions of the world where a major earthquake is expected in near future. Historical and recent major earthquakes in this area (Ref. 1) are Cachar earthquake of January 10, 1869; Assam earthquake of June 12, 1897; Srimangal earthquake of July 8, 1918; Assam earthquake of Sept. 9, 1923; Dhubri earthquake of July 3, 1930; Assam earthquake of Oct. 23, 1943; and Dibrugarh earthquake of July 29, 1947 and India - China Border earthquake of August 15, 1950. The Assam earthquake of June 12, 1897 is the greatest earthquake in human history. The major seismic events in this region have recurrence period of the order of half a century. The last major earthquake in this region occurred in 1950; and hence a similar seismic even might be expected in near future. It is with this background that intense efforts have recently been directed to develop prediction technology commensurate with seismo-tectonic environment of the region. Various effective precursory studies are being identified and initiated for prediction of seismic risk, particularly the major earthquake expected in this region in near future.

Global Seismicity

During last ninty years, about ten earthquake of magnitude (M) above

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8.5 occurred in the world, and out of these ten, two (M greater than 8.5) occurred in the north eastern region of India (20° to 30° N; 90° to 100° E). The region is thus rated as one of the most highly seismic regions of world, with potential of occurrence of largest magnitude earthquake upto M = 8.9. The Assam earthquake of 1897 with epicentre in the Shillong Massif is regarded as the largest earthquake in human history. This earthquake was accompanied by large epicentral tract with MM scale intensity of XII having ground acceleration exceeding gravity, surface faulting, changes in ground topography accompanied by wide spread land slides affecting the river regemes, felt over wide areas in India and neighbouring countries etc.. This earthquake occurred during global seismicity peak at turn-of-the-century. It is thus evident that global seismicity varies with different periodicities. An attempt has been made to assess such variations in global seismicity through b-values in Gutenberg-Richter statistics (log N = a - bM). Periodic b-values were obtained from global earthquake population for the period 1900 to 1978 to assess such global seismicity variations. Fig.1 shows 'b' value variations, earthquakes of magnitudes greater the 8.5 and earthquake energy variations on global scale. Interesting revealations from Fig.1 show that low 'b' values are associated with greater frequency of earthquakes of M greater than 8.5. During the last two decades, 'b' values have increased significantly with sharp reduction in frequency and absence of large earthquakes (M greater than 8.5). It is thus reasonable to assume that with contemporary high 'b' values, maximum magnitude of eartnquake expected in the North Eastern India is about 8.25. The present trend of global seismicity supports this conclusion. The contemporary quiscence period could also be expected to be followed by one of intense seismicity as exhibited during the turn-of-the-century. The periodicity of large scale seismicity variations in this region could thus be of the order of 250 years or so. Thus validity of 'b' values in studies of periodicity of occurrence of major earthquakes from historical and recent earthquake data is a significant result of applications of Gutenberg-Richter statistics.

EARTHQUAKE STATISTICS AND GEODYNAMICS

Earthquake Return Period

Like the global seismicity and recurrence period of largest earthquake, similar procedure may also be adopted for assessing return period of large earthquakes in the tectonic environment of North Eastern India (20°-30° N; 90°-100° E). As anticipated from probability of occurrence of major earthquakes on global scale (Fig.1) and the present global tectonic environment reflected from 'b'-values variations, probability of occurrence of an earthquake of magnitude 8.5 or so is low. And hence recurrence period of an earthquake of magnitude less than 8.5, may 8.25, will be considered following Gutenberg - Richter statistics (log N = a - bM). From least square fitting of post 1950 earthquake (M = 8.6) data for the period 1950 - 1980 in North Eastern India, the Gutenberg - Richter relationship is obtained as log N = 5.57 - 0.67 M (Fig.2) which gives return period (T) as 40 to 50 years for an earthquake of magnitude of 8.25 in the North Eastern India - a result which is very much consistent with past seismicity

as reflected in the occurrence of major earthquakes 1950 (M = 8.6) and 1897 (M = 8.7) in the region. Thus from Gutenberg-Richter Seismo-Statistical considerations of global and regional seismicities, it can be reasonably assumed that a major earthquake of magnitude about 8.25 could be expected in the region, and the magnitude of the impending earthquake may be less than 8.5 as evident from presently higher b-values (Fig. 1) and current global trend in seismicity.

Geodynamics

Return period of large earthquakes at the plate boundaries is given by

$$T = \frac{U}{SV}$$

where S = seismic slip / total slip;

V = relative speed of the plates

and U = average slip over fault during the earthquake.

For Mexican subduction zone Singh et al (Ref. 2) estimates T to be between 30 to 40 years which is about the order observed during the last 150 years or so. Though detailed estimates of fault parameters in North Eastern India are very much lacking, return period for earthquake of magnitude 8.25 could be about 40 to 50 years. This estimate is also confirmed from above statistical analysis.

STUDIES ON PRECURSORS

General Outline

In addition to the above probabilistic studies, various precursors have been developed to supplement informations on magnitude and time of the impending major seismic event. Precursory period for such a major earthquake according to Rikitake's equation, $\log T_1 = 0.60\ M - 1.01$ (Ref. 3) would be about thirty years. Thus the precursory studies generated of late, such as electrical resistivity, magnetic field, Radon emission, spring water (volume and temperature), well water level, abnormal animal behaviour could thus be expected to yield significant results during the ensuing decade in respect of magnitude, time and place of occurrence of the impending major seismic event in the region. Recent measurements of resistivity, earth current, magnetic field, spring discharge and water level in well in the Shillong Massif of the North Eastern India have indicated efficacy of these precursors for earthquake magnitude range 4.0 - 5.0 in the geology of the area for effective prediction (Ref. 4). The precursory period varied between 7 to 20 days depending on magnitude; and amplitudes of anomaly associated with precursors decreased with hypocentral distances of the earthquakes. Two Radon measuring stations have been commissioned at Shillong and at Dauki. Some precursory changes preceding smaller earthquakes have already been noticed. More observation stations, specially in the area designated as

'Seismic Gap' are planned in near future (Fig. 3).

Geodetic Observations

During past major earthquakes in the area, significant changes in geodetic bench marks were observed specially in the epicentral area. Large displacements were observed in the epicentral area of 1897 earthquake. Similar geodetic changes as precursory phenomena have been observed before many earthquakes in Japan, Italy, USA, USSR and New Zealand. Thus, precursory geodetic changes had been observed as very reliable premonitory index in varied geological environment. And hence two long geodetic profiles have been suitably planned taking into account the 'Seismic Gap' and geotectonic features in the region so that precursory changes could be obtained through repetative surveys along these profiles at suitable interval. Preliminary surveys are in progress.

Micro Gravity Observations

Very minute changes in gravity of the order of a very small fraction of milligal associated with seismic event had been observed in Japan. It is thus proposed to initiate surveys in very limited interesting areas with micro-gravitymeter (Lacosta Romberg). In view of serious limitation in speed of such surveys, this could be taken up at later stages when sufficient results are already available from other reconnaisance surveys.

Hot Spring Flow

Hot springs at Garampani, Kopili Project are being closely observed (though irregularly) for increase of volume of water, temperature changes etc. (Ref. 4). Very limited data suggest utility of such observations for earthquake prediction work.

Geomorphological Changes

Geomorphological work such as anomalous sedimentation and erosion in the Brahmaputra valley could indicate relative subsidence and upheaval respectively. Though ground work has been in progress for quite some time, recent attempts are being made to use satallite imageries for widespread and periodic evaluation in respect of progressive anomalous sedimentation and erosion in the region. Large earthquakes (M greater than 8.0) would certainly initiate wide spread anomalous sedimentation and erosion in the alluvial tracts of the Brahmaputra valley. Present indications are that this type of work could be very much effective in identifying seismogenic areas much in advance and would thus be powerful precursor, specially for major earthquake (M greater than 8.0), associated with widespread land deformation.

Abnormal Animal Behaviour

Organised research has of late been initiated in the region to record animal behaviour in reserved forest areas and in zoological gardens. The work is more of exploratory type at present though its potential use in future as precursor is not excluded. The region has few established wild

sanctuary with large animal population and is thus ideal for development of research in 'abnormal animal behaviour' as short term precursor for earthquake prediction.

Ground Tilt Changes

Ground tilt has been found to be effective precursor in many instances. There are number of established methods of measuring ground tilt but, tilt of water reservoir area could be found out from differential lake levels at two points separated by a few kilometers or so. The principle involved is same as that of Nagiwara water tube tiltmeter, widely used in Japan. Observations have been initiated at the Umiam Barapani lake situated in the Shillong Massif. Similar observations at other man-made lakes are being initiated. Though very simple, these observations would be very effective in isolating areas undergoing anomalous tilting associated with tectonic process.

b-Value Variations

As mentioned earlier, b-values could indicate effectively stress building process associated with earthquakes (Ref. 5). Advantage has thus been taken of the earthquakes recorded by the short period seismograph system of WWSSN at Shillong (Lat. 25°34' N Long.91°53' E) installed in 1963. These significant seismograph records even at one station could be effectively used for computation of b-values from large number earthquakes recorded specially below magnitude 4.0. Thus, all earthquakes with epicentral distances less than 500 km recorded at the WWSSN short period component at Shillong have been used to compute periodic b-values from 1963 onwards. The 'duration method' has been used to compute magnitude as follows :

$$M = -P + Q \log T_o \qquad \ldots (1)$$

and hence $\log N = a - bM$

or $\log N = a - b(-P + Q \log T_o)$

$\log N = a + bP - bQ \log T_o$

$$\log N = A - B \log T_o \qquad \ldots (2)$$

where $A = a + bP$

and $B = bQ$.

The slope in eqn. (2) would give $B (= bQ)$. The value of the coefficient Q is assumed 2.0 as in California, and hence periodic b-values are obtained from slopes of the equation (2). A total of about 8000 earthquakes has been analysed for the period 1963 - 1978. Fig.4 shows variation of earthquake population (N) and the cumulative values (N_c) on the one hand and yearly and two yearly b-values with two significant earthquakes during the period on the other hand. Since 1963, there has been significant fall in b-values with some variations. It is interesting that the two earthquakes on 29.7.1970 ($M=6.4$)

and on 8.7.1975 (M = 6.7) follow troughs in b-value variations. Some instances (Ref. 5) of low b-values preceding earthquakes are available, specially Koyna earthquake of Dec. 10, 1967. Further, there is overal fall in b-values since 1963 - which could indicate tectonic stress building process in operation in the region. This significant fall in b-values for the last 15 years considering earthquake population over the entire North Eastern region could very well signify that the regional lithospheric plate is currently developing stress symptomatic of a major earthquake (M = 8.25). Occurrence of two above earthquakes during the period associated with precursory low b-values (Fig.4) lends further credence to stress building process in operation associated with low b-values over the entire region. The order of precursory period given by Rikitake's equation (Ref. 3) is thirty years for an earthquake of magnitude 8.25. Thus the probable period of occurrence of this major seismic event (M = 8.25) could be around 1993 (1963 + 30) or so, which fits in reasonably well with the return period of about 45 years (1950 + 45 = 1995) in this region as evaluated earlier. Moreover, the gradual fall in earthquake population during last one decade or so (Fig.4) is yet another evidence of existence of quiscence period immediately preceding an impending major seismic event (M = 8.25).

DISCUSSIONS AND CONCLUSIONS

During the historical past several major earthquake visited the region. Periodicity of the major earthquakes is about half a century or so. From the distribution of epicentres of moderate to major earthquakes in the region Khattri and Wyss (Ref. 6) postulated an elliptical 'Seismic Gap' of about four hundred kilometers in dimension (Fig.3) as the most promising area of epicentre of the impending major earthquake without any time frame of occurrence. From seismo-tectonic studies of the region, the suggested area of the 'Seismic Gap' has not been very convincing as the area has conspicuously few epicentres of past earthquakes thereby indicating the possibility that the area could be relatively inactive or could have very long recurrence period (T). There has thus been serious lacuna in the postulation of the gap. It is not unreasonable that even in such acute seismic region, there could be pockets of geologically lesser active areas. There has thus been haste and inadequate consideration while postulating this gap. Recently Khattri and other have further tried to justify the 'Seismic Gap' from micro-earthquake data covering much shorter time span. However, these micro-earthquake data also do not rule out the possibility that the area of the 'Seismic Gap' could be aseismic or have long recurrence period.

The time of occurrence of the impending major seismic event, as presented in the paper, partially depends on assessment of the magnitude of the seismic event somewhat independently. Unconventional method (Fig.1) has been used for the purpose on the broad assumption that global seismicity is having a trough presently, and hence maximum probable magnitude of the impending earthquake has been assumed as 8.25. The time of occurrence of the event depends on this magnitude and hence the present study suffers from this limitation.

As development of precursors has been taken up very recently, thus present studies are thus restricted to seismo-statistical considerations backed by

tectonophysical data. While evaluation of recurrence period from Gutenberg - Richter statistics reveals mean period of occurrence of major earthquake, the same does not signify contemporaneous existance of earthquake generating stress in lithosphere. b-values in Gutenberg-Richter statistics do not only indicate the stress level but also justify existence of precursory signal indicating possible magnitude and time of occurrence of the impending major earthquake. Necessary large earthquake population required for such quantitative study was obtained from analysis of all earthquakes recorded in original seismograms down to magnitude of 2.0. The periodic b-value since 1963 showed significant decrease indicating thereby existence of earthquake generating lithospheric stress in operation over wide areas in the region. Duration of anomolous variations of the precursor (b-values) gives fair indication of the time of occurrence of the major event characteristic of the tectonic set-up. Thus this possible time of occurrence of the major event has also been confirmed from recurrence period corresponding to the event. Both the approaches suggest the period around 1993-1995 as possible time of occurrence of the impending major seismic event (M = 8.25) in the region.

In order to locate the possible epicentral area with more precision, present analysis is being attempted in four separate sectors in the region as more and more data are available. Comparative seismo-statistical studies of the four sectors would further narrow down the possible area of epicentre (Seismic Gap), magnitude and time of occurrence of the major seismic event. The study will lead to development of necessary 'short term' precursors with the approach of the impending event.

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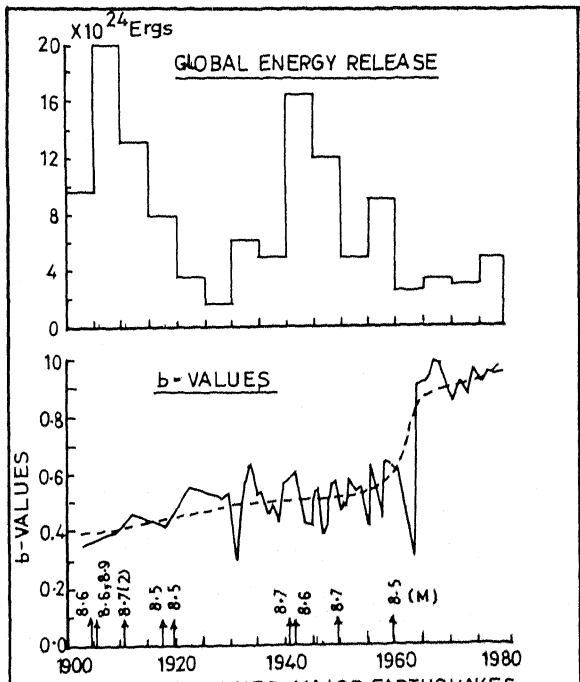

FIG.1 GLOBAL b-VALUES, MAJOR EARTHQUAKES (M≥8·5) AND ENERGY RELEASE.

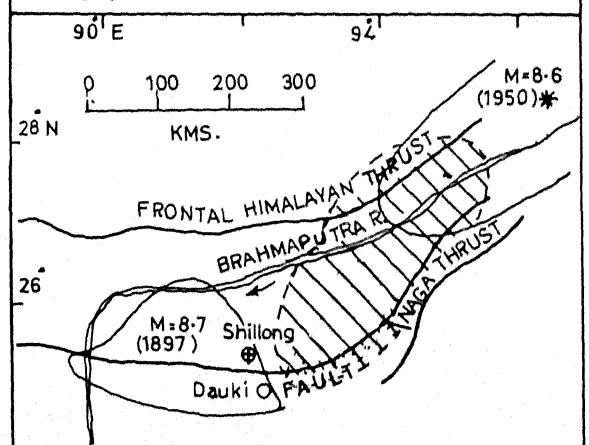

FIG.3 PRINCIPAL TECTONIC FEATURES, SEISMOLOGICAL(⊕)(WWSSN) AND RADON MEASURING STATIONS(O), SEISMIC GAP AND MAJOR EARTHQUAKES.

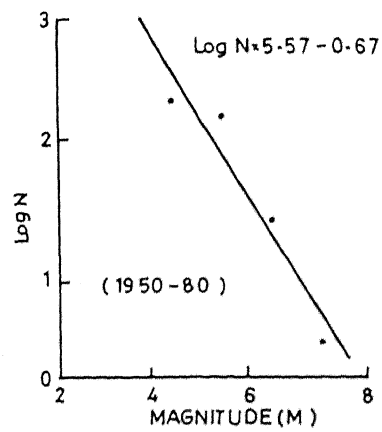

FIG 2 GUTENBERG-RICHTER RELATIONSHIP FOR N-E INDIA.

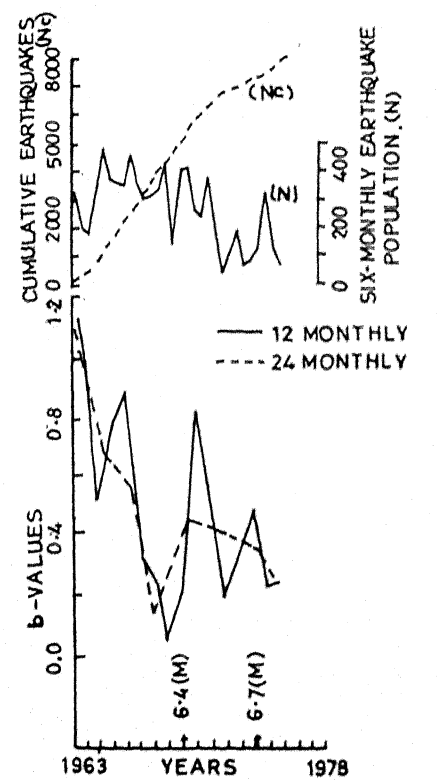

FIG.4 b-VALUES AND EARTHQUAKES IN N-E INDIA.